GOVERNMENT OF WESTERN AUSTRALIA

Environmental Protection Authority

EPA Referral Form

Form for the referral of a proposal to the Environmental Protection Authority under Section 38 of the *Environmental Protection Act 1986*

Referrer information			
Who is referring this proposal?		X Proponent	
Name: Ivan Vella		**Signature:**	
Position	Director	Organisation	Robe River Mining Co. Pty. Limited
Email			
Address	152 – 158 St Georges Terrace		
	Perth	WA	6000
Date	June 2017		
Does the referrer request that the EPA treat any part of the proposal information in the referral as confidential? *Provide confidential information in a separate attachment.*		X No	

Referral declaration for organisations, proponents and decision-making authorities:

I, Ivan Vella, declare that I am authorised to refer this Proposal on behalf of Robe River Mining Co. Pty. Limited and further declare that the information contained in this form is true and not misleading.

Part A: Proponent and proposal description

Proponent information

Name of the proponent/s (including Trading Name if relevant)	Robe River Mining Co. Pty. Limited
Australian Company Number(s)	008 694 246
Contact for the proposal (if different from the referrer) *Please include: name; physical address; phone; and email.*	Melinda Brand Principal Advisor Environmental Approvals Rio Tinto 152-158 St Georges Tce, Perth WA 6000 Telephone (08) 6211 6991 Email: Melinda.brand@riotinto.com
Does the proponent have the legal access required for the implementation of all aspects of the proposal? *If yes, provide details of legal access*	X Yes Legal access to the Development Envelope is via ML248SA (section 104 and a portion of section 103) under the *Iron Ore (Robe River) Agreement Act 1964*.

authorisations / agreements / tenure. *If no, what authorisations / agreements / tenure is required and from whom?*	The Proposal overlaps with the co-existing Land Administration Act 1997 tenure: • Pastoral Lease N49500 held by Yarraloola Pastoral Station. Yarraloola Station is Robe Joint Venture (JV) controlled entity. • Pastoral Lease N49492 held by Yalleen Pastoral Station. Yalleen Station is held by Yalleen Pastoral Co. Pty. Limited which is a Robe Joint Venture (JV) controlled entity. Grants of additional tenure easements will be required for sections of infrastructure such as powerlines outside the existing ML248SA.
Proposal type	
What type of proposal is being referred? For a change to an approved proposal please state the Ministerial Statement number/s (MS No./s) of the approved proposal For a derived proposal please state the Ministerial Statement number (MS No.) of the associated strategic proposal	X significant – new proposal ☐ significant – change to approved proposal ☐ proposal under an assessed planning scheme ☐ strategic ☐ derived
For a significant proposal: • Why do you consider the proposal may have a significant effect on the environment and warrant referral to the EPA?	The Proposal may have a significant effect on the environment in the following ways: • Clearing of up to 2,200 ha of native vegetation generally in Good to Excellent condition. • Priority flora located in the Development Envelope including: - *Triodia* sp. Robe River [M.E. Trudgen et al. MET 12367] P3. - *Indigofera* sp. Bungaroo Creek (S. van Leeuwen 4301) P3. - *Rhynchosia bungarensis* P4. • Priority Ecological Communities occur within the Development Envelope: - *Subterranean invertebrate communities of mesas in the Robe Valley region* (P1). - *Subterranean invertebrate community of pisolitic hills in the Pilbara* (P1). • Removal of subterranean fauna habitat as a consequence of mining. • Dewatering of mine pits. • Surface discharge of surplus water.

For a proposal under an assessed planning scheme, provide the following details: • Scheme name and number For the Responsible Authority: • What new environmental issues are raised by the proposal that were not assessed during the assessment of the planning scheme? • How does the proposal not comply with the assessed scheme and/or the environmental conditions in the assessed planning scheme?	N/A
Proposal description	
Title of the proposal	Mesa H Proposal
Name of the Local Government Authority in which the proposal is located.	Shire of Ashburton
Location: a) street address, lot number, suburb, and nearest road intersection; or b) if remote the nearest town and distance and direction from that town to the proposal site.	16km south west of the township of Pannawonica (refer to Figure 1-1 of the Supplementary Information document)
Proposal description – including the key characteristics of the proposal *Provide as an attachment to the form*	Please refer to the attached supporting information document.
Have you provided electronic spatial data, maps and figure in the appropriate format? *Refer to instructions at the front of the form*	X Yes
What is the current land use on the property, and the extent (area in hectares) of the property?	The Proposal is located in the Shire of Ashburton. Existing land uses include pastoral activities (Yarraloola and Yalleen Stations), mineral exploration, mining activities and cultural / recreational activities (predominantly by Traditional Owners) such as camping, fishing and hunting.
Have you had pre-referral discussions with the OEPA? If so, quote the reference number and/or the OEPA contact.	Yes. OEPA contact is Peter Tapsell.
Part B: Environmental impacts	
Environmental factors	
What are the likely significant environmental factors for this proposal?	☐ Benthic Communities and Habitat ☐ Coastal Processes ☐ Marine Environmental Quality ☐ Marine Fauna

	X Flora and Vegetation ☐ Landforms X Subterranean Fauna ☐ Terrestrial Environmental Quality X Terrestrial Fauna X Hydrological Processes X Inland Waters Environmental Quality ☐ Air Quality X Social Surroundings ☐ Human Health

For the environmental factors identified above, complete the following table, or provide the information in a supplementary report. Please be sure to complete a separate table per factor identified above.

Potential environmental impacts

1	***EPA Factor***	Please refer to the attached supporting information document.
2	***EPA policy and guidance*** - What have you considered and how have you applied them in relation to this factor?	
3	***Consultation*** – Outline the outcomes of consultation in relation to the potential environmental impacts	
4	***Receiving environment*** - Describe the current condition of the receiving environment in relation to this factor.	
5	***Proposal activities*** – Describe the proposal activities that have the potential to impact the environment	
6	***Mitigation*** - Describe the measures proposed to manage and mitigate the potential environmental impacts.	
7	***Impacts*** - Assess the impacts of the proposal and review the residual impacts against the EPA objective.	
8	***Assumptions*** - Describe any assumptions critical to your assessment *e.g. particular mitigation measures or regulatory conditions.*	

Part C: Other approvals and regulation

State and Local Government approvals

Is rezoning of any land required before the proposal can be implemented? If yes, please provide details.	X No
If this proposal has been referred by a decision-making authority, what approval(s) are required from you?	

Proposal activities e.g. clearing, dewatering, mining, processing, dredging,	**Land tenure/access** e.g. Crown land – LA Act, Min Act, CALM Act specify type	**Type of approval** e.g. Native Vegetation Clearing Permit, licence, mining proposal,	**Legislation regulating the activity** e.g. *EP Act 1986* – Part V, *RiWI Act 1914*, *Mining Act 1979*
Clearing	State Agreement (ML248SA)	Native Vegetation Clearing Permit	*EP Act 1986* – Part V
Dewatering	State Agreement (ML248SA)	Licence	*RiWI Act 1914*
Mining	State Agreement (ML248SA)	State Agreement	*Iron Ore (Robe River) Agreement Act 1964*
Heritage	State Agreement (ML248SA)	Section 18 consent to disturb a protected site	*Aboriginal Heritage Act 1972*
Construction and operation of plant, camp and discharge of surplus water	State Agreement (ML248SA)	Works Approval and Licence	*EP Act 1986 – Part V*
Closure	State Agreement (ML248SA)	Closure Plan	*Mining Act 1978*

Commonwealth Government approvals

Does the proposal involve an action that may be or is a controlled action under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act)?	X Yes
Has the proposed action been referred? If yes, when was it referred and what is the reference number (EPBC No.)?	X No
If referred, has a decision been made on whether the proposed action is a controlled action? If 'yes', check the appropriate box and provide the decision in an attachment.	X No ☐ Decision – controlled action ☐ Decision – not a controlled action
Do you request that this proposal be assessed under the bilateral agreement or as an accredited assessment?	X Yes - Bilateral X Or Yes - Accredited
Is approval required from other Commonwealth Government/s for any part of the proposal? *If yes, describe.*	X No Approval:

Rio Tinto

Section 38 referral – supporting information

Mesa H Proposal

RTIO-HSE-0310732

Robe River Mining Co. Pty. Limited

152-158 St Georges Terrace, Perth

GPO Box A42, Perth, WA 6837

June 2017

Rio Tinto

Disclaimer and Limitation

This report has been prepared by Rio Tinto's Iron Ore Group (Rio Tinto), on behalf of Robe River Mining Co. Pty. Limited (the Proponent), specifically for the Mesa H Proposal. Neither the report nor its contents may be referred to without the express approval of Rio Tinto, unless the report has been released for referral and assessment of proposals.

Document Status					
Rev	Author	Reviewer/s	Date	Approved for Issue	
				To Whom	Date
A	M Brand	Study team	8 May 2017		
B	M Brand	J English, F Sinclair	30 May 2017		
1	M Brand	T Savage P Royce H Scott C Richards	June 2017	OEPA	June 2017

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1. INTRODUCTION

Robe River Mining Co. Pty. Limited (the Proponent) operates the Robe Valley mining operations, which includes iron ore mines at Mesa J, Mesa K, Mesa A and Warramboo. The Mesa J and Mesa K mines are located approximately 16 km south west of Pannawonica in the Pilbara region of Western Australia (Figure 1-1). The Mesa H deposit is located adjacent to the Mesa J mine. The Proponent is seeking to develop the Mesa H deposit to sustain iron ore production from the Robe Valley.

The following terminology is used throughout this document:

- **Mesa J operation** – The Mesa J mine as approved under Ministerial Statement 208 (MS 208)
- **Mesa H deposit –** pisolite iron ore formation occurring as a partial mesa landform (also known as a Channel Iron Deposit).
- **Proposal** – the proposed activities (as detailed in Section 3) incorporating above water table (AWT) and below water table (BWT) mining of the Mesa H deposit.
- **Development Envelope** - the proposed boundary within which the Proposal will be contained.

1.1 Purpose of this Document

This document has been prepared to support the referral of the Proposal under section 38 of the *Environmental Protection Act 1986* (EP Act). It provides information on the Proposal characteristics, existing environment, potential environmental impacts and proposed management commitments. This document has been prepared in accordance with Part IV Division 1 of the EP Act and the *Environmental Impact Assessment (Part IV Divisions 1 and 2) Administrative Procedures 2016*.

1.2 Proponent Details

The Proponent is the manager for the Robe River Iron Associates joint venture (RRIA) which is an unincorporated joint venture comprising the following participants:

- Robe River Mining Co. Pty. Limited (30% share);
- North Mining Limited (35% share);
- Mitsui Iron Ore Development Pty Ltd (20% share);
- Cape Lambert Iron Associates, a partnership carried on by Nippon Steel & Sumitomo Metal Australia Pty Ltd, Nippon Steel & Sumikin Resources Australia Pty Ltd and Mitsui Iron Ore Development Pty Ltd (5% share); and
- Pannawonica Iron Associates, a partnership carried on by Nippon Steel & Sumitomo Metal Australia Pty Ltd, Nippon Steel & Sumikin Resources Australia Pty Ltd (10% share).

The Rio Tinto contact person in relation to the environmental approvals process for the Proposal is:

Melinda Brand

Rio Tinto: Principal advisor environmental approvals

Telephone: (08) 6211 6991

Email: melinda.brand@riotinto.com

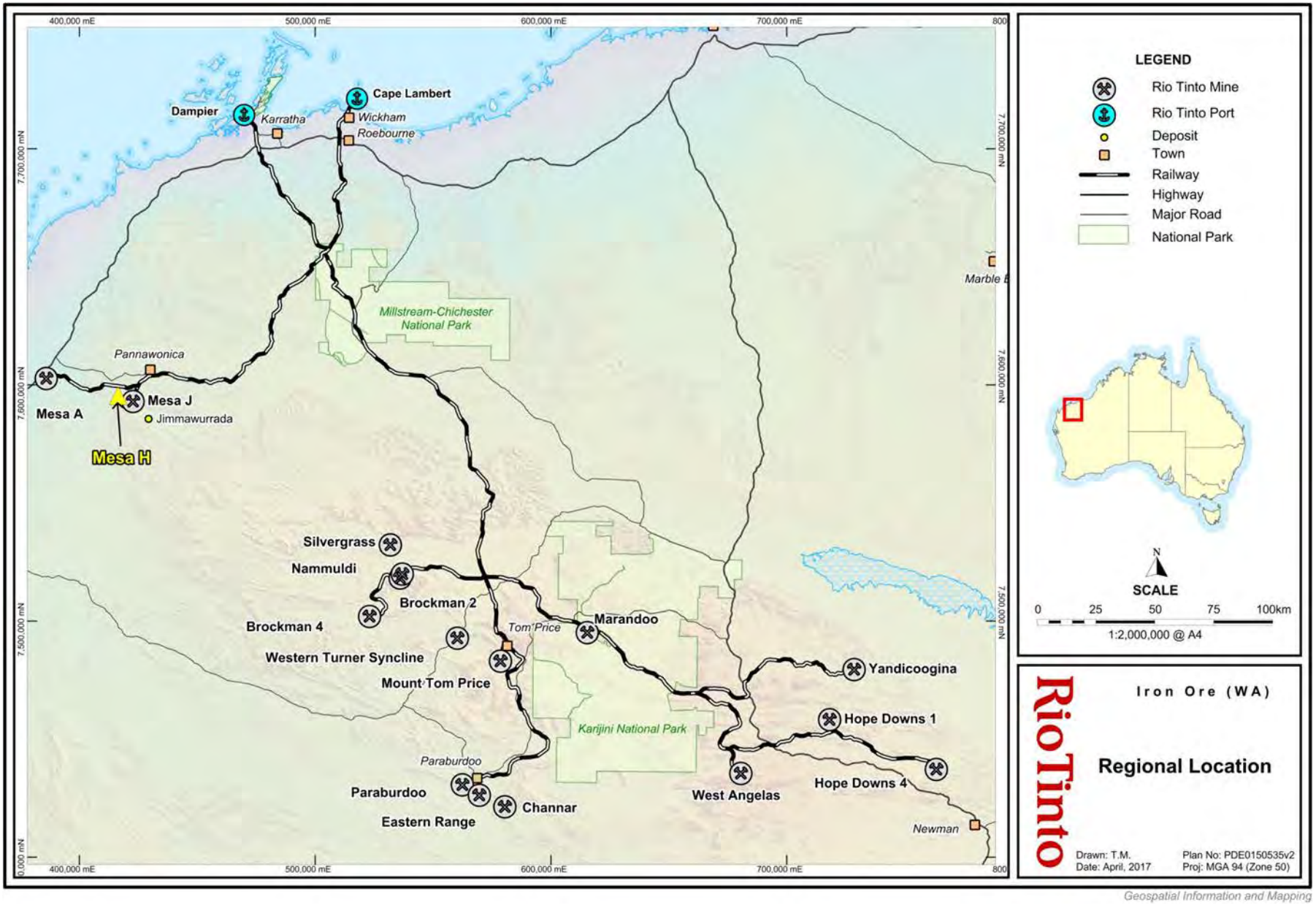

Figure 1-1: Regional Location

2. LAND USE AND TENURE

2.1 Land Use

The Proposal is located in the Shire of Ashburton, approximately 16 km south west of Pannawonica. Existing land uses in the Development Envelope include: pastoral activities (Yarraloola and Yalleen Stations); mineral exploration; mining activities; and cultural / recreational activities (predominantly by Traditional Owners) such as camping, fishing and hunting. The mesa landform / profiles of the Robe Valley are also used by Traditional Owners as landmarks when travelling though the countryside.

2.2 Tenure

The Robe Valley mining operations, including this Proposal, are predominantly located within the State Agreement Mineral Lease ML248SA granted pursuant to the *Iron Ore (Robe River) Agreement Act 1964*. ML248SA is appropriate tenure for mining and mining related infrastructure.

Existing tenure in and near the Development Envelope is shown in Figure 2-1. The Proposal pits, dumps and the majority of infrastructure are located within ML248SA (section 104 and a portion of section 103). A powerline to the east of Mesa J will require new tenure under the *Mining Act 1978*.

The main co-existing LAA tenure in the Development Envelope includes the Yarraloola Pastoral Station (Lease N49500) and the Yalleen Pastoral Station (Lease N49492). These pastoral leases are held by the RRIA.

2.3 Native Title

The Proposal lies within the Kuruma Marthudunera (K&M) Native Title Claim (WCD2016/006). The Proponent has a Participation Agreement and Indigenous Land Use Agreement with the K&M that includes an established consultation framework and ongoing engagement on relevant aspects of the Proponent's operations. These Agreements set obligations for processes such as: land access; tenure acquisition; heritage surveys; environmental management; mining benefit payments and reporting; and consultation and communication between the parties.

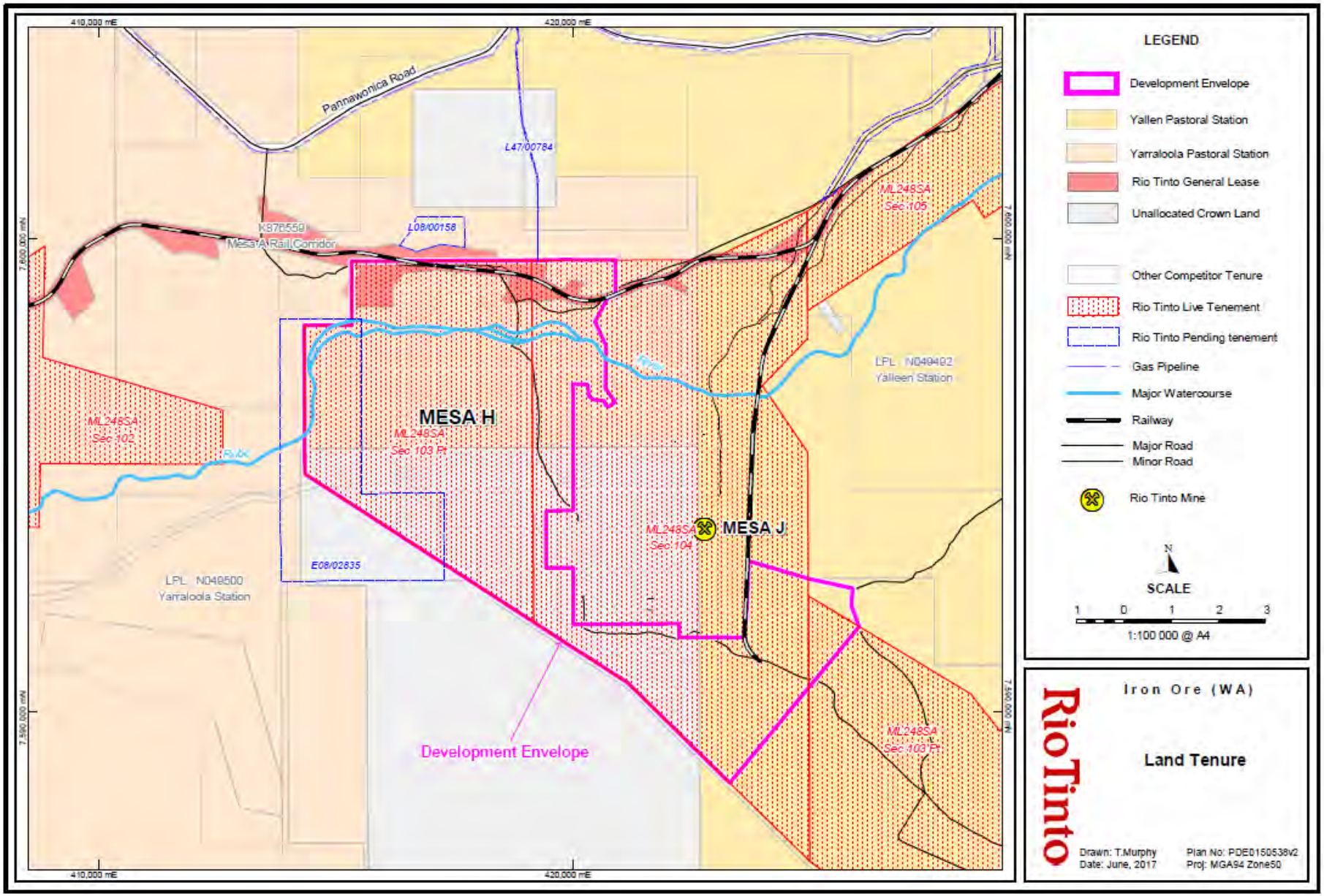

Figure 2-1: Land Tenure

3. MESA H PROPOSAL

3.1 Overview

A summary of the Proposal is provided in Table 3-1.

Table 3-1: Summary of the Proposal

Proposal Title	Mesa H Iron Ore Project
Proponent Name	Robe River Mining Co. Pty Limited
Short description	The Proposal is located approximately 16 km south west of Pannawonica in the Pilbara region of Western Australia, adjacent to the existing Mesa J mine. The Proposal includes development of above and below water table open cut iron ore pits and associated infrastructure, including water management infrastructure.

The Proposal consists of the following items and activities:

- **Mine pits** - development of open AWT and BWT iron ore pits
- **Dewatering and dewatering infrastructure** – including but not limited to bores, pipelines, and discharge outlet(s).
- **Surplus water management** – including but not limited to use in processing, on-site use and controlled discharge to the Robe River and tributaries.
- **Mineral waste management** – including but not limited to backfilling, ex-pit waste dumps, low grade ore dumps, topsoil and sub-soil stockpiles.
- **Processing facilities** – this Proposal will be supported by the existing processing facilities at Mesa J but may require other processing facilities including but not limited to waste fines storage facilities.
- **Support facilities** – including but not limited to workshops, power supply infrastructure, hydrocarbon storage, laydown areas, offices and waste water treatment plants.
- **Infrastructure for surface water management** – including but not limited to surface water diversion drains, levees and culverts.
- **Linear infrastructure** – including but not limited to heavy vehicle and light vehicle access roads, upgrades to existing vehicle access roads; pipelines and power (including sub-stations) and communications distribution networks.
- **Water supply** – utilising groundwater abstracted for dewatering, surface water that reports to pits, the existing Mesa J borefield (Southern Cutback borefield) and potentially additional bores.

Mined and processed ore will be railed to Rio Tinto's port operations at Dampier and/or Cape Lambert via the existing rail infrastructure.

The preliminary key characteristics for the Proposal are provided in Table 3-2.

An indicative conceptual mine layout is shown in Figure 3-1. Mine planning and engineering for the Proposal is currently still in progress therefore this layout is subject to change.

Table 3-2: Preliminary key characteristics of the Proposal

Element	Location	Proposed Extent
Physical Elements		
Mine and Associated Infrastructure	Figure 3-1	Clearing of no more than 2,200 ha within a Development Envelope of 4,930 ha.
Operational Elements		
Pit dewatering	-	Abstraction of no more than 10 GL/a of groundwater(including surface water run-off).
Surplus water management	-	Surplus water management options include use on site, and controlled discharge to the Robe River and tributaries.
Water supply	-	Supplied from an existing borefield within a current licence limit of 30 GL/a and surface water harvesting.
Ore Processing (waste)	-	In-pit disposal of waste fines at Mesa H and the adjacent Mesa J mine into in-pit waste fines storage facilities.

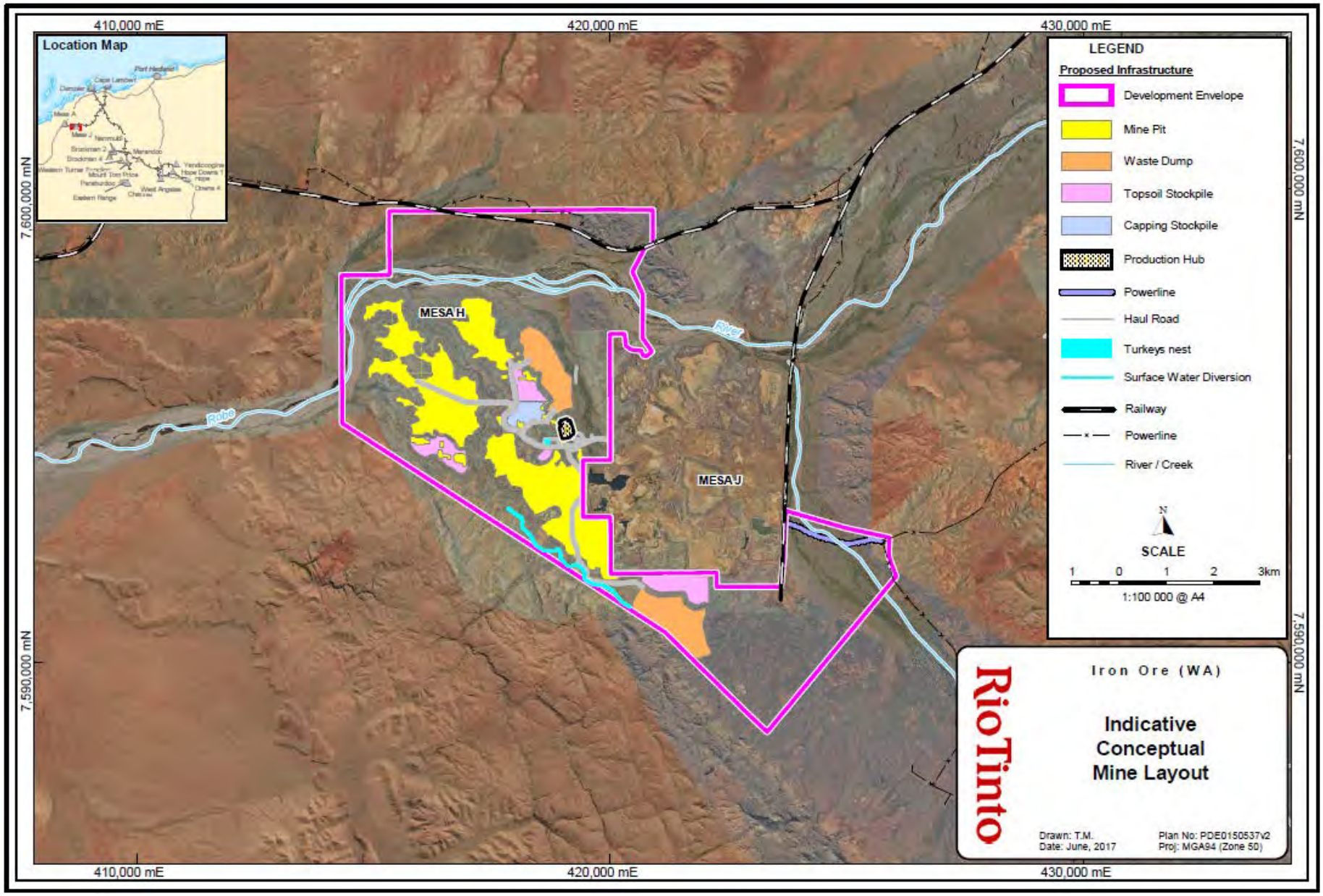

Figure 3-1: Indicative Conceptual Mine Layout

3.2 Proposal Description

3.2.1 Mining

The Mesa H deposit is a continuation of the Robe Pisolite iron ore deposit present at Mesa J, known more generally as a Channel Iron Deposit (CID).

The Proposal includes development of new open cut mine pits at Mesa H with approximately 20% of ore proposed for mining occurring BWT.

Ore will be mined using open cut mining methods comprising conventional drill, blast, load and haul as currently used in the adjacent Mesa J operations.

3.2.2 Exclusions

Exclusions from the scope of the Proposal comprise the following:

- Activities and additional infrastructure at the Mesa J operation approved under MS 208.
- Low impact activities within the Development Envelope prior to Part IV approval of the Proposal (to be subject to relevant provisions under Part V [Land Clearing] of the EP Act), including drilling and associated activities (such as upgrades to existing roads/tracks) for the purposes of resource evaluation, geotechnical assessment and hydrogeological investigation.
- Establishment of a construction camp to support the construction phase of the Proposal (to be subject to relevant provisions under Part V [Land Clearing and Works Approvals/Licensing] of the EP Act).
- Establishment of temporary services (communications, water supply, power), temporary concrete batch plant, site offices, access roads, laydown areas, and borrow pits to support establishment of a construction camp (to be subject to relevant provisions under Part V [Land Clearing and Works Approval/Licensing] of the EP Act).
- Facility upgrades in Pannawonica to support the expanded workforce.
- Power network upgrades at Pannawonica, and a 9 km section of overhead power line between the Pannawonica switchyard and the Mesa A/J tee-off (to be subject to relevant provisions under Part V [Land Clearing and Works Approval/Licensing] of the EP Act).

3.2.3 Ore handling and transport

Haul roads will be developed to enable haulage of ore from the Proposal to the Mesa J operation for dry and wet processing. Ore will then be transported to the ports via the existing Mesa J rail line.

3.2.4 Mineral waste

The Proposal mine plan has incorporated a pit sequence that enables progressive in-pit backfill of the majority of waste, using both the Proposal and the adjacent Mesa J pits. Where pit sequencing and scheduling do not allow waste to be used for backfilling, out-of-pit waste dumps will be utilised. Currently, two locations have been identified for out-of-pit waste dumps that minimise direct impact to significant environmental and heritage areas. Out-of-pit storage for competent material, low grade ore, sub-soil and topsoil will also be required.

Wet processing of low grade ore from the Proposal will generate waste fines. The mine plan will incorporate the use of pits within the Development Envelope and at the Mesa J operation for in-pit waste fines storage facilities (WFSF) over the life of the Proposal.

3.2.5 Surface water management

Surface water management will be required for the watercourses draining local catchments from the Buckland Hills south of the Proposal which intersect the southern pits. A drainage diversion is required during operations south of the southern pits, directing flow to the watercourse between the northwest and southern pits, and subsequently into the Robe River. The diversion will not be maintained post closure.

3.2.6 Pit dewatering

Approximately 20% of the ore proposed for mining at Mesa H is below the current water table. Dewatering to access the BWT ore is therefore required at an average rate of 3 GL/a and peak rate of 10 GL/a. Dewatering is currently expected to commence in approximately 2025 and will be via sump pumping, powered by diesel generators. Groundwater abstracted for dewatering purposes will contribute to meeting operational demands for the Proposal and Mesa J operation, primarily wet processing, however the timing for BWT pit dewatering and average dewatering rate will not be sufficient to meet these processing demands, hence an additional water supply will be required for the Proposal as detailed in Section 3.2.7.

3.2.7 Water supply and surplus water discharge

Water is required for the Proposal to enable:

- construction activities;
- general mining activities;
- dust suppression on haul roads; and
- potable water supply.

Mine pit dewatering for the Proposal of an average of 3 GL/a (peak up to 10 GL/a) will not be sufficient to meet operational demands, requiring continued operation of the existing Mesa J water supply borefield (Southern Cutback borefield) located immediately to the south of the Mesa J operations. The total abstraction from this water supply borefield (to include the requirements for this Proposal) is not expected to require an increase to the current abstraction licence limit.

The site water demand for the Proposal and continuation of the Mesa J operation is estimated to be approximately 11 GL/a, which is similar to the existing Mesa J water demand.

Based on water balance estimates, and depending on fluctuations in site water usage requirements and seasonal fluctuations, limited surplus water is expected to be generated from mine pit dewatering. After large rainfall events however, significant ponding would result in a requirement to discharge. In these circumstances, and combined with temporal variability in mine water use, up to a peak of 10 GL/a may be required to be discharged.

Any surplus water discharge will be predominantly via the existing Mesa J operation discharge points, in Jimmawurruda Creek east of Mesa J or West Creek, between the Proposal and the Mesa J operation. Additional discharge points may be established if required, pending further hydrological studies to support options to manage the identified values of the Robe River ecosystem.

3.2.8 Mine support facilities and infrastructure

Additional power supply to the Mesa J operation is required as part of the Proposal, comprising a powerline of approximately 2.5 km in length from the existing Coastal Water Supply powerline to Mesa J (Figure 3-1).

A production hub will be established at the Proposal comprising: truck park up; laydown; offices; ablutions; waste water treatment plant; and other facilities as required to support the operation. A power line will connect the production hub to the Mesa J power network.

A turkey's nest will be established near the production hub to provide water for dust suppression.

Communications systems will be extended to the Proposal including installation of fibre optic cables.

The Proposal will utilise the existing Mesa J rail infrastructure.

3.2.9 Workforce

The Proposal will be operated as an extension to the existing Mesa J operation and will require an increase in the operational workforce. The workforce will continue as mixed residential / FIFO workforce, housed in existing accommodation in Pannawonica. Some facilities in Pannawonica will be upgraded and expanded (not part of this Proposal).

The construction workforce is proposed to be accommodated in a 'dry hire' mobile construction camp north of the Proposal (not part of this proposal).

3.2.10 Timing

Under the current project schedule, construction activities are planned to commence in Quarter 4 2018 once all required internal and external approvals are granted.

4. ENVIRONMENTAL STUDIES

Environmental baseline studies and compliance monitoring have been completed in the vicinity of the Development Envelope as described in Table 4-1.

Table 4-1: Environmental studies completed in the vicinity of the Development Envelope

Study	Description
Flora and vegetation	
Biota Environmental Sciences (2011). *Baseline Flora and Vegetation Assessment of Robe Valley Mesas (Mesas B, C, D, E, F, H and I)*. Unpublished report prepared for Rio Tinto Iron Ore, April 2011.	Survey conducted in October 2010 documenting flora, vegetation units and conservation listed flora in the Development Envelope.
Astron (2016*). Mesa H Level 2 Vegetation and Flora Assessment.* Unpublished report prepared for Rio Tinto Iron Ore, May 2016.	Surveys conducted in September / October 2014 and May and July 2015 documenting vegetation units and conservation listed flora in the Development Envelope.
Astron (2016*). Mesa H Riparian Vegetation Baseline Monitoring.* Unpublished report prepared for Rio Tinto Iron Ore, June 2016.	Monitoring transects established across riverine vegetation in the Robe River in May-June 2016.
Astron (2016) *Mesa H Riparian Community Assessment*. Unpublished report prepared for Rio Tinto Iron Ore, June 2016.	Level 2 vegetation and flora assessment of the Robe River riparian community, and a Level 1 fauna assessment desktop assessment, including database searches and literature review of available resources, vegetation and flora assessment, fauna and fauna habitat assessment and baseline aquatic assessment.
Rio Tinto (2017). *Assessment of Groundwater Dependent Vegetation distribution on the Robe River - Targeted Riparian Vegetation Survey.* Unpublished report prepared by Rio Tinto Iron Ore, May 2017.	Detailed survey and spatial mapping of the distribution of Robe River Groundwater Dependent Vegetation (GDV). Interpretation of the significance and sensitivity of these communities to potential hydrological change – providing an interpreted risk map throughout the Development Envelope and immediate surrounds.
Other	
Various targeted surveys associated with Rio Tinto exploration and pastoral activities.	Flora/vegetation and fauna surveys conducted in localised areas subject to Native Vegetation Clearing Permit applications.
Terrestrial fauna	
Streamtec (1991 - 2016). Aquatic Ecosystems Study (annual monitoring).	Annual aquatic ecosystems monitoring survey to assess potential environmental impacts of the Mesa J Operation on the adjacent and downstream aquatic ecosystem. The survey is an integrated assessment of biological parameters including aquatic fauna (macroinvertebrates and fish), channel/pool morphology, riparian vegetation condition and water quality.

Study	Description
Biota Environmental Sciences (2011). *Robe Valley Mesas Fauna Report*. Unpublished report prepared for Rio Tinto Iron Ore, March 2011.	Survey conducted in October 2010 documenting terrestrial fauna, fauna habitats, species of conservation significance and habitats that may require specific management.
Astron (2015). *Level 2 Terrestrial Fauna Surveys: Mesa H*. Unpublished report prepared for Rio Tinto Iron Ore, November 2015.	Surveys conducted in May and September 2015 documenting terrestrial fauna, fauna habitats, species of conservation significance and habitats that may require specific management.
Astron (2016). *Mesa H Ghost Bat, Macroderma gigas – Contextual Study*. Unpublished report prepared for Rio Tinto Iron Ore, June 2016.	Contextual analysis for the conservation significant Ghost Bat (*Macroderma gigas*) within the vicinity of the Mesa H Development Envelope, including desktop review and field survey involving mapping of potential habitat and targeted survey for the Ghost Bat.
WRM (2017) Mesa H Project: Baseline Aquatic Ecosystem Survey. Wet Season Sampling 2016. Unpublished report prepared for Rio Tinto Iron Ore, April 2017.	Baseline wet season sampling program undertaken to document the current ecological condition of the Robe River for aquatic ecosystems, with a focus on permanent and semi-permanent pools and sampling of sites upstream and downstream of Mesa H.
Bat Call WA (2017). *Robe Valley Mesa H Ghost Bat roost cave assessment.* Unpublished report prepared for Rio Tinto, April 2017.	Extensive search for Ghost Bat presence at Mesa H conducted in April 2017, including assessment of the conservation value of caves associated with the presence of Ghost Bats.
Bat Call WA (2017). *Robe Valley Mesa A to Mesa 2405A, assessment of mining on Ghost Bat presence and activity.* Unpublished report prepared for Rio Tinto, April 2017.	Assessment of impact of mining on Ghost Bat viability in the broader Robe valley including a desktop and field review of historical mined areas, current mining operations and proposed mining developments.
Subterranean fauna	
Biota Environmental Sciences (2006). Mesa A and Robe Valley Mesas Troglobitic Fauna Survey. Unpublished report prepared for Robe River Iron Associates, March 2006).	Surveys conducted November 2004 to January 2005, April to May 2005, July to September 2005 documenting subterranean fauna and assessing subterranean fauna habitat.
Biota Environmental Sciences (2017). *Mesa H Subterranean Fauna Assessment.* Unpublished report prepared for Rio Tinto.	Surveys conducted June to August 2015 and August to October 2015 documenting subterranean fauna and assessing subterranean fauna habitat.
Hydrological Processes and Inland Waters Environmental Quality	
Rio Tinto (2016) *Mesa H Chemistry and Isotopes.* Unpublished report prepared by Rio Tinto Iron Ore, 2016.	Groundwater and surface water chemical and isotope analysis aiming to assess groundwater dependency of the Robe River pools.
Rio Tinto (2016) *Mesa H Chemistry and Isotopes.* Unpublished report prepared by Rio Tinto Iron Ore, 2016.	Groundwater and surface water chemical and isotope analysis aiming to assess groundwater dependency of the Robe River pools.
Rio Tinto (2016). *Mesa H 2016 Pre-Feasibility Study Hydrogeological Drilling Program Completion Report.* Unpublished report prepared by Rio Tinto Iron Ore, 2016.	Report detailing drilling and installation of 19 monitoring bores and 4 water bores, and test pumping of all completed water bores.
Rio Tinto (2016). *Mesa H Hydrogeological Conceptual Model Report.* Unpublished report prepared by Rio Tinto Iron Ore, 2016.	Mesa H hydrogeological conceptual model report to support the development of the groundwater numerical model.

Study	Description
Rio Tinto (2016). *Mesa H Dewatering, Water Supply and Impact Assessments*. Unpublished report prepared by Rio Tinto Iron Ore, 2016.	Groundwater numerical model to support the Mesa H Proposal assessing dewatering requirements, water supply strategy and impact prediction.
Rio Tinto (2016). *AMD Risk Assessment Summary for the Robe Valley.* Unpublished report prepared by Rio Tinto Iron Ore, 2016.	A review of the AMD risk assessment for the Robe Valley including Mesa H.
Rio Tinto (2016). *Mesa H Order of Magnitude Design Flood Estimation and Floodplain Mapping.* Unpublished report prepared by Rio Tinto Iron Ore, Feb 2016.	Investigation to provide design flood estimates and floodplain mapping for the Mesa H deposit to inform the development of surface water management options.
Rio Tinto (2017). *Mesa H PFS Surface Water Management.* Unpublished report prepared by Rio Tinto Iron Ore, March 2017.	Study describing the interaction between natural surface water runoff, the local environment and the Mesa H study area and proposed water management measures.
Rio Tinto (2017). *Surplus water discharge extent assessment: Mesa H*. Unpublished report prepared by Rio Tinto Iron Ore, March 2017.	Study was to estimate the extent of impact of surplus water discharge along the proposed watercourses based on discharge location options.
Rio Tinto (2017) Mesa H H3 Hydrogeological Level Assessment. Unpublished report prepared by Rio Tinto Iron Ore, 2017.	Report detailing the Mesa H and J hydrogeological conceptualisation, numerical model predictions, aquifer impact assessment, monitoring program and proposed GW management.

Environmental studies that are still in progress relevant to the Proposal are described in Table 4-2.

Table 4-2: Environmental studies in progress relevant to this Proposal

Study	Description
Flora and vegetation	
Astron.	Baseline Monitoring – Phase II (Monitoring transects established across riverine vegetation in the Robe River).
Rio Tinto (in prep).	Assessment of Groundwater Dependent Vegetation distribution on the Robe River - Targeted Riparian Vegetation Survey.
Subterranean fauna	
Biota Environmental Sciences (in prep).	Surveys conducted June to August 2015, August to October 2015 and January to March 2016 documenting subterranean fauna and assessing subterranean fauna habitat.
Aquatic fauna	
Streamtec Aquatic Ecosystems Study	Ongoing annual aquatic fauna monitoring as part of existing Mesa J Operations.
WRM.	Baseline Aquatic Fauna Monitoring – Phase II.
Visual impact assessment	
Rio Tinto (in prep).	Visual impact assessment considering vantage points along Pannawonica Road, the Robe River and sites of heritage significance.

5. ASSESSMENT OF PRELIMNARY KEY ENVIRONMENTAL FACTORS

The environmental factors and objectives adopted by the Environmental Protection Authority (EPA) are listed in the EPA's Statement of Environmental Principles, Factors and Objectives (EPA 2016). The Proponent has identified the following preliminary key environmental factors that are relevant to the Proposal:

- Flora and Vegetation
- Terrestrial Fauna
- Subterranean Fauna
- Hydrological Processes
- Inland Waters Environmental Quality
- Social Surroundings

The above factors are discussed in sections 5.1 to 5.5. The Proponent considers that the remaining environmental factors identified in (EPA 2016) are either not relevant to the Proposal or will not result in a significant impact (refer to Section 6).

5.1 Flora and Vegetation

5.1.1 EPA objective

The EPA objective for Flora and Vegetation is *to protect flora and vegetation so that biological diversity and ecological integrity are maintained.*

5.1.2 Potential environmental impact

Consideration of the potential impacts relevant to Flora and Vegetation is captured in Table 5-1.

Table 5-1: Consideration of potential environmental impacts – Flora and Vegetation

Potential environmental impacts	
EPA policy and guidance - What have you considered and how have you applied them in relation to this factor?	The following EPA guidelines and technical guidance have been considered for the proposal in relation to Flora and Vegetation in order to meet the EPA's objectives as outlined above: EPA Statement of Environmental Principles, Factors and Objectives (2016). • EPA Environmental Factor guideline (Land): *Environmental Factor Guideline – Flora and Vegetation* (2016). • EPA Technical Guidance (Land): *Flora and Vegetation Surveys for Environmental Impact Assessment* (2016). Flora and vegetation surveys have been, and will continue to be, undertaken consistent with The EPA's technical guidance for this factor. Any survey limitations relative to the technical guidance will be noted in the flora and vegetation survey report. The Proposal and supporting studies focus on presenting the current state of knowledge, and defines significant flora and vegetation communities within the Development Envelope and the immediate surrounding region. The Proposal has been designed such that activities and pathways which may have the potential to impact on priority flora or locally significant vegetation communities have been avoided or minimised where possible via the application of the mitigation hierarchy. Any survey limitations relative to the guidance will be noted in the flora and vegetation survey report.
Consultation – Outline the outcomes of consultation in relation to the potential environmental impacts	**Office of the Environmental Protection Authority (OEPA)** A summary of the Mesa H Proposal was provided pre-referral. • Proponent to complete studies and prepare referral documentation. • DMA consult to be undertaken with key agencies.
	Department of Parks and Wildlife (Parks and Wildlife) An outline of the scope of the Mesa H proposal was provided, including the status of surveys and an overview of survey results. • Proponent should seek confirmation from Parks and Wildlife whether the vegetation community that is analogous to the Triodia sp. Robe River PEC is actually the PEC or is possibly a new / subset of the PEC. • If the community is a PEC then further surveys may be required to define the community more rigorously.
	Department of Water (DoW) Refer to consultation notes summarised in Section 5-4.

Potential environmental impacts	
Receiving environment - Describe the current condition of the receiving environment in relation to this factor.	Numerous Flora and Vegetation surveys have been undertaken across the Development Envelope and surrounds. During the more recent two phase seasonal survey effort (2015-2016) across the Development Envelope, 38 vegetation associations were described, none of which represent a TEC. All but three vegetation associations recorded are well represented beyond the Development Envelope and do not support assemblages of species that are unique, on restricted landforms, or of high conservation significance. • One vegetation association is considered to represent the Priority 3 Priority Ecological Community (PEC) '*Triodia sp. Robe River assemblages of mesas of the West Pilbara'*. Vegetation representing this PEC accounted for 14.6 ha within the Development Envelope. • One vegetation association (ChAsppGOrGsppPlSsTeTw) contained all three of the recorded Priority flora species. This vegetation was associated with drainage lines comprising approximately 135 hectares (3%) of the Development Envelope. Similar vegetation has been recorded from other regional surveys. • The riparian vegetation association containing MaEcCv, represents approximately 174 hectares (3%) of the Development Envelope, and is considered a groundwater dependent ecosystem as it is characterised by the obligate phreatophyte *Melaleuca argentea*. MaEcCv was mapped on the fringes of permanent and semi-permanent water pools both in and outside the Development Envelope and the main flow channels of the Robe River, and as such supported a number of species that were unique to this habitat. Approximately 60% of the Priority 4 species *Rhynchosia bungarensis* P4 occurred in MaEcCv in the Development Envelope. The families and genera recorded in the Riverine and Drainage lines are typical of what would be expected in riparian vegetation of major drainage lines in the Pilbara. No Threatened taxa were recorded. There were 23 weed species recorded within the riparian habitats. None of the weed species recorded is listed as a declared pest for the Shire of Ashburton or a Weed of National Significance. Vegetation condition ranged from 'very poor' to 'excellent' with approximately 67% of the Development Envelope classified as being in 'excellent' condition. The area is also subject to a history of pastoral activity with cattle grazing evident on the plains, floodplains and drainage lines. There were 310 vascular flora species from 53 families and 150 genera recorded in the Development Envelope. The most represented families were Fabaceae, Poaceae and Malvaceae. No Threatened flora were recorded during the survey or are expected to occur. Three State-listed Priority flora were identified: *Indigofera* sp. Bungaroo Creek (S. van Leeuwen 4301) P3, *Triodia* sp. Robe River (M.E. Trudgen et al. MET 12367) P3 and *Rhynchosia bungarensis* P4.
Proposal activities – Describe the proposal activities that have the potential to impact the environment.	The following aspects of the Proposal may affect flora and vegetation values: • Clearing of vegetation in mining and infrastructure development areas including vegetation communities of local significance and Priority Flora species. • Mining and ore transportation may increase dust emissions causing localised stress of adjacent vegetation. • Vehicle and earth movements may result in spread of existing weeds and/or introduction of new weeds. • Groundwater abstraction, surplus water discharge, and surface water diversions could potentially impact environmental values, including flora and vegetation, as discussed in section 5.4.

Potential environmental impacts	
Mitigation - Describe the measures proposed to manage and mitigate the potential environmental impacts.	Strategies to minimise the impacts to vegetation include: • Minimising the disturbance footprint during the study and mine planning phase. • Preferentially avoiding flora and vegetation of elevated conservation significance. • The mesa escarpment at Mesa H will be retained, through establishment of a Mining Exclusion Zone (MEZ). The majority of the '*Triodia sp. Robe River assemblages of mesas of the West Pilbara'*, occur along the margins of the Mesa escarpment, and will be protected from direct disturbance by the MEZ. • Minimal direct disturbance to the Robe River riparian vegetation which comprises the important Riverine habitat vegetation associations (ChAsppGOrGsppPlSsTeTw - containing all three of the recorded Priority flora species and MaEcCv). • The proposed development is located outside the 1% AEP (Annual Exceedance Probability) floodplain of the adjacent Robe River. • Conducting flora and vegetation surveys in all parts of the Development Envelope. • Detailed mapping of riparian vegetation and assessment of risk related to groundwater dependency to support water monitoring and water management approach. • Monitoring riparian vegetation along the Robe River for the duration of abstraction, discharge, and as required post closure during water table recovery. • Development of a monitoring and management plan, with trigger and threshold levels and actions, to ensure no significant detrimental impact to the identified environmental values of the Robe River ecosystem due to groundwater abstraction and discharge. This plan will consider precautionary mitigation options for groundwater drawdown, such as supplementary water supply to the Robe River ecosystem via controlled discharge. • Implementing vehicle hygiene procedures to prevent the introduction and spread of weeds. • Mapping and controlling weed species as necessary to protect conservation values. • Undertaking progressive rehabilitation where practicable.
Impacts - Assess the impacts of the proposal and review the residual impacts against the EPA objective.	The Proposal is expected to result in the progressive clearing of up to 2,200 ha of native vegetation. The Proposal is not expected to alter the conservation status or viability of any Priority Flora species or have a significant effect on the representation of vegetation at a local or regional level. No TECs, Environmentally Sensitive Areas or Declared Rare Flora will be affected by the Proposal as none have been recorded in the Development Envelope. Vegetation units of high local significance, associated with drainage lines (riparian habitat containing phreatophytic vegetation), are present along the Robe River. Dewatering at Mesa H may result in temporary, seasonal stress, particularly to the vegetation units containing obligate phreatophytic vegetation (e.g. *Melaleuca Argentea*) within the extent of drawdown. However, groundwater abstraction and surplus water discharge as a result of the Proposal are considered unlikely to have significant impacts on the identified environmental values of the Robe River and Jimmawurrada Creek ecosystems (including riparian vegetation), as discussed in section 5.4. The Proponent considers that the Proposal is likely to meet the EPA objective for Flora and Vegetation.

Potential environmental impacts	
Assumptions - Describe any assumptions critical to your assessment *e.g. particular mitigation measures or regulatory conditions.*	Key assumptions are related to the extent of information collected and degree of seasonal variability naturally experienced in an arid environment. The assessment of sensitivity of the riparian vegetation species to changes to water availability is based on scientific publications and responses recorded at other Rio Tinto mine sites. These assumptions are detailed in the supporting vegetation and flora studies. Assumptions regarding hydrogeological modelling, that informs assessment of the potential impacts of groundwater drawdown on the Robe River ecosystem are detailed in section 5.4. Surveys and studies have been undertaken by specialist consultants to ensure an appropriate level of independent rigour and ensure that EPA guidance, methodologies and industry standards have been adopted.

5.2 Terrestrial Fauna

5.2.1 EPA objective

The EPA objective for Terrestrial Fauna is *to protect terrestrial fauna so that biological diversity and ecological integrity are maintained.*

5.2.2 Potential environmental impact

Consideration of the potential impacts relevant to Terrestrial Fauna is captured in Table 5-2.

Table 5-2: Consideration of potential environmental impacts – Terrestrial Fauna

Potential environmental impacts	
EPA policy and guidance - What have you considered and how have you applied them in relation to this factor?	The following EPA guidelines and technical guidance have been considered for the proposal in relation to Terrestrial fauna in order to meet the EPA's objective as outlined above: • EPA Statement of Environmental Principles, Factors and Objectives (2016). • EPA Environmental Factor guideline (Land): *Environmental Factor Guideline – Terrestrial Fauna* (2016). • EPA Technical Guidance (Land): *Terrestrial Fauna Surveys* (2016). • EPA Technical Guidance (Land): *Sampling methods for terrestrial vertebrate fauna* (2016). • EPA Technical Guidance (Land): *Sampling of Short Range Endemic invertebrate fauna* (2016). Terrestrial Fauna surveys (including sampling for Short range endemic fauna) have been, and will continue to be, undertaken consistent with the EPA's technical guidance for this factor. Any survey limitations relative to the technical guidance will be noted in the terrestrial fauna survey report. The Proposal and supporting studies focus on presenting the current state of knowledge, defines significant terrestrial fauna species within the Development Envelope and surrounds. The Proposal has been designed such that activities which may have the potential to impact on significant fauna have been avoided or minimised where possible via the application of the mitigation hierarchy. Any survey limitations relative to the guidance will be noted in the terrestrial fauna survey report.
Consultation – Outline the outcomes of consultation in relation to the potential environmental impacts	**OEPA** A summary of the Mesa H proposal was provided pre-referral. • Proponent to complete studies and prepare referral documentation. • DMA consult to be undertaken with key agencies.
	Parks and Wildlife An outline of the scope of the Mesa H Proposal was provided, including the status of surveys and an overview of survey results. • Parks and Wildlife indicated that additional Ghost Bat work would be prudent to undertake (as planned) given the recent EPBC listing. Requested further information regarding the Pilbara Leaf-nose Bat roost location estimated 10km to the south (if this was the known 'super-roost') and habitat usage in the Robe River.

Potential environmental impacts	
Receiving environment - Describe the current condition of the receiving environment in relation to this factor.	**Vertebrate Fauna** Seven broad fauna habitat types were recorded in the Development Envelope: Riverine; Drainage Line; Gorge; Breakaway; Rocky Hills; Low Hills and Slopes; and Loamy/Stony Plain. The Gorge, Riverine and Breakaway habitats in the Development Envelope are considered important for fauna due to the microhabitats they provide such as caves and water pools; the Gorges and Breakaway habitats represent an important site of refuge due to their location close to the Robe River and as habitat for conservation listed fauna. There were 169 vertebrate fauna species recorded within the Development Envelope, including two amphibian species, 55 reptile species, 85 bird species and 27 mammal species (including four introduced species). The faunal assemblage recorded is considered typical of the Hamersley Range subregion extending from near Pannawonica to Mt Brockman. Eight conservation listed fauna species have been recorded in the Development Envelope: Pilbara Olive Python (VU; S3) (*Liasis olivaceus barroni*); Northern Quoll (EN; S2) (*Dasyurus hallucatus*); Pilbara Leaf-nosed Bat (VU; S3) (*Rhinonicteris aurantia*); Ghost Bat (VU; S3) (*Macroderma gigas*); Rainbow Bee-eater (Mi; S5) (*Merops ornatus*); Eastern Great Egret (Mi; S5) (*Ardea modesta*); Lined Soil-crevice Skink (P4) (*Notoscincus butleri*); and Western Pebble-mound Mouse (P4) (*Pseudomys chapmani*). Four of the eight recorded conservation listed species are classified under the *Environment Protection and Biodiversity Act* 1999 (EPBC Act) as Matters of National Environmental Significance (MNES) species: the Pilbara Olive Python; Northern Quoll; Ghost Bat; and Pilbara Leaf-nosed Bat. • A single juvenile Pilbara Olive Python and two Pilbara Olive Python scats were recorded within the Riverine and the Breakaway habitat type within the Development Envelope. • The Northern Quoll was recorded 27 separate times comprising: six capture records; 19 remote camera location records; and from two scats within the Breakaway, Riverine and Gorge habitat types in and immediately outside the Development Envelope. • The Ghost Bat was recorded twice through scat collections and acoustic recordings. Eleven caves were identified within the Development Envelope during the surveys during detailed assessments undertaken by Bat Call WA (2017), including two potential diurnal roost caves and nine nocturnal roost shelters based on their size, complexity and the presence of Ghost Bats and /or scats. The two diurnal caves were assessed as being maternity cave candidates although no evidence of intensive Ghost Bat use for this purpose was found during the survey. • The Pilbara Leaf-nosed Bat was recorded at eight of the 14 SM2 bat detector locations, all at low activity levels apart from one location (BAT 14) located outside the Development Envelope which recorded 257 calls. Further data and analysis of the BAT 14 sites confirmed that the Pilbara Leaf-nosed Bats originated from a known roost site approximately 10 kms south of the Development Envelope. Table 5-3 provides a summary of conservation listed species recorded or likely to be recorded in the Development Envelope.

Potential environmental impacts	
	Short Range Endemic Invertebrate Fauna The Loamy/Stony Plains habitat supported some Short Range Endemic (SRE) species however this habitat type is widespread in the Development Envelope and is considered unlikely to restrict dispersal in SRE fauna. The Breakaway, Gorge and Riverine habitats (most suited to SRE species), did not support rich SRE communities. Consequently, prospective SRE habitats within the Development Envelope are not considered restricted at the local, sub-regional or regional scale. A total of 36 specimens belonging to at least 14 invertebrate morphospecies were collected from the Development Envelope. Scorpions were the most diverse group with seven species and 12 specimens, followed by slaters (three species; 16 specimens), pseudoscorpions (two species; four specimens) and spiders (two species; four specimens). No centipedes, harvestmen, millipedes or snail specimens (aquatic or terrestrial) were collected during the current survey. No listed invertebrate species were collected during the survey. Nine of the species (64%) were not considered to be, or are unlikely to be, SRE's. No confirmed SRE species were collected; however, five species (36%) were classified as potential SRE species, primarily in the scorpion (three species), spider (two species) and slater (one species) faunas.
Proposal activities – Describe the proposal activities that have the potential to impact the environment	The following aspects of the Proposal may affect terrestrial fauna values: • Clearing of vegetation in mining and infrastructure development areas will directly disturb fauna habitat and may result in the loss of individuals. • Vibration from mining operations may damage the integrity of Ghost Bat roosts on Mesa H. • Noise and dust from mining and ore transportation may disturb Ghost Bat roosts. • Vehicle movements may result in the loss of individuals. • Groundwater abstraction, surplus water discharge, and surface water diversions could potentially impact environmental values, including fauna habitat, as discussed in section 5.4.
Mitigation - Describe the measures proposed to manage and mitigate the potential environmental impacts.	Strategies to minimise the impacts to terrestrial fauna include: • Minimising the disturbance footprint during the mine planning phase. • The mesa escarpment at Mesa H will be retained, through establishment of a MEZ. The majority of the important Gorge and Breakaway Habitats, and all of the Ghost Bat roosts, occur in the Mesa escarpment, and will be protected from direct disturbance by retention of the MEZ. • Similarly, the Northern Quoll and Pilbara Olive Python habitats (Gorge, Breakaway and Riverine) will be protected by retention of the MEZ and limited disturbance to the creekline. • Minimal direct disturbance to the Robe River riparian vegetation which comprises the important Riverine habitat. • Maintaining appropriate speed limits for vehicles.

Potential environmental impacts	
Impacts - Assess the impacts of the proposal and review the residual impacts against the EPA objective.	The Proposal is expected to result in the progressive clearing of up to 2,200 ha of native vegetation (incorporating fauna habitat). It is recognised that the escarpments of Mesa H adjacent to the Robe River are some of the most significant habitat features in the Development Envelope for both vertebrates and SREs. The mesa escarpment adjacent to the Robe River will be retained through establishment of a MEZ, ensuring that these habitats continue to be available to a range of fauna. Note that Mesa landform only occurs in the northern area of the deposit. Refer to Section 6. Semi-permanent and permanent pools and riparian vegetation of the Robe River adjacent to Mesa H are considered significant habitat features. Groundwater abstraction and surplus water discharge as a result of the Proposal are considered unlikely to have significant impacts on the identified environmental values of the Robe River and Jimmawurrada Creek ecosystems (including terrestrial fauna habitat), as discussed in section 5.4. The area of potential impact is a small proportion of the total terrestrial fauna habitat on these creekline ecosystems. Based on the above considerations, it is unlikely that the Proposal will significantly affect the regional distribution of terrestrial fauna habitat or the conservation status of any fauna species. The Proponent considers that the Proposal is likely to meet the EPA objective for Terrestrial Fauna.
Assumptions - Describe any assumptions critical to your assessment *e.g. particular mitigation measures or regulatory conditions.*	Key assumptions are related to the extent of information collected and seasonal variability – these assumptions are detailed in the supporting terrestrial fauna studies. Assumptions regarding hydrogeological modelling, that informs assessment of the potential impacts of groundwater drawdown on the Robe River ecosystem are stated in section 5.4. These surveys and studies have been undertaken by specialist consultants to ensure an appropriate level of independent rigour and ensure that EPA guidance, methodologies and industry standards have been adopted. Where significant uncertainty exists, a ‘worst case scenario’ will presented in the impact assessment and options of mitigation will be considered.

Table 5-3: Conservation listed species recorded or likely to be recorded in the Development Envelope

Common name	Scientific name	Conservation status		Likelihood of occurrence
		WC Act	EPBC Act	
Northern Quoll	*Dasyurus hallucatus*	S 2	Endangered	Confirmed
Pilbara Leaf-nosed Bat	*Rhinonicteris aurantia* (Pilbara form)	S 3	Vulnerable	Confirmed
Pilbara Olive Python	*Liasis olivaceus barroni*	S 3	Vulnerable	Confirmed
Ghost Bat	*Macroderma gigas*	S 3	Vulnerable	Confirmed
Western Pebble-mound Mouse	*Pseudomys chapmani*	P 4	-	Confirmed
Lined Soil-crevice Skink	*Notoscincus butleri*	P 4	-	Confirmed
Rainbow Bee-eater	*Merops ornatus*	S 5	Migratory	Confirmed
Eastern Great Egret	*Ardea modesta*	S 5	Migratory	Confirmed
Blindsnake	*Anilios ganei*	P 1	-	High
Cattle Egret	*Ardea ibis*	S 5	Migratory	Moderate
Fork-tailed Swift	*Apus pacificus*	S 5	Migratory	Moderate
Letter-winged Kite	*Elanus scriptus*	P 4	-	Moderate
Australian Painted Snipe	*Rostratula benghalensis (sensu lato)*	S 5	Endangered	Moderate
Common Sandpiper	*Actitis hypoleucos*	S 5	Migratory	Moderate
Sharp-tailed Sandpiper	*Calidris acuminata*	S 5	Migratory	Moderate
Wood Sandpiper	*Tringa glareola*	S 5	Migratory	Moderate
Common Greenshank	*Tringa nebularia*	S 5	Migratory	Moderate
Oriental Pratincole	*Glareola maldivarum*	S 5	Migratory	Moderate
Long-tailed Dunnart	*Sminthopis longicaudata*	P 4	-	Moderate
Short-tailed Mouse, Karekanga	*Leggadina lakedownensis*	P 4	-	Moderate
Brush-tailed Mulgara	*Dasycercus blythi*	P 4	-	Moderate
Greater Bilby, Dalgyte	*Macrotis lagotis*	S 3	Vulnerable	Low
Northern Marsupial Mole	*Notoryctes caurinus*	-	Endangered	Low
Eastern Osprey	*Pandion cristatus*	S 5	Migratory	Low
Oriental Plover	*Charadrius veredus*	S 5	Migratory	Low
Greater Sand Plover	*Charadrius leschenaultii*	S 5	Migratory	Low
Whimbrel	*Numenius phaeopus*	S 5	Migratory	Low
Barn Swallow	*Hirundo rustica*	S 5	Migratory	Low

5.3 Subterranean Fauna

5.3.1 EPA objective

The EPA objective for subterranean fauna is *to protect subterranean fauna so that biological diversity and ecological integrity are maintained*.

5.3.2 Potential environmental impacts

Consideration of the potential impacts relevant to Terrestrial Fauna is captured in Table **5-4**

Table 5-4: Consideration of potential environmental impacts – Subterranean Fauna

Potential environmental impacts	
EPA policy and guidance - What have you considered and how have you applied them in relation to this factor?	The following EPA guidelines and technical guidance have been considered for the proposal in relation to Subterranean fauna in order to meet the EPA's objective as outlined above: • EPA Statement of Environmental Principles, Factors and Objectives (2016). • EPA Environmental Factor guideline (Land): *Environmental Factor Guideline – Subterranean Fauna* (2016). • EPA Technical Guidance (Land): *Sampling methods for subterranean fauna* (2016). • EPA Technical Guidance (Land): *Subterranean Fauna Survey* (2016). Subterranean fauna surveys are being undertaken consistent with the EPAs technical guidance for this factor. The design of the subterranean fauna surveys is consistent with the requirements of the EPA technical guidance as is the level of survey effort. Vouchering and lodgement of specimens is underway consistent with the guidance. The Proposal and supporting studies focus on presenting the current state of knowledge and defines subterranean species within the Development Envelope and surrounds. The Proposal has been designed to minimise impact to and maintain viable habitat for subterranean fauna via the application of the mitigation hierarchy. Any survey limitations relative to the technical guidance will be noted in the subterranean fauna survey report.
Consultation – Outline the outcomes of consultation in relation to the potential environmental impacts	**OEPA (Terrestrial Ecosystems Branch)** An outline of the scope of the Mesa H proposal was provided, including a summary of troglofauna sampling and results; conceptual proposed troglofauna habitat retention areas; and singleton avoidance areas. • Justification for the areas, volumes and widths selected as habitat retention zones in terms of suitability for troglofauna to be included in the EIA. • Clearly show which holes were sampled during each of the 6 phases of sampling including null results and which holes were resampled. • Data from troglofauna sampling at Mesa A and analysis of habitat aspects (downhole humidity and temperature data) would help to support approach to habitat retention.
	Parks and Wildlife An outline of the scope of the Mesa H Proposal was provided, including the status of surveys and an overview of survey results, and a discussion of the subterranean fauna PEC's. Parks and Wildlife suggested that there may be a need to context troglofauna habitat cumulatively between Mesas H and J.
	DMP An outline of the scope of the Mesa H Proposal for closure was provided. Clarification sought whether different or similar subterranean fauna species recorded on each mesa and whether contextual survey work for subterranean fauna and other fauna had been undertaken on remaining mesas. Contextual information to be provided in the EIA and considered in the closure plan.
	DoW Refer to consultation notes summarised in Section 5.4.

Potential environmental impacts	
Receiving environment - Describe the current condition of the receiving environment in relation to this factor.	Three Priority 1 PECs relevant to subterranean fauna are present in (or overlap with) the Development Envelope namely: • *Subterranean invertebrate communities of mesas in the Robe Valley region*; • *Subterranean invertebrate community of pisolitic hills in the Pilbara*; and • *Stygofaunal Community of the Bungaroo Aquifer.* **Troglofauna** Subterranean fauna assessments have identified troglofauna from the proposed mining area. Some species recorded at Mesa H appear to be restricted to the mesa. A total of 27 troglobitic taxa recorded from the survey at Mesa H are regarded as potential SRE fauna. Of these, 19 taxa are represented by singleton records. Two potential SRE species recorded from a previous survey occur within the Mesa H development envelope, *Paradraculoides* sp. nov. 'Mesa H' and *Troglarmadillo* sp. 1. Three taxa have been recorded from both inside and outside of the Development Envelope, with the remaining 24 taxa recorded only from within the Mesa H Development Envelope. **Stygofauna** Stygofauna have been recorded in the Development Envelope and the surrounding area. A total of 337 stygofauna specimens were recorded over the four phases of sampling, comprising at least 34 species-level taxa, with 6 taxa representing singleton records. Two Amphipoda species of conservation significance have been recorded within the Development Envelope during previous surveys: *Nedsia hurlberti* and *Nedsia sculptilis*, both of which are Schedule 3 species. An additional species of conservation significance was also recorded from a previous survey within 1 km of the Mesa H Development Envelope: Blind Cave Eel (*Ophisternon candidum* – Vulnerable; Schedule 3). All but 4 of the 15 potential SRE stygofauna taxa recorded are known to occur outside Development Envelope and impact area.
Proposal activities – Describe the proposal activities that have the potential to impact the environment.	The following aspects of the Proposal may affect subterranean fauna values: • Mining will result in physical loss and or degradation of a proportion of troglofauna habitat within the Development Envelope and loss of individuals. • Groundwater abstraction will temporarily reduce stygofauna habitat. • Surplus water discharge may temporarily increase the extent and connectivity of stygofauna habitat. • Spills of hydrocarbons or waste water may degrade the subterranean environment. • Localised seepage from placement of waste fines in-pit at Mesa H may result in minor local loss or impact to stygofauna habitat.

Potential environmental impacts	
Mitigation - Describe the measures proposed to manage and mitigate the potential environmental impacts.	Strategies to minimise the impacts to subterranean fauna include: • Characterising the troglofauna and stygofauna habitat present in the conceptual footprint. • Characterising the local and regional conservation significance of troglofauna and stygofauna in the impact area and Development Envelope. • Establishing Mining Exclusion Zones (MEZ) to retain troglofauna habitat. • Undertaking further troglofauna sampling. • Maintaining groundwater and surface water quality by managing erosion, sedimentation and contamination (e.g. hydrocarbon spills). • Undertaking monitoring of stygofauna habitat (via hydrological parameters) through the life of the mine. • Undertaking backfilling of mine pits to assist in protecting troglofauna habitat retention zones.
Impacts - Assess the impacts of the proposal and review the residual impacts against the EPA objective.	The Proposal may result in direct mortality and reduction in available habitat due to pit excavation and groundwater drawdown. Potential impacts will be localised to the proposed pit area and the groundwater drawdown zone during mining operations – however is not expected to significantly impact subterranean fauna species persistence. The risk of pollutants being transported into the subterranean habitat is low and is likely to be locally restricted. The connectivity of the habitat maintained in the alluvial aquifers together with proposed habitat retention in the CID maintains habitat viability for subterranean fauna populations during and post mining. **Troglofauna** Loss of troglofauna habitat will occur as a consequence of excavation from mining. Many troglofauna recorded appear to be restricted to Mesa H and are unlikely to occur more widely. Significant volumes of troglofauna habitat at Mesa H is proposed to be retained via establishment of a MEZ. Examples of existing and historical mining operations and the ongoing representation of troglofauna species has been investigated at Mesa K and ongoing sampling at Mesa A (currently still in operation) supports this approach. **Stygofauna** Dewatering of pits and abstraction of groundwater water will temporarily reduce stygofauna habitat in the CID until the water table recovers following cessation of water abstraction. The majority of the stygofauna taxa recorded at Mesa H are known to occur outside the Development Envelope and additional habitat is present in the alluvials and basement aquifers. The results of hydrogeological modelling will provide greater certainty regarding the extent of potential impacts. Based on the proposed management approach and the anticipated residual impacts, the Proponent considers that the Proposal is likely to meet the EPA objective for Subterranean Fauna.

Potential environmental impacts	
Assumptions - Describe any assumptions critical to your assessment *e.g. particular mitigation measures or regulatory conditions*.	Key assumptions are related to the extent of information collected and seasonal variability, and limitations of sampling in the subterranean environment – these assumptions are detailed in the supporting subterranean fauna studies. These surveys and studies have been undertaken by specialist consultants to ensure an appropriate level of independent rigour and ensure that EPA guidance, methodologies and industry standards have been adopted. Outcomes of the subterranean fauna habitat characterisation work at the nearby Mesa K and Mesa A Projects are considered analogous and applicable to the Mesa H Proposal based on having the same geology and habitat features.

5.4 Hydrological Processes and Inland Water Environmental Quality

5.4.1 EPA objective

The EPA objective for Hydrological Processes is *to maintain the hydrological regimes of groundwater and surface water so that environmental values are protected*.

The EPA Objective for Inland Waters Environmental Quality is *to maintain the quality of groundwater and surface water so that environmental values are protected.*

5.4.2 Potential environmental impacts

Consideration of the potential impacts relevant to Hydrological Processes and Inland Waters Environmental Quality is captured in Table 5-5.

Table 5-5: Consideration of potential environmental impacts – Hydrological Processes and Inland Waters Environmental Quality

Potential environmental impacts	
EPA policy and guidance - What have you considered and how have you applied them in relation to this factor?	The following EPA guidelines have been considered for the proposal in relation to Hydrological Processes and Inland Waters Environmental Quality in order to meet the EPA's objectives as outlined above: EPA Statement of Environmental Principles, Factors and Objectives (2016). EPA Environmental Factor guideline (Water): Environmental Factor Guideline – Hydrological Processes (2016). • EPA Environmental Factor guideline (Water): *Environmental Factor Guideline – Inland Waters Environmental Quality* (2016). The Proposal identifies the environmental values supported by hydrological processes and inland waters environmental quality, and their significance including water dependent ecosystems, amenity, cultural values, recreation, and agricultural use of water, and the chemical, physical, biological and aesthetic characteristics of inland waters. The Proposal and supporting studies focus on presenting the current state of knowledge, defines environmentally significant water dependant ecosystems and focusses on activities and pathways that can impact on hydrological processes and inland waters environmental quality – with the application of the mitigation hierarchy in the design of the Proposal in order to avoid and minimise impacts to hydrological processes / inland waters environmental quality and associated environmental values, where possible.
Consultation – Outline the outcomes of consultation in relation to the potential environmental impacts	**OEPA** A summary of the Mesa H Proposal was provided pre-referral. Proponent to complete studies and prepare referral documentation. DMA consult to be undertaken with key agencies.
	DoW A summary of the hydrogeological drilling and monitoring program in the Robe Valley was presented including conceptual hydrogeological models for Mesa H. A field trip to the Robe Valley was also completed. • The proposed consultant for peer review of the hydrogeological models was discussed and agreed. • H3 report to be included with the EIA. • Cumulative impact assessment required for the lower Robe River in the EIA. • Further conceptualisations and testing of the connectivity between the CID and the alluvium. • Quantification of impacts to stygofauna in the drawdown impact area and cumulatively. • Quantification of impacts to riparian vegetation from both drawdown and discharge and current monitoring and management program. • Discussion of limited impacts to the semi-permanent and permanent pools predicted, and proposed mitigation options (if required) to address any significant uncertainties in the modelling to be presented in the EIA.
	DMP An outline of the scope of the Mesa H Proposal for closure was provided. Clarification sought whether the diversion controls being considered will apply for operation only or will they remain post closure, and if pooling/damming of surface flow occur. Further modelling and consideration being undertaken for closure requirements.

Potential environmental impacts	
Receiving environment - Describe the current condition of the receiving environment in relation to this factor.	Mesa H lies within the Robe River catchment which has a catchment area of approximately 7,500 km^2. Major watercourses occurring within the catchment include the Robe River and the Jimmawurrada, Bungaroo and Mungarathoona Creek's. The major water courses generally flow from the southeast to the northwest through high relief areas of the Hamersley Ranges on to the more gently sloping areas of the coastal plain before discharging into the ocean approximately 150 km south of Dampier. For the majority of its course, the Robe River is ephemeral with a wide, shallow flood plain which carries a significant underflow in its alluvial bed. This sub-surface flow maintains permanent pools in the river channel, and these pools play an important role in the river ecosystem. During the dry season water is often restricted to a series of permanent pools that are maintained by sub-surface flow (Bowman *et al* 1991). Surface water and groundwater in the Mesa H locality has been modified and managed for a number of years (since the mid 1990s) by the Mesa J mining operation. This includes pit dewatering and groundwater abstraction, and discharge of surplus water to Jimmawurrada Creek.
Proposal activities – Describe the proposal activities that have the potential to impact the environment	The following aspects of the Proposal may affect hydrological processes and inland waters environmental quality: **Groundwater abstraction:** • Modelling has considered the cumulative impact of dewatering and groundwater abstraction for this Proposal, the Mesa J operation and the Coastal Water Supply borefield. • Groundwater abstraction for water supply and pit dewatering will result in localised groundwater drawdown in the CID and basement aquifers that may have some connectivity to the Robe River alluvial aquifer and the Jimmawurrada creek alluvial aquifer. • Hydrogeological modelling indicates the potential for limited reduction in water levels in the Robe River alluvial aquifer and pools, with recovery of the groundwater table over time once water abstraction ceases. The predicted limited reduction in water levels in the alluvial aquifers is considered unlikely to have significant impacts on the identified environmental values of the Robe River, including riparian vegetation, terrestrial and aquatic fauna, and associated habitats. • Hydrogeological modelling indicates that ongoing dewatering and groundwater abstraction for the Proposal may potentially further extend drawdown in the Jimmawurrada Creek and will extend the timeframe for the predicted groundwater recovery once water abstraction ceases. This may result in changes to structure and composition of riparian vegetation and temporary localised impacts to aquatic and stygofauna; however riverine ecosystem function is expected to be maintained. • Further hydrogeological investigations and modelling will be undertaken to confirm findings to date. **Discharge:** • Discharge of surplus water may be required from Mesa H into an existing discharge point in Jimmawurrada Creek, and /or the Robe River and tributaries. • Discharge is modelled to extend no further than 8 km from the discharge point under natural no-flow conditions (or ~19km during discharge during flood events). • Discharge could potentially reduce water quality via increased sediment loads and contamination via hydrocarbons. • Discharge could result in stress in riparian vegetation due to waterlogging, and increase in distribution and proliferation of weeds. However discharge water is expected to be of similar quality, and of lower volumes, than has historically occurred from the Mesa J mine, which ongoing monitoring indicates has not had significant impacts on the identified environmental values of the Robe River ecosystem. **Minor creek diversions and flood protection structures:** • Alteration to natural surface drainage regimes has the potential to affect downstream vegetation. Of the three local catchments diverted, two are already intersected by pits at Mesa J operation.

Potential environmental impacts	
Mitigation **-** Describe the measures proposed to manage and mitigate the potential environmental impacts.	Strategies to minimise the impacts to Hydrological Process and Inland Environmental Waters Quality include: • Minimal direct disturbance to the Robe River and Jimmawurrada Creek. • Infrastructure and pit designs avoid disruption of natural flood flows where possible. • Undertaking further hydrogeological investigations and modelling to improve understanding of the potential impacts of groundwater abstraction, including the cumulative effects of the Mesa J mine (including the Southern Cutback Borefield) and the Coastal Water Supply Borefield. • Monitoring groundwater water levels and abstraction rates during operations with ongoing validation of the hydrogeological modelling. • Undertaking aquatic fauna surveys in the Robe River pools, and ongoing monitoring during operations. • Establishing a baseline of seasonal water levels and water quality in the Robe River pools, and ongoing monitoring during operations. • Groundwater to be discharged to the Robe River is generally of good quality; additional water samples will be collected to confirm water quality. • Limiting surplus water discharge to the Robe River by preferential use on site for operational purposes. Preferential use of existing Mesa J discharge outlets, if new discharge locations are required, surface water management structures will be installed to prevent erosion and sediment transport. • Hydrocarbon bunding and hydrocarbon treatment facilities will be installed to prevent hydrocarbons contaminating surface water and groundwater. • Development of a monitoring and management plan, with trigger and threshold levels and actions, to ensure no significant detrimental impact to the identified environmental values of the Robe River and Jimmawurrada creek ecosystems due to groundwater abstraction and discharge. This plan will consider precautionary mitigation options for groundwater drawdown, such as supplementary water supply to the Robe River ecosystem via controlled discharge. Management strategies for potential impacts to flora and vegetation, terrestrial fauna, subterranean fauna and social surrounds arising from hydrological processes are discussed in sections 5.1, 5.2, 5.3, and 5.5.

Potential environmental impacts	
Impacts - Assess the impacts of the proposal and review the residual impacts against the EPA objective.	**Groundwater abstraction:** Modelling has considered the cumulative impact of dewatering and groundwater abstraction for the Mesa H Proposal, the Mesa J mine and the Coastal Water Supply Borefield. Modelling has adopted a conservative approach to current hydrogeological uncertainties, generally applying more pessimistic parameters to test a 'worst case' scenario. Dewatering for water supply and pit dewatering will result in localised groundwater drawdown in the CID and basement aquifers that may have some connectivity to the Robe River alluvial aquifer and the Jimmawurrada Creek alluvial aquifer. Hydrogeological modelling indicates the potential for limited reduction in water levels in the Robe River alluvial aquifer and pools, with recovery of the groundwater table over time once water abstraction ceases. The predicted reduction in groundwater levels in the alluvial aquifer is considered unlikely to have significant impacts on the identified environmental values of the Robe River ecosystem (including riparian vegetation and terrestrial and aquatic fauna). Hydrogeological modelling indicated that ongoing dewatering and groundwater abstraction for the Proposal may potentially further extend drawdown in the Jimmawurrada Creek area, and extend the timeframe for predicted groundwater recovery once groundwater abstraction ceases. This may result in changes to structure and composition of riparian vegetation, and temporary, localised impacts to aquatic and stygofauna, however riverine ecosystem function may be maintained. The predicted reduction in water levels due to the Proposal is not considered to have significant impacts on the identified environmental values of the Jimmawurrada Creek ecosystem. Further hydrogeological investigations and modelling will be undertaken to confirm findings to date. **Discharge:** Discharge of surplus water may be required from Mesa H into the Robe River and tributaries. Discharge will extend no further than 8 km from the discharge point under natural no-flow conditions, and 19km if emergency discharge, resulting from surface water flooding of the pits, is required. Discharge is expected to be of similar quality, and of lower volumes, than has historically occurred from the Mesa J mine, that ongoing monitoring indicates has not had significant impacts on the identified environmental values of the Robe River ecosystem (including riparian vegetation, and terrestrial and aquatic fauna). **Drainage:** Acid rock drainage risk has been assessed as low due to the geology. Site drainage will be designed to minimise or eliminate surface runoff into areas where activities with a potential risk of hydrocarbon contamination occur. Management of waste dumps will ensure that risks of contamination of surface and groundwater are minimised. Anticipated residual impacts to flora and vegetation, terrestrial fauna, subterranean fauna and social surrounds arising from hydrological processes are discussed in sections 5.1, 5.2, 5.3 and 5.5. The Proponent considers that the Proposal is likely to meet the EPA objective for Hydrological Processes and Inland Environmental Water Quality.
Assumptions - Describe any assumptions critical to your assessment *e.g. particular mitigation measures or regulatory conditions.*	Key assumptions are related to the extent of information collected and calibration of existing systems to support hydrogeological and hydrological conceptualisations – these assumptions are detailed in the supporting hydrogeological / hydrological studies. These studies have been peer reviewed to ensure appropriate methodologies and industry standards in approach have been adopted. Hydrogeological modelling has adopted a conservative approach to current uncertainties, generally applying more pessimistic parameters to test a 'worst case' scenario to inform the environmental impact assessment. The Proposal assumes no 3rd party changes to the local hydrogeological regime.

5.5 Social Surroundings

5.5.1 EPA objective

The EPA objective for Social Surroundings is *to protect social surroundings from significant harm.*

5.5.2 Potential environmental impacts

Consideration of the potential impacts relevant to Social Surroundings is captured in Table 5-6.

Table 5-6: Consideration of potential environmental impacts – Social Surroundings

Potential environmental impacts	
EPA policy and guidance - What have you considered and how have you applied them in relation to this factor?	The following EPA guidelines and technical guidance have been considered for the proposal in relation to Subterranean fauna in order to meet the EPA's objective as outlined above: • EPA Statement of Environmental Principles, Factors and Objectives (2016). • EPA Environmental Factor guideline (People): *Environmental Factor Guideline – Social Surroundings* (2016). The Proposal and supporting studies focus on presenting the current state of knowledge and defines the aesthetic, cultural (physical and biological), economic and/or social values which may be impacted within the Development Envelope. The Proposal has been designed to minimise impact to social surroundings via the application of the mitigation hierarchy. Any limitations relative to the work undertaken will be noted in the impact assessment and supporting studies.
Consultation – Outline the outcomes of consultation in relation to the potential environmental impacts.	**Traditional Owners (Kuruma Marthudunera)** The Proponent maintains ongoing regular consultation with the K&M through multiple forums, including the Local Implementation Committee (LIC) meetings, KMAC Heritage Sub-Committee (HSC) meetings, and heritage surveys. The Proponent has provided a copy of this referral to the K&M people concurrently with this submission; The Mesa H proposal has been discussed on multiple occasions with the K&M, and consultation will continue. Key outcomes of consultation to date comprise: • The highly significant ethnographic site *Jirti Thalu*, and a significant quarry site, will be protected. • The mesa escarpment has significant cultural value, particularly where adjacent to the Robe River, and will be retained via a MEZ. • The proposed location and design (height restricted) of the northern waste dump location was agreed as the preferred option to minimise visual impact. • Agreement to obtain precautionary Section 18 consents under the *Aboriginal Heritage Act 1972* (Heritage Act) for rock shelters in the mesa escarpment that may be impacted by blasting vibrations. • The Robe River and pools are of high cultural significance, and are regularly used for cultural and recreational activities. • Watercourses other than the Robe River are also of cultural importance. • Agreement to retain the central watercourse through the mesa and main gullies on the western side of the mesa (protected by establishment of a MEZ). • The project footprint will directly impact multiple archaeological sites as discussed with the K&M. Consent under the Heritage Act will be required to disturb these sites. **Yarraloola and Yalleen Stations** • Further consultation as part of existing subleasing arrangement; and • Update on Mesa H Proposal, planned activities, scope of the proposal and dates/ timeframes.

Potential environmental impacts	
Receiving environment - Describe the current condition of the receiving environment in relation to this factor.	Existing land uses in the Development Envelope include pastoral activities (Yarraloola and Yalleen Stations), mineral exploration, mining activities and cultural / recreational activities (predominantly by Traditional Owners) such as camping, fishing and hunting. The mesa landform / profiles are also used by Traditional Owners as landmarks when travelling though the countryside. The Proposal falls within the K&M native title claim (WCD2016/006). The K&M People have a Claim Wide Participation Agreement and Indigenous Land Use Agreement with Rio Tinto. The agreements commit Rio Tinto and the K&M People to work together to manage and maintain the areas in which Rio Tinto operates. The agreements set clear requirements for processes such as land access, tenure, heritage and environmental approvals, mining benefit payments and reporting and communication requirements. All of the archaeological survey work and the majority of the ethnographic survey work has been completed for the Proposal. Heritage sites of high significance in the vicinity of the Proposal Area and broader Development Envelope are ethnographic sites (including mythological locations, named pools and places of importance due to current use); the Robe River, and the mesa profiles which are used as landmarks within the landscape. The Proposal is located at the centre of a series of pisolite mesa formations associated with the Robe River. These mesas punctuate a landform of plains and low angle talus slopes that generally fall away to the Ashburton Plain in the west. In the Development Envelope, the land rises into the adjacent Hamersley Ranges, where more robust formations create more rugged and highly dissected landforms. Mesa H forms a mesa ridge on its north west margin where it abuts the Robe River, and merges into the footslope of the Buckland Hills in the south-east, with a smaller less prominent gully dissecting central part of the formation. The Pannawonica Road is the main travel route though the area, that is used predominantly by Robe Valley mining operations personnel to access Pannawonica (a closed town) and the Mesa J Operation. Other roads are generally unformed pastoral access roads. Long distance views of the surrounding country are available at certain locations along the Pannawonica Road, due to the open nature of the landforms and sparse vegetation; however views become confined close to, and between, mesa formations, in gullies and near the riverine vegetation. Mesa H is approximately 5 km south of the Pannawonica Road and is visible in the distance from approximately a 6.8 km section of the road. Mesa H lies within the Robe River catchment with major watercourses including the Robe River and the Jimmawurrada, and Mungarathoona Creek's. The Robe River is the major watercourse in the Development Envelope which contains semi-permanent and permanent pools in the river channel. The pools and the riparian ecosystem within the Development Envelope are utilised by the K&M for cultural and recreational activities, by the public for recreation, and by Yaraloola and Yalleen Stations. Surface water and groundwater in the Mesa H locality has been modified and managed for a number of years (since the mid 1990s) by the Mesa J Operations. The Proposal also overlaps with the Yarraloola and Yalleen Pastoral Leases which are currently active pastoral stations running cattle in the lower plains and riverine areas.
Proposal activities – Describe the proposal activities that have the potential to impact the environment	• Ground disturbance for the Proposal could directly impact heritage sites. • Blasting vibrations could indirectly impact heritage sites. • Groundwater abstraction and surplus water discharge could potentially have limited impact on water levels in the Robe River alluvial aquifer and pools, however significant impacts on the identified environmental values of the Robe River ecosystem are considered unlikely, as discussed in section 5.4. • Mining activities will result in external waste dumps retained in the landscape and will remove the central core of the mesa formation.

Potential environmental impacts	
Mitigation **-** Describe the measures proposed to manage and mitigate the potential environmental impacts.	• Biological survey work for the Proposal, and more generally in the Robe Valley, has included K&M involvement. • Heritage surveys are undertaken with participation of the K&M. • Heritage sites will be avoided where practicable. Where heritage sites cannot practically be avoided, the Proponent will consult with the K&M and seek appropriate approval under the Heritage Act. • The Proponent has an established internal system for managing all ground disturbing activities to ensure compliance with heritage commitments and regulatory requirements. • The project footprint has been modified to protect the highly significant ethnographic site *Jirti Thalu*, and a significant quarry site, in consultation with the K&M. • The culturally significant mesa escarpment will be retained via establishment of a MEZ, as discussed with the K&M. Pit designs will incorporate the outcomes of geotechnical investigations to ensure the long-term stability of the retained escarpment, and appropriate blast management will be applied during operations. • The proposed location and design (height restricted) of the northern waste dump location was agreed with the K&M as the preferred option to minimise visual impact. • Rockshelters within the mesa escarpment will not be directly impacted by mining but may be impacted by blasting vibration, requiring Heritage Act consents as agreed with the K&M. • Additional hydrogeological investigations and modelling will be undertaken to confirm the current predictions of limited impact due to this Proposal on the Robe River alluvial aquifer and pools and the Jimmawurrada Creek area. • The central watercourse through the mesa and main gullies on the western side of the mesa are protected from direct mining impacts by the MEZ. • Groundwater abstraction and surplus water discharge from the Proposal are considered unlikely to have significant impacts on the identified environmental values of the Robe River and Jimmawurrada ecosystems. A monitoring and management plan, with trigger and threshold levels and actions will ensure no significant detrimental impact to the identified environmental values of the Robe River and Jimmawurrada Creek ecosystems. This plan will consider precautionary mitigation options for groundwater drawdown, such as supplementary water supply to the Robe River ecosystem via controlled discharge.

Potential environmental impacts	
Impacts - Assess the impacts of the proposal and review the residual impacts against the EPA objective.	**Heritage values** • The project footprint has been modified to protect the highly significant ethnographic site *Jirti Thalu*, and a significant quarry site, in consultation with the K&M. • The culturally significant mesa escarpment will be excluded from mining as discussed with the K&M. • Rockshelters within the mesa escarpment will not be directly impacted by mining but may be impacted by blasting vibration, requiring Heritage Act consents as agreed with the K&M. • The project footprint will directly impact multiple archaeological sites. Consent under the Heritage Act will be required to disturb these sites. • Groundwater abstraction and surplus water discharge as a result of the Proposal are considered unlikely to have significant impacts on the identified environmental values of the Robe River and Jimmawurrada ecosystems. Further hydrogeological investigations and modelling will be undertaken to confirm findings to date. • Further consultation will be undertaken with the K&M regarding the physical and biological cultural values of the Robe River and Jimmawurrada Creek ecosystems and how these interrelate with management of the identified environmental values. **Visual Amenity** • The Proposal will not have a significant impact to visual amenity due to the retention of the mesa escarpment, and location and design (height restriction) of external waste dumps. **Pastoral** • The mine pit is located in an area not normally utilised by cattle for grazing activities, hence limited impacts to pastoral activities are anticipated. The Proponent considers that the Proposal is likely to meet the EPA objective for Social Surroundings.
Assumptions - Describe any assumptions critical to your assessment *e.g. particular mitigation measures or regulatory conditions.*	Key assumptions are related to the extent of consultation and information collected in combination with the degree of seasonal variability naturally experienced in an arid environment – these assumptions are detailed in the supporting studies. Assumptions regarding the potential for impacts of groundwater drawdown on the Robe River ecosystem are outlined in previous sections. Consultation has been undertaken with the K&M regarding cultural values of the Robe River and pools, and the impact assessment considers cultural values in the context of where they relate to the identified physical and biological values of the ecosystem. Further discussion will be undertaken with the K&M on this relationship. Surveys and studies have been undertaken by specialists in conjunction with key K&M group representatives to ensure an appropriate level of rigour and ensure that EPA guidance, methodologies and industry standards have been adopted. Where significant uncertainty exists, a 'worst case scenario' will be considered in the impact assessment and mitigation options to prevent significant impacts will be provided.

6. OTHER ENVIRONMENTAL FACTORS

The following factors, although not considered key, are relevant to the Proposal:

- Landforms
- Air Quality

Table 6-1 outlines the consideration of the above factors relevant to the Proposal.

All other factors (Benthic Communities and Habitat, Coastal Processes, Marine Environmental Quality, Marine Fauna, Terrestrial Environmental Quality and Human Health) are not considered to be relevant to the Proposal.

Table 6-1: Consideration of factors unlikely to be key environmental factors

EPA Objective & policy / Guideline consideration	Potential impact	Management	Anticipated residual impact
Air Quality			
To maintain air quality and minimise emissions so that environmental values are protected. The following EPA guidelines and technical guidance have been considered for the proposal in relation to Air in order to meet the EPA's objective as outlined above: • EPA Statement of Environmental Principles, Factors and Objectives (2016). • EPA Environmental Factor guideline (Air): *Environmental Factor Guideline – Air Quality* (2016).	• Dust will be generated by construction, mining, processing, ore handling and transportation and vehicle movements • Greenhouse gas emissions will be generated by the Proposal. Estimates are currently being calculated, however it is anticipated that emissions will be reduced due to utilisation of existing infrastructure and facilities at the Mesa J Operations.	• Use of dust extraction, water sprays and dust suppressants as applicable. • Clearing work areas only where required. • Rehabilitation of disturbed areas, especially following construction activities, to reduce potential dust lift-off from open areas. • Designing and operating the Proposal to maximise energy efficiency and minimise greenhouse gas emissions.	No significant dust impacts are anticipated due to the proposed management controls and remote location of the Proposal. Greenhouse gas emissions are not considered to be significant and will partly replace the current greenhouse gas emissions from the Mesa J mine as mining transitions from Mesa J to Mesa H. The Proponent considers that the Proposal is likely to meet the EPA objective for Air Quality.
Landforms			
To maintain the variety and integrity of distinctive physical landforms so that environmental values are protected. • EPA Statement of Environmental Principles, Factors and Objectives (2016). • EPA Environmental Factor guideline (Land): Environmental Factor Guideline – Landforms (2016).	• There is limited potential for impact to the mesa landforms as the Mesa H landform comprises escarpments only on the NW margins, adjacent to the Robe River. This escarpment will be retained / avoided during mining.	• Retention of the mesa escarpment. • location and design (height restriction) of external waste dumps to minimise visual • Pit designs will incorporate the outcomes of geotechnical investigations to ensure the long-term stability of the retained escarpment, and appropriate blast management will be applied during operations. • Continuing to locate infrastructure in previously disturbed areas where possible.	The Development Envelope is adjacent to an existing mining operation at Mesa J with similar components to those of the Proposal. No significant additional impacts are anticipated. The Proponent considers that the Proposal is likely to meet the EPA objective for Landforms.

7. PRINCIPLES OF ENVIRONMENTAL PROTECTION

The principles of environmentally sustainable development are incorporated into Section 4A of the EP Act. These principles have been considered for the Proposal as summarised in Table 7-1.

Table 7-1: Environmental principles of the EP Act

Principle	Consideration given in the Proposal
1. Precautionary principle Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation. In the application of the precautionary principle, decisions should be guided by: (a) Careful evaluation to avoid, where practicable, serious or irreversible damage to the environment; and (b) An assessment of the risk-weighted consequences of various options.	Comprehensive biological surveys have already been undertaken and others are well underway. The results of the biological surveys are being used to guide the design phase of the Proposal. Where significant potential environmental impacts are identified measures have been, and will continue to be, incorporated into the Proposal design and management to avoid or minimise these impacts where practical.
2. Intergenerational equity The present generation should ensure that the health, diversity and productivity of the environment is maintained or enhanced for the benefit of future generations.	The Proposal will make a long-term contribution to the economic prosperity of Western Australia. The Proposal will not compromise current or foreseeable future land use options in the area. The Proposal can be effectively managed through avoidance, management and mitigation measures to ensure that the health, diversity and productivity of the environment is maintained or enhanced for the benefit of future generations.
3. Improved valuation, pricing and incentive mechanisms (a) Environmental factors should be included in the valuation of assets and services. (b) The polluter pays principle – those who generate pollution and waste should bear the cost of containment, avoidance or abatement. (c) The users of goods and services should pay prices based on the full life cycle costs of providing goods and services, including the use of natural resources and assets and the ultimate disposal of any wastes. (d) Environmental goals, having been established, should be pursued in the most cost-effective way, by establishing incentives structures, including market mechanisms, which enable those best placed to maximise benefits and/or minimise costs to develop their own solutions and responses to environmental problems.	The Proposal will be subject to a Mine Closure Plan prepared in accordance with the DMP and EPA *Guidelines for Preparing Mine Closure Plans* (May 2015) and the Rio Tinto Closure Standard. This will provide the basis for ensuring that post-mining land use objectives are identified (through a consultative process) and can be met. The Proponent will undertake land rehabilitation activities to underpin the mine closure process.

Principle	Consideration given in the Proposal
4. Conservation of biological diversity and ecological integrity. Conservation of biological diversity and ecological integrity should be a fundamental consideration.	Comprehensive biological surveys have already been undertaken and others are other are underway to identify aspects of the environment that are of conservation significance. Where significant potential environmental impacts are identified measures have been, and will continue to be, incorporated into the Proposal design and management to avoid or minimise these impacts where practical. The Proponent's HSECQ Management System has established rehabilitation procedures for restoring disturbed environments.
5. Waste minimisation All reasonable and practicable measures should be taken to minimise the generation of waste and its discharge into the environment.	Application of the Proponent's management policies, systems and procedures, in combination with the Mine Closure Plan, will provide the basis for minimising the generation of waste and its discharge into the environment. Mine planning objectives to minimise stripping ratios, thereby reducing mineral waste materials volumes, will assist in meeting the aims of this principle.

8. REFERENCES

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EPA Environmental Factor guideline (Land): *Environmental Factor Guideline – Flora and Vegetation* (2016).

EPA Technical Guidance (Land): *Flora and Vegetation Surveys for Environmental Impact Assessment* (2016).

EPA Environmental Factor guideline (Land): *Environmental Factor Guideline – Terrestrial Fauna* (2016).

EPA Technical Guidance (Land): *Terrestrial Fauna Surveys* (2016).

EPA Technical Guidance (Land): *Sampling methods for terrestrial vertebrate fauna* (2016).

EPA Technical Guidance (Land): *Sampling of Short Range Endemic invertebrate fauna* (2016)

EPA Environmental Factor guideline (Land): *Environmental Factor Guideline – Subterranean Fauna* (2016).

EPA Technical Guidance (Land): *Sampling methods for subterranean fauna* (2016).

EPA Technical Guidance (Land): *Subterranean Fauna Survey* (2016).

EPA Environmental Factor guideline (People): *Environmental Factor Guideline – Social Surroundings* (2016).

EPA Environmental Factor guideline (Air): *Environmental Factor Guideline – Air Quality* (2016)

EPA Environmental Factor guideline (Land): *Environmental Factor Guideline – Landforms* (2016).

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Our Ref: *CMS17155*
Enquiries: *Matt Spence, 6364 0819*
Email: *matt.spence@dwer.wa.gov.au*

Dear Mr Vella

MESA H PROPOSAL (REVISION TO MESA J IRON ORE DEVELOPMENT) – ASSESSMNET NO: 2121

The Environmental Scoping Document (ESD) dated 31 October 2017 (DWERDA-010464) specifying the scope and content of the Environmental Review Document (ERD) for the above proposal was considered by the Environmental Protection Authority at Meeting No. 1106 on 19 October 2017. The ESD has been approved as providing an acceptable basis for the preparation of the ERD.

During the preparation of the ERD you are encouraged to consult with the Office of the Environmental Protection Authority assessment officer for the proposal, Matt Spence, who can be contacted on telephone number 6364 6805. Please quote the above "Our Ref" on any further correspondence.

Yours sincerely

Dr Robert Harvey
DEPUTY CHAIRMAN

31 October 2017

Encl. Environmental Scoping Document – Mesa H Proposal (Revision to Mesa J Iron Ore Development)

DRAFT ENVIRONMENTAL SCOPING DOCUMENT

Proposal name:	**Mesa H Proposal (Revision to the Mesa J Iron Ore Project)**
Proponent:	**Robe River Mining Co. Pty. Ltd.**
Assessment number:	**2121**
Location:	**16 kilometres south west of Pannawonica in the Pilbara region of Western Australia**
Local Government Area:	**Shire of Ashburton**
Public review period:	**Environmental Review Document – 2 weeks**
EPBC Reference No:	**2017/8017**

1. Introduction

The Environmental Protection Authority (EPA) has determined that the above Proposal is to be assessed under Part IV of the *Environmental Protection Act 1986* (EP Act).

The purpose of the Environmental Scoping Document (ESD) is to define the form, content, timing and procedure of the environmental review, required by s. 40(3) of the EP Act. Robe River Mining Co. Pty. Ltd. (the Proponent) has prepared this draft ESD according to the procedures in the EPA's *Procedures Manual.*

Form

The EPA requires that the form of the report on the environmental review required under s. 40 (Environmental Review Document, ERD) is completed according to the *Environmental Review Document template.*

Content

The EPA requires that the environmental review includes the content outlined in sections **2** to **6** of this ESD.

Timing

Table 1 sets out the timeline for the assessment of the Proposal agreed between the Proponent and the EPA.

Table 1: Assessment timeline

Key assessment milestones	Completion Date
EPA approves Environmental Scoping Document	19 October 2017
Proponent submits first draft Environmental Review Document	5 February 2018
EPA provides comment on first draft Environmental Review Document *(6 weeks from receipt of ERD)*	19 March 2018
Proponent submits revised draft Environmental Review Document	30 April 2018
EPA authorises release of Environmental Review Document for public review *(2 weeks from EPA approval of ERD)*	14 May 2018
Proponent releases Environmental Review Document for public review for 2 weeks	28 May 2018
Close of public review period	11 June 2018
EPA provides Summary of Submissions *(3 weeks from close of public review period)*	2 July 2018
Proponent provides Response to Submissions	13 August 2018
EPA reviews the Response to Submissions *(4 weeks from receipt of Response to Submissions)*	10 September 2018
EPA prepares draft assessment report and completes assessment *(6 weeks from EPA accepting Response to Submissions)*	22 October 2018
EPA finalises assessment report (including two weeks consultation on draft conditions) and gives report to Minister *(6 weeks from completion of assessment)*	10 December 2018

*The Assessment Timeline is yet to be agreed to between the Proponent and the EPA. This will be confirmed once the EPA has endorsed the final ESD.

Procedure

The EPA requires the Proponent to undertake the environmental review according to the procedures in the *Administrative Procedures* and the *Procedures Manual*. This ESD has not been released for public review. The ESD will be available on the EPA website (www.epa.wa.gov.au) upon endorsement and must be appended to the ERD.

Assessment as an accredited assessment

The Proposal has been referred to the Commonwealth Department of Environment and Energy and has been determined to be a controlled action under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). The Proposal is being assessed as an accredited assessment. The relevant matters of national environmental significance (MNES) for this proposal are:

- Listed threatened species and communities (Sections 18 and 18A).

This ESD includes work required to be carried out and reported on in the ERD document in relation to MNES. The ERD will also address the matters in Schedule 4 of the *Environment Protection and Biodiversity Conservation Regulations 2000*.

MNES that may be impacted by the Proposal will be identified and the potential impacts on these matters addressed within each relevant preliminary environmental factor as identified in Table 4. The ERD will include a separate section which summarises the potential impacts on MNES and describes, to the extent practicable, any feasible alternatives to the proposed action and possible mitigation measures. Proposed offsets to address significant residual impacts on MNES are also to be discussed.

2. The Proposal and Regional Context

2.1 The Proposal

The subject of this ESD is the proposed development of the Mesa H Proposal (the Proposal) by Robe River Mining Co. Pty. Ltd. (Joint Venture entities include: Robe River Mining Co. Pty. Ltd., North Mining Limited, Mitsui Iron Ore Development Pty. Ltd., Cape Lambert Iron Associates, a partnership carried on by Nippon Steel & Sumitomo Metal Australia Pty Ltd, Nippon Steel & Sumikin Resources Australia Pty Ltd and Mitsui Iron Ore Development Pty Ltd and Pannawonica Iron Associates, a partnership carried on by Nippon Steel & Sumitomo Metal Australia Pty Ltd, Nippon Steel & Sumikin Resources Australia Pty Ltd).

The Mesa H Proposal is located approximately 16 kilometres (km) south-east of Pannawonica in the Pilbara region of Western Australia. The Proposal is to sustain production from the existing Mesa J Operation [approved under Ministerial Statement 208 (MS 208)] and includes development of above and below water table mine pits and associated infrastructure, waste dumps, stockpiles and associated infrastructure, as well as processing facilities and water management infrastructure. The Proposal will utilise and integrate with existing infrastructure and facilities of the Mesa J Operation including ore processing facilities, water management infrastructure, power, and rail.

The regional location of the Proposal is shown in Figure 1 and the Development Envelope encompassing the physical elements of the Proposal is delineated in Figure 2.

The key characteristics of the Proposal are set out in Tables 2 and 3. The key Proposal characteristics may change during the EIA process as a result of the findings of studies and investigations conducted and the application of the mitigation hierarchy by the Proponent.

The Mesa H Proposal is predominantly located on Mineral Lease ML248SA granted pursuant to the Iron Ore (Robe River) Agreement Act 1964. The Proposal pits, dumps and the majority of infrastructure are located within ML248SA (section 104 and a portion of section 103). A powerline to the east of Mesa J will require new tenure under the Mining Act 1978. Grant of Land Administration Act 1997 (LAA) tenure for this area will be required prior to construction of the powerline connection.

The main co-existing LAA tenure in the Development Envelope includes the Yarraloola Pastoral Station (Lease N49500) and the Yalleen Pastoral Station (Lease N49492). These pastoral leases are held by the Robe River Iron Associates.

The Mesa J Operation was referred under Part IV of the EP Act and was assessed as Consultative Environmental Review. The EPA published its Report and

Recommendations (Bulletin 574) in August 1991 which described the environmental aspects considered by the EPA, as:

- riparian vegetation communities (Vegetation and Flora);
- groundwater drawdown and surface water discharge (Hydrological Processes and Inland Environmental Water Quality); and
- rehabilitation.

The Minister for Environment approved implementation of the Mesa J Proposal, subject to the conditions of MS 208, on 16 January 1992.

A number of s45c's have been submitted and approved during the life of the Mesa J Operation during 2005 - 2007. These related to rail works and fibre optic cable and one clarified the Part IV disturbance area boundary.

The existing approved environmental management plan for the Mesa J Operation will continue to be implemented and will be updated, in addition to new management plans developed, specifically relating to Mesa H, subject to approval.

2.2 Regional Context

The Proposal is located in the Robe River valley which has a catchment area of approximately 7,500 km^2. Major watercourses occurring within the catchment include the Robe River and creek systems of the Jimmawurrada, Bungaroo, and Mungarathoona Creeks. Groundwater and surface water systems in the area are complex, variable, and linked. For the majority of its course the Robe River is ephemeral with a wide, shallow flood plain that carries a significant underflow in its alluvial bed.

The escarpment of the Robe River valley provides habitat for listed threatened species, including the Northern Quoll, Pilbara Leaf-nosed Bat, Ghost Bat, and the Pilbara Olive Python. Furthermore, riparian habitat containing groundwater dependent vegetation (e.g. *Melaleuca Argentea*) of high local significance are associated with drainage lines along the Robe River.

Surface water and groundwater in the Proposal's locality has been modified and managed for a number of years (since the mid-1990s). This includes pit dewatering and groundwater abstraction, and discharge of surplus water to Jimmawurrada Creek, to allow below water-table mining at the Mesa J operations. Other operating mines located within the catchment include the Mesa A Hub, comprising existing Mesa A operations and the proposed future mining of nearby deposits, including the Mesa B and Mesa C deposits, which will sustain the Mesa A operation.

Noting the above, the cumulative impacts of the Proposal need to be considered in the ERD, in the regional context of the existing and proposed mining activities in the Robe River catchment.

Table 2: Summary of the Proposal

Proposal title	Mesa H Proposal (Revision to the Mesa J Iron Ore Project)
Proponent name	Robe River Mining Co. Pty. Ltd.
Short description	The Proposal is located 16 km south-west of Pannawonica in the Pilbara region of Western Australia. The Proposal is to develop the Mesa H deposit adjacent to the existing Mesa J Iron Ore Project utilising the adjacent Mesa J infrastructure including but not limited to the development of above and below water table open cut iron ore pits and associated infrastructure, including ore processing facilities, waste dumps, waste fines storage facilities, water management infrastructure and rail.

Table 3: Location and proposed extent of physical and operational elements

Element	Location	Existing approval (MS 208)	Proposed Extent (This Proposal)	Proposed Extent (Revised Proposal)
Physical Elements				
Mine and associated infrastructure	Figure 2	Clearing of up to 1,800 ha for mine development.	Clearing of up to 2,200 ha (within a Development Envelope of 4,930 ha).	Clearing of up to 4,000 ha (within a Development Envelope of 6,730 ha).
Rail / Linear Infrastructure	Figure 1	Single gauge railway line with sidings and a voice and radio data communications system with fibre optic cable from Cape Lambert.	N/A.	Single gauge railway line with sidings and communications system with fibre optic cable from Cape Lambert.
Operational Elements				
Pit dewatering	–	Not specified.	Up to 5 GL/annum.	Up to 10 GL/a.
Surplus Water Management	–	Not specified. Surplus water management includes use on site and controlled discharge to the environment at discharge points in Jimmawurrada Creek and a tributary west of Mesa J.	Controlled surface discharge to extend along Jimmawurrada Creek / Robe River no further than 8 km downstream of the discharge point under natural no-flow conditions. Surplus water management options include use on site and discharge to the environment or alternative means of disposal.	Controlled surface discharge to extend along Jimmawurrada Creek / Robe River no further than 8 km downstream of the discharge point under natural no-flow conditions. Surplus water management options include use on site and discharge to the environment or alternative means of disposal.
Water supply	–	Not specified.	Up to 10 GL/annum from a water supply borefield.	Up to 10 GL/annum from a water supply borefield.

3. Preliminary key environmental factors and required work

The preliminary key environmental factors for the environmental review are:

1. Flora and Vegetation.
2. Subterranean Fauna.
3. Terrestrial Fauna.
4. Hydrological Processes and Inland Waters Environmental Quality.
5. Social Surrounds.
6. Air Quality.

Table 4 outlines the work required for each preliminary key environmental factor and contains the following elements for each factor:

- **EPA factor** and **EPA objective** for that factor.
- **Relevant activities** – the Proposal activities that may have a significant impact on that factor.
- **Potential impacts and risks** to that factor.
- **Required work** for that factor.
- **Relevant policy and guidance** – EPA (and other) guidance and policy relevant to the assessment.

Table 4: Preliminary key environmental factors and required work

Flora and Vegetation	
EPA objective	To protect flora and vegetation so that biological diversity and ecological integrity are maintained.
Relevant activities	Clearing of native vegetation, groundwater abstraction, potential alteration of surface water flows, and potential discharge of excess mine dewater.
Potential impacts and risks	• Disturbance to up to 2,200 ha of native vegetation. • Disturbance to riparian vegetation units considered to be of local significance that are present in the Development Envelope and discharge footprint. • Disturbance to three Priority Flora taxa recorded in the Development Envelope: o *Triodia* sp. Robe River (M.E. Trudgen et al. MET 12367) (Priority 3); o *Indigofera* sp. Bungaroo Creek (S. van Leeuwen 4301) (Priority 3); and o *Rhynchosia bungarensis* (Priority 4).
Required work	1. Identify and characterise flora and vegetation in accordance with the requirements of EPA 2016 Technical Guidance – *Flora and Vegetation Surveys for Environmental Impact Assessment*. The survey should take into account areas that are likely to be directly or indirectly impacted as a result of the Proposal. 2. Map weed occurrences in areas likely to be directly or indirectly impacted by the Proposal.

3. Describe the vegetation and conservation significant flora species present and likely to be present within the Development Envelope and indirect disturbance areas outside of the Development Envelope. Include an assessment of the relevance of any vegetation and conservation significant flora species in a local and regional context.
4. Provide an analysis of any additional potential impacts from the Proposal in relation to dewatering and discharge activities, including consideration of potential impacts from waste fines storage facilities.
5. Provide a detailed description of the cumulative impacts associated with the Proposal, including direct impacts from clearing, and indirect impacts such as groundwater drawdown, altered drainage, changes in water quality, spread of weeds, fragmentation of vegetation, altered fire regime, and dust.
6. Provide tables and maps of the proposed clearing and predicted indirect impact to vegetation and conservation significant flora species, including but not limited to threatened and/or priority ecological communities, threatened flora, Priority flora or new flora species.
7. Discuss, and determine significance of, potential direct, indirect (such as dust, weeds and downstream impacts) and cumulative impacts to conservation listed flora and vegetation as a result of the Proposal at a local and regional level (i.e. the Robe Valley).
8. Demonstrate that all practical measures have been taken to reduce the area of the proposed disturbance footprint based on progress in the Proposal design and understanding of the environmental impacts.
9. Discuss proposed objectives, management, monitoring and mitigation methods to be implemented demonstrating that the design of the Proposal has addressed the mitigation hierarchy to avoid and minimise impacts to flora and vegetation.
10. Review and revise the existing Mesa J environmental management plan to apply to the Proposal. The objective of the plan is to ensure the protection of conservation significant vegetation communities within the Development Envelope and areas of indirect impact. The following should be addressed in the plan:
    - Invasive species control – control of weeds, in particular through transport and/or entry and exit points, and in areas of vegetation units considered to have high local significance.
    - Monitoring program – to monitor the health of conservation listed vegetation communities including (but not limited to) the protection of obligate phreatophytic communities that will be impacted by the Proposal.
11. Prepare a Mine Closure Plan consistent with DMP and EPA *Guidelines for Preparing Mine Closure Plans* (2015) which considers the proposed rehabilitation methodologies to achieve successful progressive rehabilitation of all areas disturbed by mining with vegetation composed of native species of local provenance.
12. Predict the inherent and residual impacts before and after applying the mitigation hierarchy and identify whether the residual impacts are significant by applying the Significant Residual Impact Model in the WA Environmental Offsets Guideline.
13. Quantify any significant residual impacts by completing the Offset Template, spatially defining the area of 'good' to 'excellent' native vegetation that will be disturbed as a result of this proposal (excluding the approved Mesa J Operation), and propose an appropriate offsets package that demonstrates application of the WA Environmental Offsets Policy and Guideline.
14. Demonstrate and document in the ERD how the EPA's objective for this factor can be met.

Relevant policy and guidance	<u>EPA Policy and Guidance</u> Advice of the Environmental Protection Authority to the Minister for Environment under Section 16 of the *Environmental Protection Act 1986*, *Cumulative environmental impacts of development in the Pilbara region.* EPA *Statement of Environmental Principles, Factors and Objectives* (2016). EPA *Environmental Factor Guideline: Flora and Vegetation* (2016). EPA *Technical Guidance: Flora and Vegetation Surveys for Environmental Impact Assessment* (2016). EPA *Instructions on how to prepare Environmental Protection Act 1986 Part IV Environmental Management Plans* (2016). DMP and EPA *Guidelines for Preparing Mine Closure Plans* (2015). <u>Other policy and guidance</u> Department of Water *Western Australian Water in Mining Guideline* (2013). Government of Western Australia *WA Environmental Offsets Policy* (2011). Government of Western Australia *WA Environmental Offsets Guidelines* (2014).
Subterranean Fauna	
EPA objective	To protect subterranean fauna so that biological diversity and ecological integrity are maintained.
Relevant activities	Mining (excavation), groundwater abstraction, surplus water discharge and disposal of waste fines.
Potential impacts and risks	Reduction in troglofauna habitat and loss of individuals from mine pit development. Reduction in stygofauna habitat due to abstraction of groundwater. Reduction in subterranean fauna habitat from seepage from waste fines placed in-pit. Reduction in the quality of subterranean habitat due to contaminants (e.g. spills of hydrocarbons). Potential impacts and risks to the EPBC Act listed vulnerable Blind Cave Eel (*Ophisternon candidum*) including the loss of individuals and loss or degradation of habitat due to mining activity and associated abstraction of groundwater.
Required work	15. Conduct Level 2 fauna surveys within areas to be impacted and in surrounding areas in accordance with EPA 2016 Environmental Factor Guideline – Subterranean Fauna. 16. Present the results of the subterranean fauna surveys and discuss the potential for direct, indirect and cumulative impacts to subterranean fauna and habitat including consideration of altered water regimes and water quality as a result of the Proposal, and other operating/planned mining operations within the Robe River Valley. 17. Assess any impacts to subterranean fauna with reference to relevant impacts from the Proposal (including taking into consideration any relevant guidelines, policies, plans and statutory provisions). For species which are likely to be impacted, including MNES listed species (Blind Cave Eel), provide information, including maps on habitat extent and an appropriate explanation of the likely distribution of species within those habitats, including information to support habitat connectivity. 18. Provide a detailed description of the cumulative impacts to conservation significant and other species within the Development Envelope and on a regional scale.

	19. Discuss proposed objectives, management, monitoring and mitigation methods to be implemented demonstrating that the design of the Proposal has addressed the mitigation hierarchy to avoid and minimise impacts to subterranean fauna. 20. Develop a Subterranean fauna management plan(s) to apply to the Proposal. The objective of the plan is to ensure the protection of conservation listed subterranean fauna species within the Development Envelope and areas of indirect impact. 21. Prepare a Mine Closure Plan consistent with DMP and EPA Guidelines for Preparing Mine Closure Plans (2015) which delineate and considers the use of Mining Exclusion Zones (MEZ) to protect troglofauna habitat and takes into consideration groundwater recovery to support stygofauna habitat. 22. Predict the inherent and residual impacts before and after applying the mitigation hierarchy and identify whether the residual impacts are significant by applying the Significant Residual Impact Model in the WA Environmental Offsets Guideline. 23. Quantify any significant residual impacts by completing the Offset Template and propose an appropriate offsets package that demonstrates application of the WA Environmental Offsets Policy and Guideline. 24. Demonstrate and document in the ERD how the EPA's objective for this factor can be met.
Relevant policy and guidance	EPA Policy and Guidance EPA *Statement of Environmental Principles, Factors and Objectives* (2016). EPA *Environmental Factor Guideline: Subterranean Fauna* (2016). EPA Technical Guidance: *Subterranean Fauna Survey* (2016). EPA Technical Guidance: *Sampling Methods for Subterranean Fauna* (2016). DMP and EPA Guidelines for Preparing Mine Closure Plans (2015). EPBC Act Policy and Guidance DoEE: Threatened Species Scientific Committee (TSSC) (2008). *Commonwealth Conservation Advice on Ophisternon candidum (Blind Cave Eel)*. Canberra: Department of the Environment, Water, Heritage and the Arts. Available from: http://www.environment.gov.au/biodiversity/threatened/species/pubs/66678-conservation-advice.pdf. DoEE: *Survey guidelines for Australia's threatened fish*. EPBC Act survey guidelines 6.4 (Department of Sustainability, Environment, Water, Population and Communities (DSEWPaC), 2011). The EPBC Act Environmental Offsets Policy and Guidelines. Other policy and guidance Department of Water *Western Australian water in mining guideline* (2013). Government of Western Australia *WA Environmental Offsets Policy* (2011). Government of Western Australia *WA Environmental Offsets Guidelines* (2014).
Terrestrial Fauna	
EPA objective	To protect terrestrial fauna so that biological diversity and ecological integrity are maintained.
Relevant activities	Clearing of native vegetation, abstraction of groundwater, discharge of surplus dewater into Jimmawurrada Creek and / or the Robe River, vehicle strike, generation of noise, vibration and dust.

	Work may also include installation of infrastructure/use of equipment (including vehicles) incorporating lighting and/or fencing (with reference to bat species).
Potential impacts and risks	• Loss of individuals due to vehicle strikes and as a result of construction and operation of the mine. • Reduction in fauna habitat and loss of individuals due to clearing of native vegetation and development of mine pits and associated infrastructure. • Direct and indirect fragmentation of habitat. • Indirect impacts to fauna due to: o altered fire regimes due to clearing of native vegetation; o altered surface and groundwater regimes; o changes to feral animal populations; o introduction or spread of weed species; and o mine related changes / restrictions to habitat (e.g. light, fencing).
Required work	25. Provide a desktop review and analysis of all surveys of the Development Envelope undertaken in accordance with EPA Policy and Assessment, Survey guidelines for Australia's threatened mammals. 26. The study should include: o a justification of how those surveys are relevant and representative of the Development Envelope and if they were carried out using methods consistent with the EPA policy; and o a comprehensive listing of vertebrate fauna and short range endemic (SRE) invertebrate fauna known or likely to occur in the habitats present, and identification of conservation significant fauna species likely to occur in the area. 27. Conduct Level 2 terrestrial fauna and SRE invertebrate surveys (including aquatic fauna) in areas not previously surveyed that are likely to be directly or indirectly impacted as a result of the Proposal. Surveys are to be undertaken in accordance with technical guidance statements and, where available, species-specific survey guidelines for relevant species listed under the *Wildlife Conservation Act 1950* and the *Environment Protection and Biodiversity Conservation Act 1999*. 28. Conduct additional targeted surveys for conservation significant fauna that are known to or likely to occupy habitats in the Development Envelope if demonstrated to be required based on the results of the desktop study and Level 2 surveys. 29. Specify MNES being assessed as part of the accredited assessment. 30. Investigate and provide a description of any potential bat populations, and habitat (including foraging habitat) in the Development Envelope, and potential impacts from the Proposal. 31. For each relevant conservation significant fauna, including MNES (Northern Quoll, Pilbara Olive Python, Pilbara Leaf-nosed Bat, and Ghost Bat) recorded or likely to occur within the Development Envelope, provide where possible: • baseline information on their distribution (including known occurrences), ecology, and habitat preferences at the site level; • information on the conservation value of each habitat type from a local and regional perspective; • if a population of a conservation significant species is present on the site, its size and the importance of that population from a local and regional perspective; and

	• maps illustrating the known recorded locations of conservation significant species and short-range endemic invertebrates in relation to the proposed disturbance and areas to be impacted. 32. Identify the fauna habitat types within and outside the areas of impact. Consider habitat types that provide important ecological function within the Development Envelope. 33. Discuss known existing threats to conservation significant fauna, whether or not attributable to the Proposal, with reference to relevant impacts from the Proposal (including taking into consideration any relevant guidelines, policies, plans and statutory provisions). 34. Provide a detailed description of the potential direct, indirect and cumulative impacts to conservation significant fauna within the Development Envelope on a local and regional scale. Propose areas of key significance that may be considered for mine exclusion zones (including cave habitats, rocky outcrops and pools). 35. For all conservation significant fauna that are not likely to be impacted by the Proposal, but for which suitable habitat is present, demonstrate that an impact on the species will not or is unlikely to occur. 36. Discuss proposed objectives, management, monitoring and mitigation methods to be implemented demonstrating that the design of the Proposal has addressed the mitigation hierarchy to avoid and minimise impacts to terrestrial fauna. 37. Develop a conservation significant fauna management plan to apply to the Proposal. The objective of the plan is to ensure the protection of threatened species that will be impacted by the Proposal and their habitat within the Development Envelope. 38. Prepare a Mine Closure Plan consistent with DMP and EPA *Guidelines for Preparing Mine Closure Plans* (2015), which addresses the need for progressive rehabilitation of habitat for conservation significant species. 39. Predict the inherent and residual impacts before and after applying the mitigation hierarchy and identify whether the residual impacts are significant by applying the Significant Residual Impact Model in the WA Environmental Offsets Guideline. 40. Quantify any significant residual impacts by completing the Offset Template, spatially defining the habitat area for each significant fauna species that will be disturbed as a result of this proposal (excluding the approved Mesa J Operation), and propose an appropriate offsets package that demonstrates application of the WA Environmental Offsets Policy and Guideline. 41. Demonstrate and document in the ERD how the EPA's objective for this factor can be met. Note: Conservation significant fauna are defined as species that are listed under the *Environment Protection and Biodiversity Conservation Act 1999* and *Wildlife Conservation Act 1950*, and the Department of Biodiversity, Conservation and Attractions Priority Species that are likely to have their conservation status changed by the proposal.
Relevant policy and guidance	<u>EPA Policy and Guidance</u> EPA *Statement of Environmental Principles, Factors and Objectives* (2016). EPA *Environmental Factor Guideline: Terrestrial Fauna* (2016). EPA Technical Guidance: *Sampling Methods for Terrestrial Vertebrate Fauna* (2016). EPA Technical Guidance: *Terrestrial Fauna Surveys* (2016). EPA Technical Guidance: *Sampling of Short Range Endemic Invertebrate Fauna* (2016).

	EPA *Instructions on how to prepare Environmental Protection Act 1986 Part IV Environmental Management Plans* (2016). DMP and EPA *Guidelines for Preparing Mine Closure Plans* (2015). EPBC Act Policy and Guidance DOEE: *Survey Guidelines for Australia's Threatened Mammals.* EPBC Act survey guidelines 6.5 (Department of Sustainability, Environment, Water, Population and Communities (DSEWPaC), 2011). DoEE: *Survey Guidelines for Australia's Threatened Bats.* EPBC Act survey guidelines 6.1 (Department of the Environment, Water, Heritage and the Arts (DEWHA), 2010). DoEE: *Survey guidelines for Australia's threatened reptiles.* EPBC Act survey guidelines *6.6* (Department of Sustainability, Environment, Water, Population and Communities (DSEWPaC), 2011). Threatened Species Scientific Committee (2005). *Commonwealth Listing Advice on Northern Quoll (Dasyurus hallucatus).* Available from: http://www.environment.gov.au/biodiversity/threatened/species/dasyurus-hallucatus.html. Department of Sustainability, Environment, Water, Population and Communities (2012). *Threat abatement plan to reduce the impacts on northern Australia's biodiversity by the five listed grasses.* Threatened Species Scientific Committee (2008). *Commonwealth Conservation Advice on Liasis olivaceus barroni (Olive Python (Pilbara subspecies)).* Canberra: Department of the Environment, Water, Heritage and the Arts. Available from: http://www.environment.gov.au/biodiversity/threatened/species/pubs/66699-conservation-advice.pdf. Threatened Species Scientific Committee (2016). *Approved Conservation Advice for Macroderma gigas (Ghost Bat).* Canberra: Department of the Environment. Available from: http://www.environment.gov.au/biodiversity/threatened/species/pubs/174-conservation-advice-05052016.pdf. Threatened Species Scientific Committee (2016). *Approved Conservation Advice for Rhinonicteris aurantia (Pilbara form) (Pilbara Leaf-nosed Bat).* Canberra: Department of the Environment. Available from: http://www.environment.gov.au/biodiversity/threatened/species/pubs/82790-conservation-advice-10032016.pdf. Other policy and guidance Government of Western Australia *WA Environmental Offsets Policy* (2011). Government of Western Australia *WA Environmental Offsets Guidelines* (2014).
Hydrological Processes and Inland Waters Environmental Quality	
EPA objective	To maintain the hydrological regimes of groundwater and surface water so that environmental values are protected. To maintain the quality of groundwater and surface water so that environmental values are protected.
Relevant activities	Abstraction of groundwater. Discharge of surplus dewater into Jimmawurrada Creek / Robe River. Alteration of surface water flows through the Development Envelope.
Potential impacts and risks	Groundwater drawdown due to mine pit dewatering and abstraction for operational water use (processing, dust management, potable water) may result in: • reduction to water levels in semi-permanent and permanent pools in the Robe River; and

	• reduction in groundwater levels in Jimmawurrada Creek. The discharge of surplus dewater into Jimmawurrada Creek / Robe River will result in surface flow downstream of the discharge point under natural no-flow conditions and could lead to erosion of the creek bank, alteration to fauna habitat. The discharge of surplus dewater into Jimmawurrada Creek / Robe River may reduce water quality. Surface water flows through the Development Envelope may become contaminated (e.g. by sediment or hydrocarbon spills).
Required work	42. Characterise the baseline hydrology and hydrogeological regimes and water quality, both in a local and regional context, including but not limited to, water levels, water chemistry, stream flows, flood patterns, and water quantity and quality. 43. Provide a detailed description of the design and location of the Proposal with the potential to impact surface water or groundwater. A figure should be provided in the ERD which depicts the predicted location of the wetting front (under natural no-flow conditions). 44. Provide a conceptual model of the surface and groundwater systems including the extent of connectivity between surface and groundwater systems and demonstrate that there will be no migration of seepage from infrastructure towards the Bungaroo Creek P1 Water Reserve. 45. Provide a conceptual mine water balance over the life of the Proposal to discuss the capacity to reuse surplus mine dewater. 46. Provide a geochemical risk characterisation of the waste material to be backfilled in pit which may be exposed to groundwater. 47. Discuss the potential environmental impacts and benefits of identified surplus water management options (i.e. discharge of excess mine dewater, reuse on site, local water supply, aquifer recharge etc.) and discuss the most appropriate water management strategy for the Proposal. 48. Analyse, discuss and assess surface water and groundwater impacts, including alternatives options to water management and the feasibility of each option: • changes in groundwater levels and changes to surface water flows associated with the Proposal; • the nature, extent, and duration of impacts; • cumulative impacts with other projects and referred proposals in the Robe Valley, for which relevant information is publicly available; and • impacts on the environmental values of significant receptors including but not limited to the Robe River catchment. 49. Demonstrate application of the mitigation hierarchy to avoid and minimise impacts to Hydrological Processes and Inland Waters Environmental Quality. 50. Prepare a Mine Closure Plan consistent with DMP and EPA *Guidelines for Preparing Mine Closure Plans* (2015) which addresses the development of completion criteria to maintain of the hydrological regimes and the quality of groundwater and surface water so that environmental values are maintained post closure. Specify whether the below water table pits will be backfilled to a level to prevent post-closure exposure of the groundwater table and the formation of permanent pit lakes. 51. Demonstrate and document in the ERD how the EPA's objective for this factor can be met.
Relevant policy and guidance	<u>EPA Policy and Guidance</u> EPA *Statement of Environmental Principles, Factors and Objectives* (2016).

	EPA *Environmental Factor Guideline: Hydrological Processes* (2016). EPA *Environmental Factor Guideline: Inland Waters Environmental Quality* (2016). EPA *Inland Waters of the Pilbara Western Australian (Part 1).* EPA *Inland Waters of the Pilbara Western Australian (Part 2).* EPA *Instructions on how to prepare Environmental Protection Act 1986 Part IV Environmental Management Plans* (2016). DMP and EPA *Guidelines for Preparing Mine Closure Plans* (2015). <u>Other policy and guidance</u> The Government of Western Australia 2011, *WA Environmental Offsets Policy.* The Government of Western Australia 2014, *WA Environmental Offsets Guidelines.*
Social Surroundings	
EPA objective	To protect social surroundings from significant harm.
Relevant activities	Clearing and excavation for mining activities. Abstraction of groundwater for mining and related activities. Discharge of surplus dewater. Alteration to hydrological processes.
Potential impacts and risks	Disturbance of sites of cultural significance. Prevention or change to access to a site. Changes to the physical and biological attributes of the environment which would impact on sites of heritage significance.
Required work	52. Characterise the heritage and cultural values of proposed disturbance areas and any other areas that may be indirectly impacted to identify sites of significance and their relevance within a wider regional context. 53. Conduct Aboriginal heritage surveys in conjunction with the native title claim (WCD2016/006) holders Kuruma Marthudunera and other local people to identify Aboriginal sites of significance and identify concerns in regard to impacts from proposed mining operations. 54. Provide a description of the heritage values within the Development Envelope and proposed disturbance. 55. Assess the impacts of the Proposal on heritage sites and/or cultural associations as a result of implementation of the Proposal, including those arising from changes to the environment which may impact on ethnographic and archaeological heritage significance. 56. Demonstrate the application of the mitigation hierarchy to avoid and minimise impacts to social surroundings. 57. Provide detail on consultation that will be undertaken with Traditional Owners in preparing the mine closure plan, particularly in relation to water management. 58. Prepare a Mine Closure Plan consistent with DMP and EPA *Guidelines for Preparing Mine Closure Plans* (2015), which addresses the need to protect the social surrounds from significant harm post closure. 59. Demonstrate and document in the ERD how the EPA's objective for this factor can be met.
Relevant policy and guidance	<u>EPA Policy and Guidance</u> EPA *Statement of Environmental Principles, Factors and Objectives* (2016).

	EPA *Environmental Factor Guideline: Social surroundings* (2016). EPA *Instructions on how to prepare Environmental Protection Act 1986 Part IV Environmental Management Plans* (2016). DMP and EPA *Guidelines for Preparing Mine Closure Plans* (2015). Other policy and guidance Department of Aboriginal Affairs and Department of Premier and Cabinet, 2013, *Due Diligence Guidelines, Version 3.0.* Perth, Western Australia.
Air Quality	
EPA objective	To maintain air quality and minimise emissions so that environmental values are protected.
Relevant activities	Clearing of native vegetation. Mining and ore processing activities.
Potential impacts and risks	Increase in Greenhouse Gas Emissions due to additional mining activities. Increase in dust to sensitive receptors due to blasting, excavation and haulage of ore.
Required work	60. Characterise the greenhouse gas emission key sources from the Proposal and estimation of expected Scope 1 (direct) and Scope 2 (energy indirect) greenhouse gas emissions. 61. Analysis of greenhouse gas intensity (i.e. quantity of CO2-e generated per tonne of product produced). 62. Demonstrate and document in the ERD how the EPA's objective for this factor can be met.
Relevant policy and guidance	EPA Policy and Guidance EPA *Statement of Environmental Principles, Factors and Objectives* (2016). EPA Environmental Factor Guideline: *Air quality* (2016). Other policy and guidance *Clean Energy Act 2011.* *National Greenhouse and Energy Reporting Act 2007.*

4. Other environmental factors or matters

The EPA has identified the following other environmental factor or matter relevant to the proposal that must be addressed during the public environmental review and discussed in the ERD:

1. Landforms

There is potential for significant cumulative impacts on landforms (particularly the mesa structures) within the Robe River valley. Taking into consideration Section 2.1 – Regional Context, the cumulative impacts on the mesa structures of the Robe River valley should be considered and detailed in the ERD, including the following required work:

- A description of the geology and morphology of the landforms within the Robe River valley;

- Spatially define the significant mesa habitat (including rocky ridge, gorge and breakaway habitat) along the Robe River, and the location of the operating and proposed mining operations; and
- Describe the cumulative impacts on the landforms from historic and reasonably foreseeable future developments.

It is also important that the Proponent be aware that other factors or matters may be identified during the course of the environmental review that were not apparent at the time that this ESD was prepared. If this situation arises, the Proponent must consult with the EPA to determine whether these factors and/or matters are to be addressed in the ERD, and if so, to what extent.

5. Stakeholder consultation

The Proponent must consult with stakeholders who are affected by, or are interested in the Proposal. This includes the decision-making authorities (see section 6), other relevant state (and Commonwealth) government agencies and local government authorities, the local community, and environmental non-government organisations.

The Proponent must document the following in the ERD:

- identified stakeholders;
- the stakeholder consultation undertaken and the outcomes, including decision-making authorities' specific regulatory approvals and any adjustments to the Proposal as a result of consultation; and
- any future plans for consultation.

6. Decision-making authorities

At this stage, the EPA has identified the authorities listed in Table 6 as decision-making authorities (DMAs) for the Proposal. Additional DMAs may be identified during the course of the assessment.

Table 6: Decision-making authorities

Decision-making authority	Relevant legislation
1. Minister for State Development.	*Iron Ore (Robe River) Agreement Act 1964.*
2. Minister for Mines and Petroleum.	*Mining Act 1978.*
3. Minister for Lands.	*Land Administration Act 1997.*
4. Minister for Environment.	*Wildlife Conservation Act 1950.*
5. Chief Executive Officer, Department of Water and Environmental Regulation.	*Environmental Protection Act 1986.*
6. Executive Director: Environment, Department of Mines, Industry, Regulation and Safety.	*Mining Act 1978.*
7. State Mining Engineer, Department of Mines, Industry, Regulation and Safety.	*Mines Safety and Inspection Act 1994.*
8. Chief Executive Officer: Department of Mines, Industry, Regulation and Safety.	*Dangerous Goods Safety Act 2004.*
9. Department of Water and Environmental Regulation.	*Rights in Water and Irrigation Act 1914.*
10. Minister for Aboriginal Affairs.	*Aboriginal Heritage Act 1972.*
11. Chief Executive Officer: Shire of Ashburton.	*Health Act 1911 & Health (Treatment of Sewage and Disposal of Effluent and Liquid Waste) Regulation 1974.*

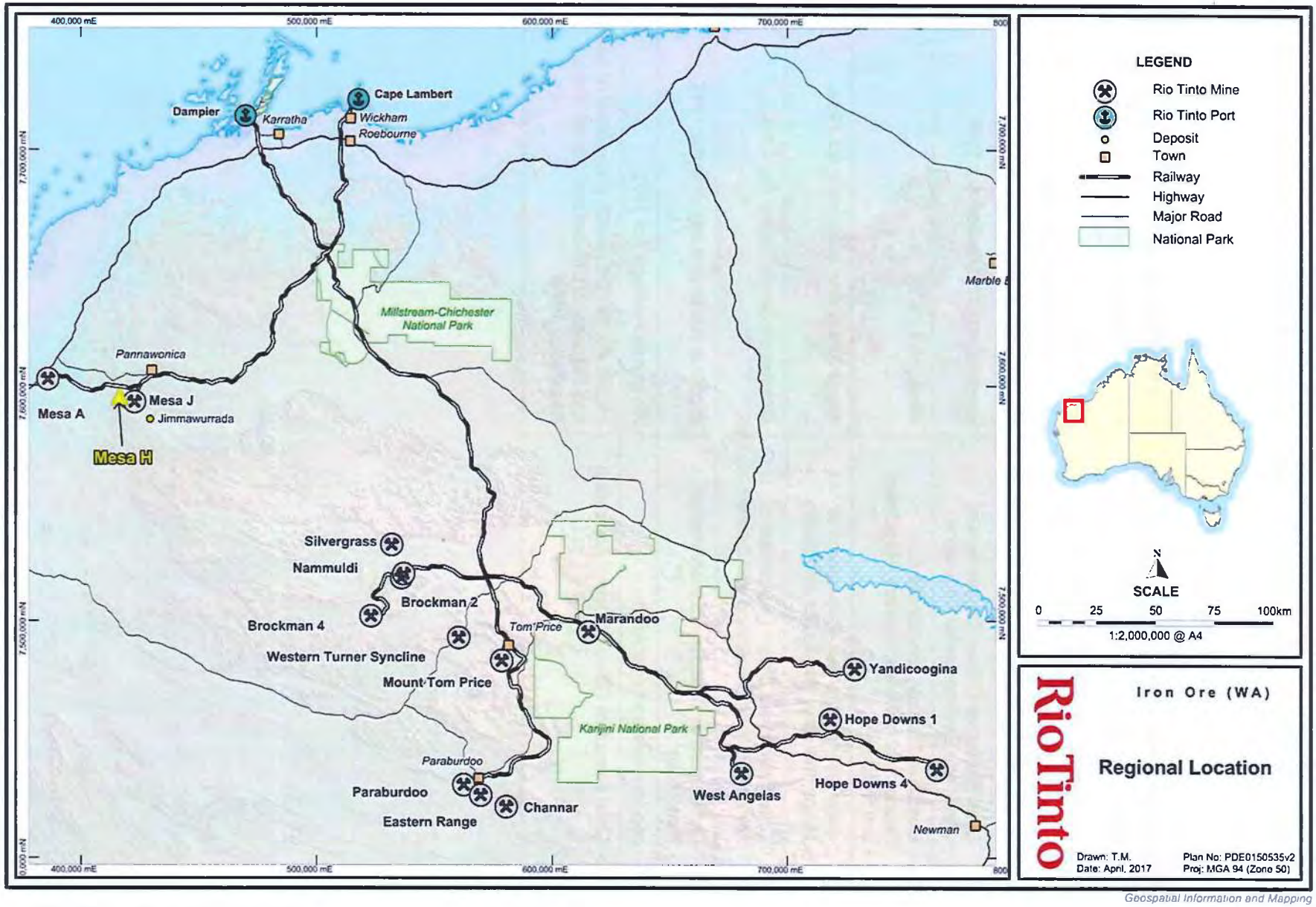


Figure 1 – Regional location

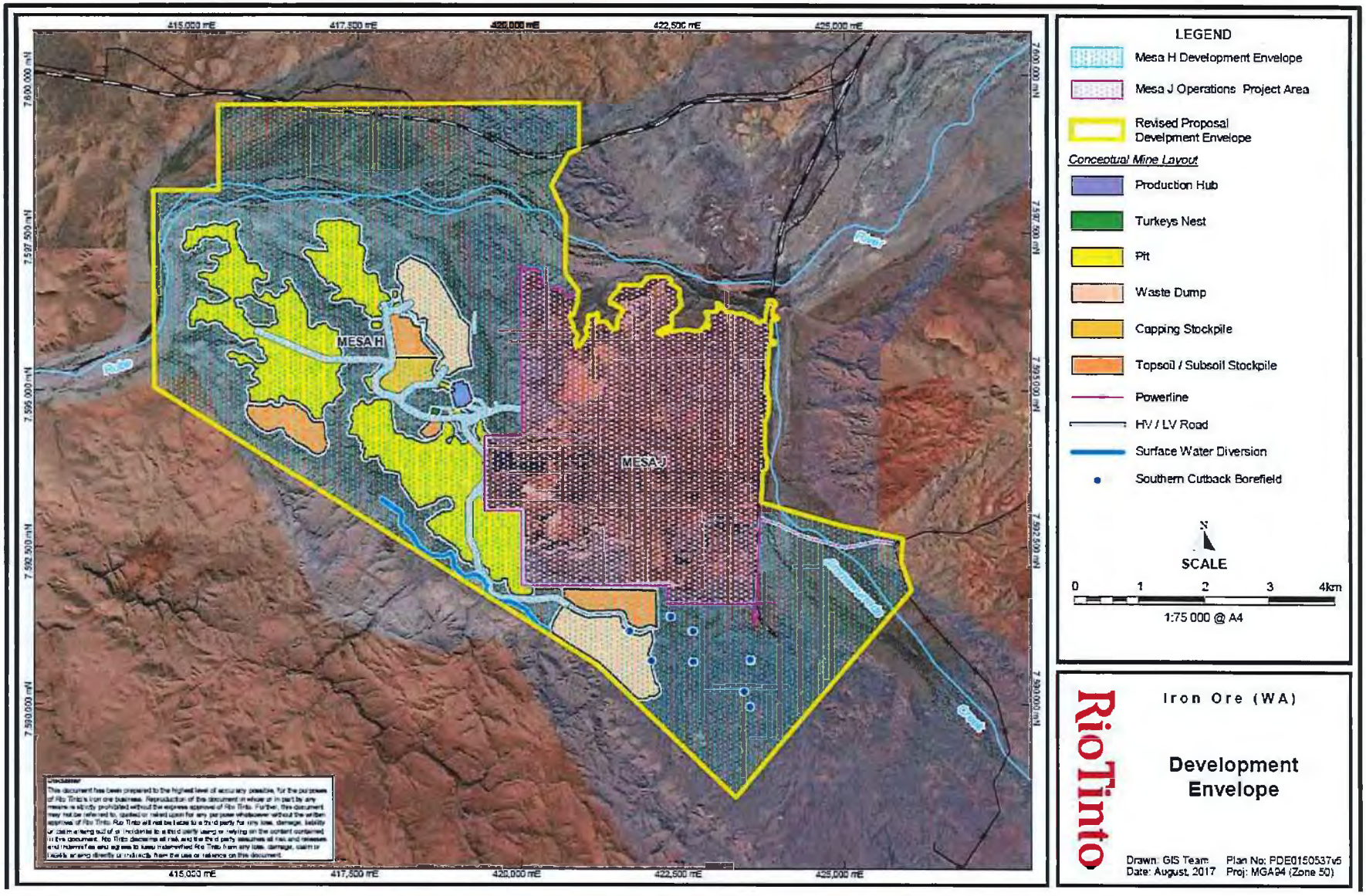


Figure 2 – Revised Development Envelope

Mesa H Proposal (Revision to the Mesa J Iron Ore Development)

Proposed Ministerial Conditions

The existing Mesa J Iron Ore Development, the subject of MS 208 is managed via nine existing Ministerial conditions:

1. Proponent Commitments
2. Implementation
3. Environmentally Significant Areas
4. Drainage Management
5. Dewatering Management
6. Rehabilitation
7. Environmental Management Programme
8. Proponent
9. Time limit on Approval

The Proponent has undertaken a review of these existing Ministerial conditions and proposes that, subject to approval, these Ministerial conditions be amended as follows:

- Conditions shall be updated to reflect contemporary wording and format, consistent with other recent Ministerial Statements for the Proponent's Pilbara iron ore operations.
- Development of conditions which reflect the requirement for Condition Environmental Management Plans to meet environmental outcomes for key environmental factors (inland waters, flora and vegetation, subterranean fauna, and terrestrial fauna) consistent with the EP Act, EPA guidance (*Statement of Environmental Principles, Factors and Objectives*, 2016) and other recent Ministerial Statements for the Proponent's Pilbara iron ore operations.
- Removal of redundant conditions, or conditions that are managed under other regulatory processes and as such, do not require regulation under Part IV the EP Act, where this can be justified.

The proposed Ministerial conditions of the Mesa H Project (revision to the Mesa J Iron Ore Development) include the following:

1. Proposal Implementation
2. Contact Details
3. Compliance Reporting
4. Public Availability of Data
5. Condition Environmental Management Plan

6. Inland Waters and Flora and Vegetation – Groundwater abstraction, discharge, riparian vegetation and pool ecosystems
7. Terrestrial Fauna - Conservation significant fauna species; Ghost Bat (*Macroderma gigas*) and Northern Quoll (*Dasyurus hallacatus*),
8. Subterranean fauna – troglofauna
9. Subterranean fauna - stygofauna (including the Blind Cave Eel: *Ophisternon candidum*)
10. Rehabilitation and Decommissioning
11. Offsets

Table 1 provides the proponents rationalisation for the proposed changes.

The proposed Ministerial conditions are closely aligned to the existing Ministerial conditions and will maintain the overall level of protection of environmental values and the required standard of management of key environmental factors. The Proponent proposes that these conditions be adopted for the new Ministerial Statement that, subject to approval, will supersede the existing MS208.

DRAFT ENVIRONMENTAL CONDITIONS

STATEMENT THAT A REVISED PROPOSAL MAY BE IMPLEMENTED (PURSUANT TO THE PROVISIONS OF SECTION 46 OF THE *ENVIRONMENTAL PROTECTION ACT 1986*)

MESA H PROJECT (REVISION TO THE MESA J IRON ORE DEVELOPMENT)

Revised Proposal:	The Mesa H Project is a revision of the existing Mesa J Iron Ore Development, the subject of Ministerial Statement 208, dated 16 January 1992. The Revised Proposal includes the existing Mesa J Iron Ore Project and a revision to include Mesa H which involves additional above and below water table mine pits and the construction and operation of associated infrastructure, waste dumps and water management infrastructure, located approximately 16 kilometres west of Pannawonica in the Pilbara region of Western Australia, as documented in Schedule 1 of this Ministerial Statement.
Proponent:	Robe River Mining Co. Pty. Ltd. Australian Company Number 008 694 246
Proponent Address:	152-158 St Georges Terrace PERTH WA 6000 GPO Box A42, PERTH WA 6001
Assessment Number:	**2121**

Report of the Environmental Protection Authority: xxxx

Previous Report of the Environmental Protection Authority: 574

Previous Ministerial Statement Number: 208

Pursuant to section 45, read with section 45B of the *Environmental Protection Act 1986,* it has been agreed that:

1. the Revised Proposal described and documented in Schedule 1 of this Statement may be implemented; and
2. from the date of this Statement, the implementation of the Revised Proposal is subject to the following revised implementation conditions which replace and supersede all previous conditions of Ministerial Statement 208.

Table 1: Rationalisation of Conditions of MS 208

Ministerial Conditions of MS 208		Proposed Change / Rationale	Proposed New Ministerial Conditions	
1	**Proponent Commitments**		**1**	**Proposal Implementation**
	In implementing the proposal, the proponent shall fulfil the commitments (which are not inconsistent with the conditions or procedures contained in this statement) made in the proponent's Consultative Environmental Review (a copy of the commitments is attached).	This Condition is still relevant and should be retained; however, it has been updated to reflect contemporary wording and format, consistent with other recent Ministerial Statements for the Proponent's Pilbara iron ore operations.	1-1	When implementing the Revised Proposal, the proponent shall not exceed the authorised extent of the Revised Proposal as defined in Table 2 in Schedule 1 of this Statement, unless amendments to the Revised Proposal and the authorised extent of the Revised Proposal have been approved under the *Environmental Protection Act 1986*.
2	**Implementation**			
	Subject to these conditions, the manner of detailed implementation of the proposal shall conform in substance with that set out in any designs, specifications, plans or other technical material submitted by the proponent to the Environmental Protection Authority with the proposal. Where, in the course of that detailed implementation, the proponent seeks to change those designs, specifications, plans or other technical material in any way that the Minister for the Environment determines on the advice of the Environmental Protection Authority, is not substantial; those changes may be effected.	This Condition is still relevant and should be retained; however, it has been updated to reflect contemporary wording and format, consistent with other recent Ministerial Statements for the Proponent's Pilbara iron ore operations.		
8	**Proponent**		**2**	**Contact Details**
	Prior to any transfer of ownership, control or management of the project being effected which would give rise to the need for the replacement of the proponent, the Minister for the Environment shall be advised of the name and details of the transferee and invited to nominate a replacement proponent	This Condition is still relevant and should be retained; however, it has been updated to reflect contemporary wording and format, consistent with other recent Ministerial Statements for the Proponent's Pilbara iron ore operations.	2-1	The proponent shall notify the Chief Executive Officer (CEO) of any change of its name, physical address or postal address for the serving of notices or other correspondence within twenty eight (28) days of such change. Where the proponent is a corporation or an association of persons, whether incorporated or not, the postal address is that of the principal place of business or of the principal office in the State.

Ministerial Conditions of MS 208		Proposed Change / Rationale	Proposed New Ministerial Conditions	
	If the Minister nominates a replacement proponent, a copy of this statement endorsed with an undertaking by the replacement proponent to carry out the project in accordance with the conditions and procedures set out in the statement shall be delivered to the Minister and thereupon the former proponent shall be released from the conditions of this statement to the extent of its interest transferred.			
3	**Compliance Reporting**		**3**	**Compliance Reporting**
		New contemporary condition.	3-1	The proponent shall prepare, submit and maintain a Compliance Assessment Plan to the satisfaction of the CEO prior to the first Compliance Assessment Report required by condition 3-6, or as agreed in writing by the CEO.
			3-2	The Compliance Assessment Plan shall indicate: 1. the frequency of compliance reporting; 2. the approach and timing of compliance assessments; 3. the retention of compliance assessments; 4. the method of reporting of potential non-compliances and corrective actions taken; 5. the table of contents of Compliance Assessment Reports; and 6. public availability of Compliance Assessment Reports.
			3-3	After receiving notice in writing from the CEO that the Compliance Assessment Plan satisfies the requirements of condition 3-2, the proponent shall assess compliance with conditions in accordance with the Compliance Assessment Plan required by condition 3-1.

Ministerial Conditions of MS 208		Proposed Change / Rationale	Proposed New Ministerial Conditions	
			3-4	The proponent shall retain reports of all compliance assessments described in the Compliance Assessment Plan required by condition 3-1 and shall make those reports available when requested by the CEO.
			3-5	The proponent shall advise the CEO of any potential non-compliance within seven (7) days of that non-compliance being known.
			3-6	The proponent shall submit to the CEO the first Compliance Assessment Report by 30 April each year addressing compliance in the previous calendar year, or as agreed in writing by the CEO. The first Compliance Assessment Report shall be submitted by 30 April 2019 addressing the compliance for the period from the date of issue of this Statement, notwithstanding that the first reporting period may be less than 12 months. The Compliance Assessment Report shall: 1. be endorsed by the proponent's Chief Executive Officer or a person delegated to sign on the Chief Executive Officer's behalf; 2. include a statement as to whether the proponent has complied with the conditions; 3. identify all potential non-compliances and describe corrective and preventative actions taken; 4. be made publicly available in accordance with the approved Compliance Assessment Plan; and 5. indicate any proposed changes to the compliance assessment plan required by condition 3-1.

Ministerial Conditions of MS 208		Proposed Change / Rationale	Proposed New Ministerial Conditions	
4	**Public Availability of Data**		**4**	**Public Availability of Data**
4-1		This Condition is still relevant and should be retained; however, it has been updated to reflect contemporary wording and format, consistent with other recent Ministerial Statements for the Proponent's Pilbara iron ore operations.	4-1	Subject to condition 4-2, within a reasonable time period approved in writing by the CEO of the issue of this Statement and for the remainder of the life of the Revised Proposal, the proponent shall make publicly available, in a manner approved in writing by the CEO, all validated environmental data (including sampling design, sampling methodologies, empirical data and derived information products e.g. maps) required under this Statement.
4-2			4-2	If any data referred to in condition 4-1 contains particulars of: 1. a secret formula or process; or 2. confidential commercially sensitive information; the proponent may submit a request for approval from the CEO to not make this data publicly available. In making such a request the proponent shall provide the CEO with an explanation and reasons why the data should not be made publicly available.
7	**Environmental Management Program**		**5**	**Condition Environmental Management Plans**
7	A comprehensive management programme for the project should be prepared to integrate the various components referred to in conditions 4, 5 and 6 above. This will allow reporting for the various aspects of the project to, be done in one document.			
7-1	Prior to construction, the proponent shall prepare an interim report outlining the key components of a comprehensive environmental management programme to the satisfaction of the Minister for the Environment on advice of the Environmental Protection Authority. The programme shall include but not necessarily be limited to: 1. drainage;	This Condition is still relevant and should be retained; however, it has been updated to reflect contemporary wording and format, consistent with other recent Ministerial Statements for the Proponent's Pilbara iron ore operations.	5-1	Within 6 months of the issue of this Statement, the proponent shall prepare and implement a Condition Environmental Management Plan to the satisfaction of the CEO. This plan shall demonstrate that the **environmental outcomes** specified in in condition 6-1, 7-1 and 8-1 and the **environmental objectives** specified in conditions 7-2, 8-2 and 9-2 will be met.

Ministerial Conditions of MS 208		Proposed Change / Rationale	Proposed New Ministerial Conditions	
	2. rehabilitation; and 3. dewatering.			
7-2	Subsequent to condition 7-1 and prior to the commencement of mining, the proponent shall prepare a comprehensive environmental management programme to the satisfaction of the Minister for the Environment on advice of the Environmental Protection Authority. Whilst initial reporting would be to the Environmental Protection Authority, future reporting could be done under the Iron Ore (Robe River) Agreement Act. The programme shall include but not necessarily be limited to: ' 1. the plan for drainage management required by condition 4-1; 2. the plan for rehabilitation required by condition 6-1; and 3. a status report on the plan for dewatering management as per condition 5-1.		5-2	For outcome based provisions, the Condition Environmental Management Plan shall: 1. specify the **environmental outcomes** to be achieved, as specified in condition 5-1; 2. specify **trigger criteria** that must provide an early warning that the threshold criteria may not be met; 3. specify **threshold criteria** to demonstrate compliance with the environmental outcomes specified in condition 5-1. Exceedance of the threshold criteria represents non-compliance with these conditions; 4. specify **monitoring** to determine if trigger criteria and threshold criteria are exceeded; 5. specify **trigger level actions** to be implemented in the event that trigger criteria have been exceeded; 6. specify **threshold contingency actions** to be implemented in the event that threshold criteria are exceeded; and 7. provide the format and timing for the reporting of monitoring results against trigger criteria and threshold criteria to demonstrate that condition 5-1 has been met over the reporting period in the Compliance Assessment Report required by condition 3-6.

Ministerial Conditions of MS 208		Proposed Change / Rationale	Proposed New Ministerial Conditions	
				For management based provisions, the Condition Environmental Management Plan shall: (1) specify the **environmental objectives** to be achieved, as specified in condition 5-1; (2) specify **management actions** to meet the environmental objective; (3) specify **management targets**; (4) specify **monitoring** to determine if management targets are being met (5) provide the format and timing for the reporting of monitoring results against management targets to demonstrate that condition 5-1 has been met over the reporting period in the Compliance Assessment Report required by condition 3-6.
			5-3	After receiving notice in writing from the CEO that the Condition Environmental Management Plan satisfies the requirements of condition 5-2 the proponent shall: 1. implement the Condition Environmental Management Plan; and 2. continue to implement the Condition Environmental Management Plan until the CEO has confirmed by notice in writing that the proponent has demonstrated the objectives specified in condition 5-1 have been met.

Ministerial Conditions of MS 208		Proposed Change / Rationale	Proposed New Ministerial Conditions	
			5-4	In the event that the monitoring indicates an exceedance of the threshold criteria specified in the Condition Environmental Management Plans, the proponent shall: 1. report the exceedance in writing to the CEO within seven (7) days of the exceedance being identified; 2. implement the threshold level contingency actions specified in the Condition Environmental Management Plans within 24 hours and continue implementation of those actions until the CEO has confirmed by notice in writing that it has been demonstrated that the threshold criteria are being met and the implementation of the threshold contingency actions is no longer required; 3. investigate to determine the cause of the threshold criteria being exceeded; 4. investigate to provide information for the CEO to determine potential environmental harm that occurred due to the threshold criteria being exceeded; and 5. provide a report to the CEO within twenty one (21) days of the exceedance being reported as required by condition 5-6(1). The report shall include; a. details of threshold contingency actions implemented; b. the effectiveness of the threshold contingency actions implemented, against the threshold criteria; c. the findings of the investigations; d. measures to prevent the threshold criteria being exceeded in the future;

Ministerial Conditions of MS 208		Proposed Change / Rationale	Proposed New Ministerial Conditions	
			5-4	e. measures to prevent, control or abate the environmental harm which may have occurred; and f. justification of the threshold remaining, or being adjusted based on better understanding, demonstrating that outcomes would continue to be met.
			5-5	The proponent: 1. may review and revise the Condition Environmental Management Plan, or 2. shall review and revise the Condition Environmental Management Plan as and when directed by the CEO.
4	**Drainage Management**		**6**	**Inland Waters and Flora and Vegetation – Groundwater abstraction, discharge, riparian vegetation and pool ecosystems**
4	The Robe River - Jimmawurrada Creek system needs to be protected from pollution and unacceptable sedimentation, recognising the requirements of mining and ore transport.	This Condition is still relevant and should be retained; however, it has been updated to reflect contemporary wording and format, consistent with other recent Ministerial Statements for the Proponent's Pilbara iron ore operations.	6-1	The proponent shall manage the implementation of the Revised Proposal to meet the following environmental outcomes: (1) No irreversible impact, as a result of the proponent's water abstraction, to the health of groundwater dependent vegetation within the Robe River. (2) No irreversible impact, as a result of the proponent's water abstraction, to the health of riparian vegetation communities within Jimmawurrada Creek. (3) No irreversible impact, as a result of the Proponent's discharge of surplus water, to the health of riparian vegetation communities of Jimmawurrada Creek and the Robe River. (4) No irreversible impact, as a result of the Proponent's drawdown and discharge, to the pool ecosystems of the Robe River.
4-1	Prior to construction at the site, the proponent shall prepare a Drainage Management Programme, to protect the Robe River - Jimmawurrada Creek system from the deleterious impacts of sedimentation and pollution from the project, to the satisfaction of the Minister for the Environment on advice of the Environmental Protection Authority, the Department of Conservation and Land Management and the Water Authority of Western Australia. The plan is to include but is not necessarily limited to:			

Ministerial Conditions of MS 208		Proposed Change / Rationale	Proposed New Ministerial Conditions	
	1. a monitoring programme to detect impacts; 2. procedures for protecting the ecology of the system; 3. procedures for reporting on the programme; and 4. a commitment to ameliorate environmental impacts to the satisfaction of the Environmental Protection Authority if impacts are detected which are deemed unacceptable by the Environmental Protection Authority.			
4-2	Subsequent to condition 4-1, the proponent shall implement the approved Drainage Management Programme to the satisfaction of the Environmental Protection Authority on advice of the Water Authority of Western Australia and the Department of Conservation and Land Management.			
5	**Dewatering Management**			
5	The permanent pools and vegetation of the Robe River - Jimmawurrada Creek system are to be protected from unacceptable environmental impacts, recognising the requirements of mining and ore transport.			
5-1	Prior to the commencement of dewatering, the proponent shall prepare a Dewatering Management Programme, to protect the Robe River - Jimmawurrada Creek system, to the satisfaction of the Environmental Protection Authority on advice of the Department of Conservation and Land Management and the Water Authority of Western Australia. The plan is to include but is not necessarily limited to: 1. a monitoring programme to detect impacts;			

Ministerial Conditions of MS 208		Proposed Change / Rationale	Proposed New Ministerial Conditions	
	2. procedures for protecting the ecology and water quality of the permanent pools and associated vegetation; 3. procedures for reporting on the programme; and 4. a commitment to ameliorate environmental impacts to the satisfaction of the Environmental Protection Authority if impacts are detected which are deemed unacceptable by the Environmental Protection Authority.			
5-2	Subsequent to condition 5-1, the proponent shall implement the approved Environmental Management Programme to the satisfaction of the Environmental Protection Authority on advice of the Water Authority of Western Australia and the Department of Conservation and Land Management.			
			7	**Terrestrial Fauna - Conservation significant fauna species; Ghost Bat (*Macroderma gigas*), and Northern Quoll (*Dasyurus hallacatus*)**
		New environmental factor condition for Mesa H		The proponent shall manage the implementation of the Revised Proposal to meet the following environmental outcomes: (1) No irreversible impact, as a result of the proponent's activities to Breakaways and Gullies habitat retained in the escarpments of Mesa H Mining Exclusion Zone, other than existing and authorised disturbance. The proponent shall manage the implementation of the Revised Proposal to meet the following environmental objective: (1) The proponent shall improve knowledge of the Ghost Bat population and utilisation of high value habitat in the Robe Valley in order to assist in maintaining biological diversity and ecological

Ministerial Conditions of MS 208		Proposed Change / Rationale	Proposed New Ministerial Conditions	
				integrity.
			8	**Subterranean Fauna - Troglofauna**
		New environmental factor condition for Mesa H	8-1	The proponent shall manage the implementation of the Revised Proposal to meet the following environmental outcome: (1) No irreversible impact, as a result of the proponent's activities, to the troglofauna habitat retained within the Mesa H MEZ The proponent shall manage the implementation of the Revised Proposal to meet the following environmental objective: (1) The Proponent shall protect the biological diversity and ecological integrity of the troglofauna assemblages of Mesa H by minimising impacts as far as practicable.
			9	**Subterranean Fauna - Stygofauna**
		New environmental factor condition for Mesa H	9-1	The proponent shall manage the implementation of the Revised Proposal to meet the following environmental outcome:

Ministerial Conditions of MS 208		Proposed Change / Rationale	Proposed New Ministerial Conditions	
				(1) No irreversible impact, as a result of the proponent's water management activities to the stygofauna habitat within the alluvial aquifer habitats of Jimmawurrada Creek and the Robe River. The proponent shall manage the implementation of the Revised Proposal to meet the following environmental objective: (1) The Proponent shall protect the biological diversity and ecological integrity of the stygofauna assemblages within the Robe River and Jimmawurrada alluvial aquifer habitats by minimising impacts as far as practicable.
6	**Rehabilitation**		**10**	**Rehabilitation and Decommissioning**
6-1	Rehabilitation is an integral part of the project and requires management throughout the life of the project. Within 12 months of the date of this statement, the proponent shall prepare a Rehabilitation Management Programme to the satisfaction of the Environmental Protection Authority on advice of the Department of' Mines and the Department of Conservation and Land Management. The programme shall include but not necessarily be limited to: 1 . proposals for rehabilitation of the project area; and 2. a monitoring programme to determine success of the rehabilitation.	This Condition is still relevant and should be retained; however, it has been updated to reflect contemporary wording and format, consistent with other recent Ministerial Statements for the Proponent's Pilbara iron ore operations.	10-1	The proponent shall manage the implementation of the Revised Proposal to meet the following environmental objective: (1) Ensure that the Revised Proposal is rehabilitated and decommissioned in an ecologically sustainable manner. (2) Ensure that closure planning and rehabilitation are undertaken in a progressive manner.
6-2	The initial programme shall be submitted to the Environmental Protection Authority, with subsequent programmes for the project to be updated annually in		10-2	Within 12 months of the issue of this Statement or as otherwise agreed in writing from the CEO, the proponent shall prepare and submit a Mine Closure Plan in accordance with the Guidelines for Preparing Mine Closure Plans, May 2015 (or any subsequent

Ministerial Conditions of MS 208		Proposed Change / Rationale	Proposed New Ministerial Conditions	
	conjunction with reporting requirements under the Iron Ore (Robe River) Agreement Act.			revisions of the guidelines), to the requirements of the CEO, on advice of the Department of Mines, Industry Regulation and Safety and the Department of Water and Environmental Regulation.
6-3	At least twelve months prior to decommissioning, the proponent shall prepare a plan for decommissioning and rehabilitating the site, to the satisfaction of the Environmental Protection Authority on advice of the Department of Mines and the Department of Conservation and Land Management.		10-3	The proponent shall review and revise the Mine Closure Plan required by condition 10-2 at intervals not exceeding three years, or as otherwise specified by the CEO, and submit the plan to the CEO at the agreed interval.
6-4	Subsequent to conditions 6-1 and 6-3, the proponent shall implement the approved programmes for rehabilitating and decommissioning the site; to the satisfaction of the Environmental Protection Authority on advice of the Department of Mines and the Department of Conservation and Land Management.		10-4	The proponent shall implement the latest revision of the Mine Closure Plan, which the CEO has confirmed by notice in writing, satisfies the requirements of condition 10-2.
10	**Offsets**		**11**	**Offsets**
		New contemporary condition	11-1	In view of the residual impacts and risks as a result of implementation of the Revised Proposal, the proponent shall contribute funds to offset: • clearing of Northern Quoll core habitat • clearing of 'good to excellent' condition native vegetation in the Hamersley IBRA subregion, • clearing of riparian vegetation in the Hamersley IBRA subregion • clearing within areas defined as Priority Ecological Communities: the *Subterranean invertebrate community of pisolitic hills* and the *Subterranean invertebrate community of mesas in the Robe Valley region*

Ministerial Conditions of MS 208		Proposed Change / Rationale	Proposed New Ministerial Conditions	
				• direct impact to the subterranean Blind Cave Eel habitat within the Priority Ecological Community: *Stygofaunal community of the Bungaroo Aquifer* The offset shall be calculated pursuant to condition 11-2 subject to any reduction approved by the CEO under condition 11-7. This funding shall be provided to a government established conservation offset fund or an alternative offset arrangement providing an equivalent outcome as determined by the Minister.
			11-2	The proponent's contribution to the initiative identified in condition 11-1 shall be paid biennially, the first payment due two years after ground disturbance. The amount of funding will be made on the following basis in accordance with the approved Impact Reconciliation Procedure required by condition 11-4: • $ 3,000 AUD (excluding GST) per hectare of clearing within Northern Quoll core habitat; • $750 AUD (excluding GST) per hectare of clearing of "good to excellent" condition native vegetation cleared within the delineated Figure x as Area x within the Hamersley IBRA subregion; $1500 AUD (excluding GST) per hectare of clearing of riparian vegetation and Priority Ecological Communities, the *Subterranean invertebrate community of pisolitic hills* and the *Subterranean invertebrate community of mesas in the Robe Valley region*; and • $1500 AUD (excluding GST) per hectare of the *Stygofaunal community of the Bungaroo Aquifer* delineated in the drawdown Zone 3 in Jimmawurrada Creek.
			11-3	The clearing of 1800 ha of native vegetation previously authorised under statement MS 208, is exempt from the requirement to offset under condition 11-2.

Ministerial Conditions of MS 208		Proposed Change / Rationale	Proposed New Ministerial Conditions	
			11-4	Within twelve months of the date of this statement develop an Impact Reconciliation Procedure that: (1) Includes a methodology to identify clearing of 'Good to Excellent' condition native vegetation, riparian vegetation and Priority Ecological Communities in the Development Envelope; (2) Includes a methodology for calculating the amount of clearing undertaken during each biennial time period; and (3) States dates for the commencement of the biennial time period and for the submission of results of the Impact Reconciliation Procedure, to the satisfaction of the CEO.
			11-5	The proponent shall implement the Impact Reconciliation Procedure required by condition 11-4.
			11-6	The real value of contributions described in condition 11-2 will be maintained through indexation to the Perth Consumer Price Index, (CPI) with the first adjustment to be applied to the first contribution.
			11-7	The proponent may seek the written approval of the CEO to reduce all or part of the contribution payable under condition 11-2 where: (1) a payment has been made to satisfy a condition of an approval under the *Environment Protection and Biodiversity Conservation Act 1999* in relation to the Revised Proposal; (2) the payment counterbalances impacts of the Revised Proposal on matters of national environmental significance; and (3) the payment counterbalances the significant residual impacts to the environmental values identified in condition 11-2.

Schedule 1

The Proponent proposes that, subject to approval, the summary of the Revised Proposal and the location and authorised extent of operational elements of Schedule 1 will be amended to consolidate the existing Ministerial Statement and this Revised Proposal, to read as follows:

Table 1: Summary of the Revised Proposal

Revised Proposal title	Mesa H Project (Revision to the Mesa J Iron Ore Development)
Proponent name	Robe River Mining Co. Pty. Ltd.
Short description	The Revised Proposal is located approximately 16 km south west of Pannawonica in the Pilbara region of Western Australia (Figure 1). The Revised Proposal includes development of above and below water table open cut pits at Mesa J and Mesa H, ore processing facilities, waste dumps, ore, topsoil and subsoil stockpiles and associated infrastructure, including water management infrastructure. This Revised Proposal utilises infrastructure including processing facilities (subject to upgrades), waste fines storage facilities and rail from the existing Mesa J operations.

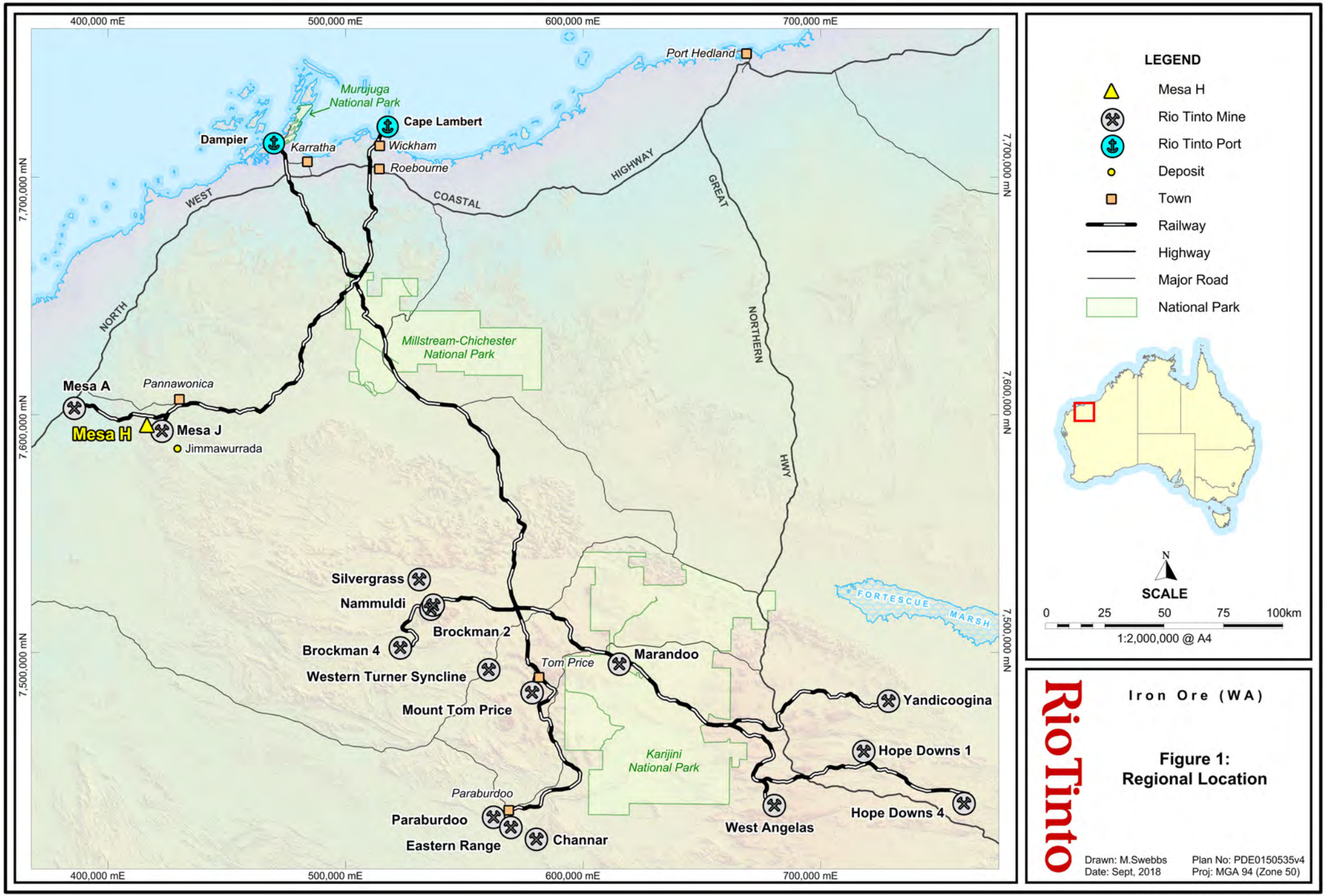
Table 2: Location and authorised extent of physical and operational elements of the Revised Proposal

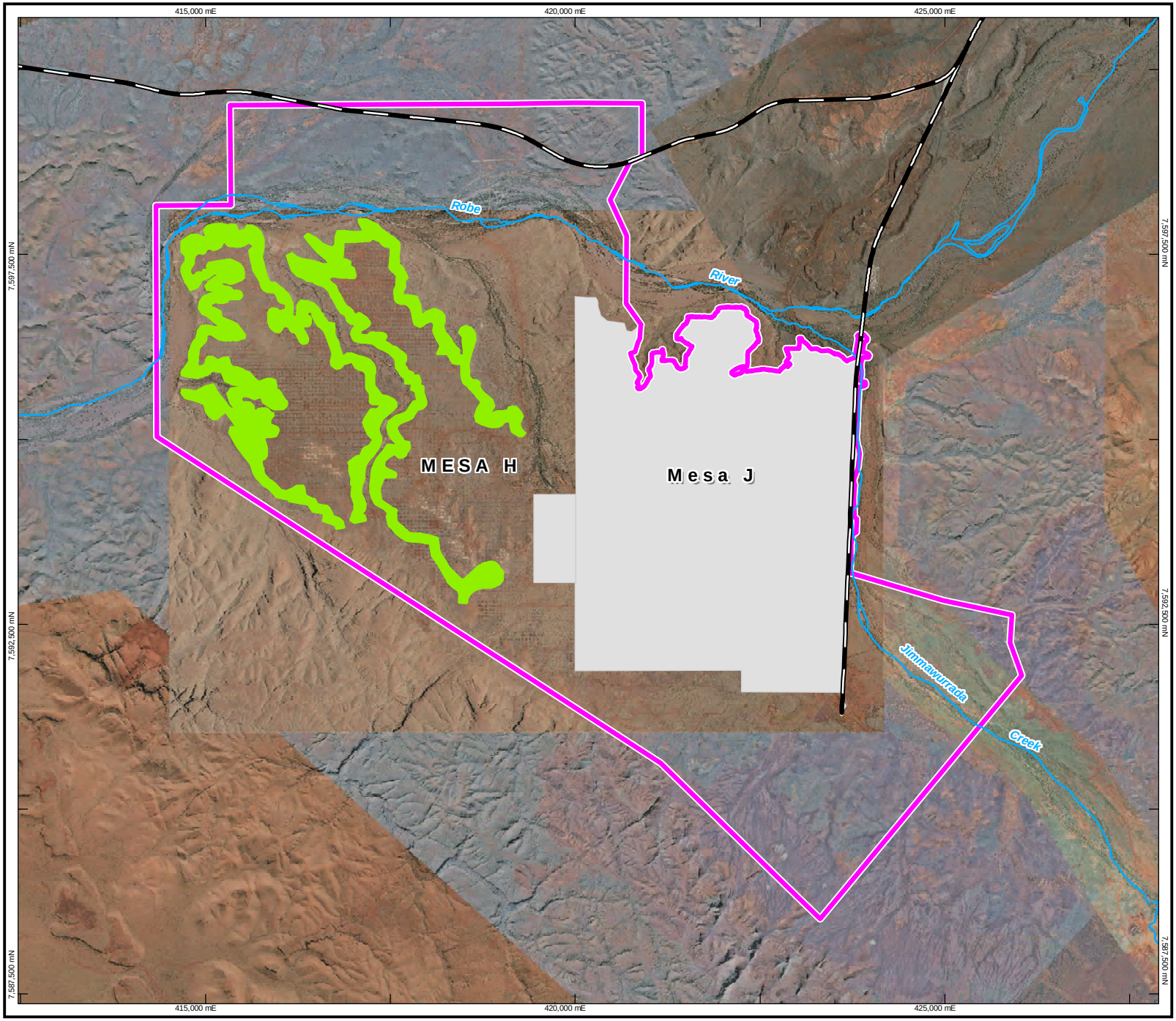
Element	Location	Existing approval (Ministerial Statement/s and other regulatory approvals)	Proposed change (This Proposal)	Proposed extent (Revised Proposal) *[total of existing approval + proposed change] [total of existing approval + proposed change]*
Physical Elements				
Mine and associated infrastructure	Figure 2	Total disturbance area (vegetation clearing) of up to 1,800 ha	Clearing of up to 2,200 ha of native vegetation within the Development Envelope of 6,638ha. Disturbance in the Mesa H Mining Exclusion Zone in accordance with the Environmental Management Plan.	Clearing of up to 4,000 ha of native vegetation within the Development Envelope of 6,638 ha. Disturbance in the Mesa H Mining Exclusion Zone in accordance with the Environmental Management Plan.
Rail	Figure 1	Single gauge railway line with sidings and a voice and radio data communications system with Fibre optic cable, from Cape Lambert.	N/A	Remove as not environmentally relevant

Element	Location	Existing approval (Ministerial Statement/s and other regulatory approvals)	Proposed change (This Proposal)	Proposed extent (Revised Proposal) *[total of existing approval + proposed change] [total of existing approval + proposed change]*
Operational Elements				
Groundwater abstraction for water supply, ore processing and pit dewatering	-	Not specified in MS 208 Annual water entitlement of 30 GL/a (Approved under *Rights in Water and Irrigation Act 1914* (RiWI) licence GWL107678(13))	No change	Groundwater abstraction up to 30 GL/a, including from: • Water supply from Southern Cutback Borefield • Pit dewatering
Surplus Water Management	-	Not specified in MS 208. Discharge of mine dewater at designated discharge points in Jimmawurrada Creek and a tributary of Robe River (Approved under Part V Operating Licence L6820/1993/12)	No change	Controlled surface discharge to extend along Jimmawurrada Creek / West Creek and into the Robe River no further than 8 km downstream of the discharge point under natural no-flow conditions.

Figures (attached)

Figure 1 – Regional Location
Figure 2 – Revised Proposal


400,000 mE
500,000 mE
600,000 mE
700,000 mE
7,700,000 mN
7,600,000 mN
7,500,000 mN
Port Hedland
Murujuga National Park
Dampier
Karratha
Cape Lambert
Wickham
Roebourne
WEST
COASTAL
HIGHWAY
GREAT
NORTHERN
HWY
NORTH
Millstream-Chichester National Park
Mesa A
Pannawonica
Mesa H
Mesa J
Jimmawurrada
Silvergrass
Nammuldi
Brockman 2
Brockman 4
Western Turner Syncline
Tom Price
Marandoo
Mount Tom Price
Yandicoogina
Hope Downs 1
Karijini National Park
Paraburdoo
Paraburdoo
Eastern Range
Channar
West Angelas
Hope Downs 4
FORTESCUE MARSH
LEGEND
Mesa H
Rio Tinto Mine
Rio Tinto Port
Deposit
Town
Railway
Highway
Major Road
National Park
N
SCALE
0
25
50
75
100km
1:2,000,000 @ A4
Iron Ore (WA)
Figure 1:
Regional Location
Drawn: M.Swebbs
Date: Sept, 2018
Plan No: PDE0150535v4
Proj: MGA 94 (Zone 50)
Geospatial Information and Mapping



LEGEND

- Development Envelope
- Proposed Mining Exclusion Zone
- Extent of Mesa J Mine Operations Area
- Railway
- Major Watercourse

N

SCALE

0 1 2 3km

1:75 000 @ A4

Disclaimer

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Rio Tinto

Iron Ore (WA)

Figure 2 Revised Proposal

Drawn: T.Murphy
Date: Mar, 2019

Plan No: PDE0152228v17
Proj: MGA94 Zone50

Geographic spatial data coordinates

Coordinates defining the following are held by the Environmental Protection Authority - Services:

1. Development Envelope
2. Mesa J Operations Area
3. Mesa H Mining Exclusion Zones

Referral of proposed action

Proposed action title:	Mesa H Proposal

1. Summary of proposed action

1.1	**Short description:** Robe River Mining Co. Pty. Limited (the Proponent), as manager and agent for the Robe River Iron Associates joint venture (RRIA), is seeking to extend the existing Mesa J operations by developing the adjacent iron ore deposit at Mesa H. The Mesa H Proposal is located approximately 16 km south west of Pannawonica in the Pilbara region of Western Australia (refer Attachment 1). This Proposed Action will involve development of additional mine pits, mineral waste dumps and associated infrastructure, processing facilities and water management infrastructure to sustain the Robe Valley Operations ore feed at 35 Mt/annum.
1.2	**Latitude and longitude** Nodes are provided in Table 1 below.

Table 1: Nodes for the area subject to the Proposed Action

Location point	Latitude			Longitude		
	degrees	minutes	seconds	degrees	minutes	seconds
1	-21	42	20.68	116	10	53.24
2	-21	42	20.68	116	13	5.45
3	-21	42	20.45	116	13	35.63
4	-21	42	20.53	116	13	35.63
5	-21	42	20.80	116	14	7.07
6	-21	42	44.29	116	14	6.94
7	-21	42	46.58	116	14	1.26
8	-21	43	3.19	116	13	51.90
9	-21	43	19.00	116	13	59.56
10	-21	43	48.73	116	13	59.17
11	-21	43	58.08	116	14	6.22
12	-21	44	1.24	116	14	1.76
13	-21	44	0.76	116	13	59.28
14	-21	43	57.50	116	13	58.17
15	-21	43	56.47	116	13	50.38
16	-21	43	54.13	116	13	47.10
17	-21	43	45.98	116	13	45.93
18	-21	43	45.72	116	13	35.20
19	-21	45	12.57	116	13	35.09
20	-21	45	12.58	116	13	15.15
21	-21	45	51.61	116	13	14.94
22	-21	45	51.70	116	13	34.88
23	-21	46	30.59	116	13	34.86
24	-21	46	30.37	116	14	52.66
25	-21	46	39.82	116	14	52.61

Location point	Latitude			Longitude		
	degrees	minutes	seconds	degrees	minutes	seconds
26	-21	46	39.93	116	15	14.50
27	-21	46	40.19	116	15	40.01
28	-21	46	20.09	116	15	42.13
29	-21	45	47.75	116	15	43.84
30	-21	46	0.00	116	16	27.65
31	-21	46	6.67	116	17	0.05
32	-21	46	18.80	116	16	59.20
33	-21	46	23.97	116	17	1.18
34	-21	46	28.43	116	17	2.89
35	-21	46	33.23	116	17	4.73
36	-21	48	19.863	116	15	29.23
37	-21	48	5.56	116	15	13.61
38	-21	47	10.90	116	14	14.47
39	-21	46	49.54	116	13	39.48
40	-21	46	49.54	116	13	39.48
41	-21	46	28.75	116	13	5.43
42	-21	46	28.75	116	13	5.43
43	-21	46	7.34	116	12	30.39
44	-21	46	7.34	116	12	30.39
45	-21	44	46.40	116	10	17.96
46	-21	43	4.57	116	10	17.96
47	-21	43	4.57	116	10	53.24

1.3	**Locality and property description:** The Proposed Action is located approximately 16 km south west of Pannawonica and 130 km south-west of Karratha in the Pilbara region of Western Australia (refer Attachment 1). The area subject to the Proposed Action (the Development Envelope) is distant from major public population centres and significant tourist attractions. The Pannawonica access road runs to the north of the Development Envelope. Existing land uses include iron ore mining, mineral exploration, pastoral activities (Yarraloola and Yalleen Stations) and traditional owner activities such as camping, fishing and hunting.	
1.4	**Size of the development footprint or work area (hectares)**	The Proposed Action will involve clearing of up to 2,200 ha within the Development Envelope of 4,930 ha.
1.5	**Street address of the site**	Not applicable
1.6	**Lot description** The Proposed Action is centred on deposits located within State Agreement Mineral Lease ML248SA granted pursuant to the *Iron Ore (Robe River) Agreement Act 1964* held by Robe River Ltd and sub-leased to RRIA (refer Attachment 2). The Proposed Action is also situated on the Yarraloola and Yalleen Pastoral Stations Leases (N49500 and N49492 respectively) held by entities associated with members of the RRIA.	

1.7	**Local Government Area and Council contact (if known):** The Proposed Action is located in the Shire of Ashburton. The main Shire offices are located in the town of Tom Price and the relevant council contact is: Mr Neil Hartley Chief Executive Officer Shire of Ashburton PO Box 567 Tom Price, WA 6751 Telephone: (08) 9188 4457 Fax: (08) 9189 2090		
1.8	**Time frame:** The Proposed Action has an estimated operational mine life of approximately 17 years. Under the current project schedule, construction activities are planned to commence in Quarter 4 2018 once all required internal and external approvals are granted.		
1.9	**Alternatives to proposed action:** Were any feasible alternatives to taking the proposed action (including not taking the action) considered which are not proposed?	✓	No. The Proposed Action is centred on substantial iron ore deposits that are critical to sustaining the existing Mesa J Operation.
1.10	**Alternative time frames, locations or activities:** Does the proposed action include alternative time frames, locations or activities?	✓	No
1.11	**Commonwealth, State or Territory assessment:** Is the action subject to other a Commonwealth, State or Territory environmental impact assessment?	✓	Yes, refer to section 2.5
1.12	**Component of larger action:** Is the proposed action a component of a larger action?	✓	No
1.13	**Related actions/proposals:** Is the proposed action related to other actions or proposals in the region?	✓	Yes: The Proposed Action involves mining, ore handling, processing, water abstraction and disposal that are inter-related with the infrastructure and activities of the existing Mesa J Operation. The Mesa J Operation has been in operation since 1992.

1.14	**Australian Government funding:** Has the person proposing to take the action received any Australian Government grant funding to undertake the proposed action?	✓	No
1.15	**Great Barrier Reef Marine Park** Is the proposed action inside the Great Barrier Reef Marine Park?	✓	No

2. Detailed description of proposed action

2.1 Description of proposed action

The Proposed Action includes development of additional mine pits, new mineral waste dumps and associated infrastructure, water treatment facilities, processing facilities and water management infrastructure. An indicative conceptual mine layout is shown in Attachment 3.

Mining

The Mesa H deposit is a continuation of the Robe Pisolite iron ore deposit present at Mesa J and Mesa K, known more generally as a Channel Iron Deposit (CID).

The Proposed Action includes development of new open cut mine pits at Mesa H with approximately 20% of ore proposed for mining occurring below water table (BWT).

Ore will be mined using open cut mining methods comprising conventional drill, blast, load and haul as currently used in the adjacent Mesa J Operation.

Exclusions

Exclusions from the scope of the Proposed Action comprise the following:

- Activities and additional infrastructure at the Mesa J Operation approved under Ministerial Statement 208 (MS 208).
- Low impact activities within the Development Envelope required prior to Part IV of the Environmental Protection Act 1986 (EP Act) approval of the Proposal. These activities will be subject to relevant provisions under Part V [Land Clearing] of the EP Act) and will include drilling and associated activities (such as upgrades to existing roads/tracks) for the purposes of resource evaluation, geotechnical assessment and hydrogeological investigation.
- Establishment of a construction camp to support the construction phase of the Proposed Action. This will be subject to relevant provisions under Part V [Land Clearing and Works Approvals/Licensing] of the EP Act.
- Establishment of temporary services (communications, water supply, power), temporary concrete batch plant, site offices, access roads, laydown areas, and borrow pits to support establishment of a construction camp. These will be subject to relevant provisions under Part V [Land Clearing and Works Approval/Licensing] of the EP Act.
- Facility upgrades in Pannawonica to support the expanded workforce.
- Power network upgrades at Pannawonica, and a 9 km section of overhead power line between the Pannawonica switchyard and the Mesa A/J tee-off. These will be subject to relevant provisions under Part V [Land Clearing and Works Approval/Licensing] of the EP Act.

Ore handling and transport

Haul roads will be developed to enable haulage of ore from the Proposed Action to the adjacent Mesa J Operation for dry and wet processing. Ore will then be transported to the Cape Lambert/Dampier ports via the existing Mesa J rail line.

Mineral waste

The Mesa H mine plan has incorporated a pit sequence that enables progressive in-pit backfill of the majority of waste, using both the Mesa H and the adjacent Mesa J pits. Where pit sequencing and scheduling do not allow waste to be used for backfilling, out-of-pit waste dumps will be utilised. Currently, two locations have been identified for out-of-pit waste dumps that minimise direct impact

to significant environmental and heritage areas. Out-of-pit storage for competent material, low grade ore, sub-soil and topsoil will also be required.

Wet processing of low grade ore at Mesa H will generate waste fines. The mine plan will incorporate the use of pits within the Development Envelope and at the Mesa J operation for in-pit waste fines storage facilities (WFSF) over the life of the Proposal.

Pit Dewatering

Approximately 20% of the ore proposed for mining at Mesa H is BWT. Dewatering to access the BWT ore is therefore required at an average rate of 3 GL/a and peak rate of 10 GL/a. Dewatering is currently expected to commence in approximately 2025 and will be via sump pumping, powered by diesel generators. Groundwater abstracted for dewatering purposes will contribute to meeting operational demands for the Proposed Action and Mesa J operation, primarily wet processing, however the timing for BWT pit dewatering and average dewatering rate will not be sufficient to meet these processing demands, hence an additional water supply will be required for the Proposed Action.

Surface water management

Surface water management will be required for the watercourses draining local catchments from the Buckland Hills south of the Proposed Action which intersect the southern pits. A drainage diversion is required during operations south of the southern pits to direct flow to the watercourse between the northwest and southern pits, and subsequently into the Robe River. The diversion will not be maintained post closure.

Water supply and surplus water discharge

Water is required for the Proposed Action to enable:

- construction activities;
- general mining activities;
- dust suppression on haul roads; and
- potable water supply.

Mine pit dewatering for the Proposal of an average of 3 GL/a (peak up to 10 GL/a) will not be sufficient to meet operational demands, requiring continued operation of the existing Mesa J water supply borefield (Southern Cutback borefield) located immediately to the south of the Mesa J Operation. The total abstraction from this water supply borefield (to include the requirements for this Proposed Action) is not expected to require an increase to the current Mesa J abstraction licence limit (which is 30GL/a).

The site water demand for the Proposed Action and continuation of the Mesa J Operation is estimated to be approximately 11 GL/a, which is similar to the existing Mesa J water demand.

Based on water balance estimates, and depending on fluctuations in site water usage requirements and seasonal fluctuations, limited surplus water is expected to be generated from mine pit dewatering. After large rainfall events however, significant ponding would result in a requirement to discharge. In these circumstances, and combined with temporal variability in mine water use, up to a peak of 10 GL/a may be required to be discharged.

Any surplus surface water discharge will be predominantly via the existing Mesa J Operation discharge points, in Jimmawurruda Creek east of Mesa J or West Creek, between the Proposal and the Mesa J operation. Additional discharge points may be established if required, pending further hydrological studies to support options to manage the identified values of the Robe River ecosystem.

Mine support facilities and infrastructure

Additional power supply to the Mesa J Operation is required as part of the Proposed Action, comprising a powerline of approximately 2.5 km in length from the existing Coastal Water Supply powerline to Mesa J (Attachment 3).

A production hub will be established at Mesa H comprising: truck park up; laydown; offices; ablutions; waste water treatment plant; and other facilities as required to support the operation. A power line will connect the production hub to the Mesa J power network.

A turkey's nest will be established near the production hub to provide water for dust suppression.

Communications systems will be extended to the Proposed Action including installation of fibre optic cables.

The Proposed Action will utilise the existing Mesa J rail infrastructure.

Workforce

The Proposed Action will be operated as an extension to the existing Mesa J operation and will require an increase in the operational workforce. The workforce will continue as mixed residential Fly In / Fly Out (FIFO) workforce, housed in existing accommodation in Pannawonica.

The construction workforce is proposed to be accommodated in a 'dry hire' mobile construction camp north of Mesa H (not part of the Proposed Action).

Timing

Under the current schedule, construction activities are planned to commence in Quarter 4 2018 once all required internal and external approvals are granted.

2.2 Feasible alternatives to taking the proposed action

No alternative iron ore deposits have been identified as being suitable for development within the timeframe required to maintain both the type of iron ore product and to sustain the existing Mesa J Operation.

2.3 Alternative locations, time frames or activities that form part of the referred action

Other than the options described in this document (e.g. water sources for wet processing), no alternative locations, timeframes, methods or activities have been identified for undertaking the Proposed Action.

2.4 Context, including any relevant planning framework and state/local government requirements

The Proposed Action is subject to the provisions of the *Iron Ore (Robe River) Agreement Act 1964.* The Proposed Action is subject to the Western Australian environmental approval requirements listed in Table 2.

Table 2: Western Australian legislation relevant to the Proposed Action

Agency/authority	Approval required
Environmental Protection Authority (EPA) / Minister for Environment.	Proposal approval under Part IV of the *Environmental Protection Act 1986* (WA) (EP Act).
Department of Jobs, Tourism, Science and Innovation / Minister for Jobs, Tourism, Science and Innovation.	Proposal approval under the *Iron Ore (Robe River) Agreement Act 1964*
Department of Water and Environment Regulation.	Project environmental impact assessment under Part IV of the EP Act. Works approvals and licences under Part V of the EP Act. Permits and licences to interfere with the bed and banks of a watercourse, take water and manage its use and construct and alter wells under the *Rights in Water and Irrigation Act 1914* (WA).
Department of Mines, Industry Regulation and Safety.	Native Vegetation Clearing Permits under Part V of the EP Act. Mining Proposals under the *Mining Act 1978* (WA).
Department of Planning, Lands and Heritage.	Protection of Aboriginal sites under the *Aboriginal Heritage Act 1972* (WA).
Shire of Ashburton.	Development approval under the Shire Town Planning Scheme No. 7.

2.5 Environmental impact assessments under Commonwealth, State or Territory legislation

The Proposed Action is subject to the Western Australian environmental impact assessment process under the EP Act. The Proposed Action was referred to the Western Australian EPA under section 38 of the EP Act on 29 June 2017. The level of assessment was set as a Public Environmental Review (PER) with a 2 week public review period. Completed and planned environmental studies associated with this referral are summarised in Table 3 and Table 4 respectively.

Table 3: Completed environmental studies relevant to the Proposed Action

Study	Description
Flora and vegetation	
Biota Environmental Sciences (2011). *Baseline Flora and Vegetation Assessment of Robe Valley Mesas (Mesas B,C,D,E,F,H and I).* Unpublished report prepared for Rio Tinto Iron Ore, April 2011.	Survey conducted in October 2010 documenting flora, vegetation units and conservation listed flora in the Development Envelope.
Astron (2016b). *Mesa H Level 2 Vegetation and Flora Assessment.* Unpublished report prepared for Rio Tinto Iron Ore, May 2016.	Surveys conducted in September / October 2014 and May and July 2015 documenting vegetation units and conservation listed flora in the Development Envelope.
Astron (2016). *Mesa H Riparian Vegetation Baseline Monitoring.* Unpublished report prepared for Rio Tinto Iron Ore, June 2016.	Monitoring transects established across riverine vegetation in the Robe River in May-June 2016.

Study	Description
Astron (2016) *Mesa H Riparian Community Assessment*. Unpublished report prepared for Rio Tinto Iron Ore, June 2016.	Level 2 vegetation and flora assessment of the Robe River riparian community, and a Level 1 fauna assessment desktop assessment, including database searches and literature review of available resources, vegetation and flora assessment, fauna and fauna habitat assessment and baseline aquatic assessment.
Rio Tinto (2017). *Assessment of Groundwater Dependent Vegetation distribution on the Robe River - Targeted Riparian Vegetation Survey.* Unpublished report prepared by Rio Tinto Iron Ore, May 2017.	Detailed survey and spatial mapping of the distribution of Robe River Groundwater Dependent Vegetation (GDV). Interpretation of the significance and sensitivity of these communities to potential hydrological change – providing an interpreted risk map throughout the Development Envelope and immediate surrounds.
Terrestrial fauna	
Streamtec (1991 - 2016). Aquatic Ecosystems Study (annual monitoring).	Annual aquatic ecosystems monitoring survey to assess potential environmental impacts of the Mesa J Operation on the adjacent and downstream aquatic ecosystem. The survey is an integrated assessment of biological parameters including aquatic fauna (macroinvertebrates and fish), channel/pool morphology, riparian vegetation condition and water quality.
Biota Environmental Sciences (2011). *Robe Valley Mesas Fauna Report*. Unpublished report prepared for Rio Tinto Iron Ore, March 2011.	Survey conducted in October 2010 documenting terrestrial fauna, fauna habitats, species of conservation significance and habitats that may require specific management.
Astron (2016a). *Level 2 Terrestrial Fauna Surveys: Mesa H*. Unpublished report prepared for Rio Tinto Iron Ore, November 2015.	Surveys conducted in May and September 2015 documenting terrestrial fauna, fauna habitats, species of conservation significance and habitats that may require specific management.
Astron (2017). *Mesa H Ghost Bat, Macroderma gigas – Contextual Study*. Unpublished report prepared for Rio Tinto Iron Ore, July 2017.	Contextual analysis for the conservation significant Ghost Bat (*Macroderma gigas*) within the vicinity of the Mesa H Development Envelope, including desktop review and field survey involving mapping of potential habitat and targeted survey for the Ghost Bat.
WRM (2017) Mesa H Project: Baseline Aquatic Ecosystem Survey. Wet Season Sampling 2016. Unpublished report prepared for Rio Tinto Iron Ore, April 2017.	Baseline wet season sampling program undertaken to document the current ecological condition of the Robe River for aquatic ecosystems, with a focus on permanent and semi-permanent pools and sampling of sites upstream and downstream of Mesa H.
Bat Call WA (2017a). *Robe Valley Mesa H Ghost Bat roost cave assessment.* Unpublished report prepared for Rio Tinto, April 2017.	Extensive search for Ghost Bat presence at Mesa H conducted in April 2017, including assessment of the conservation value of caves associated with the presence of Ghost Bats.
Bat Call WA (2017b). *Robe Valley Mesa A to Mesa 2405A, assessment of mining on Ghost Bat presence and activity*. Unpublished report prepared for Rio Tinto, April 2017.	Assessment of impact of mining on Ghost Bat viability in the broader Robe valley including a desktop and field review of historical mined areas, current mining operations and proposed mining developments.
Subterranean fauna	
Biota Environmental Sciences (2006). Mesa A and Robe Valley Mesas Troglobitic Fauna Survey. Unpublished report prepared for Robe River Iron Associates, March 2006).	Surveys conducted November 2004 to January 2005, April to May 2005, July to September 2005 documenting subterranean fauna and assessing subterranean fauna habitat.
Biota Environmental Sciences (2017). *Mesa H Subterranean Fauna Assessment.* Unpublished report prepared for Rio Tinto.	Surveys conducted June to August 2015 and August to October 2015 documenting subterranean fauna and assessing subterranean fauna habitat.

Study	Description
Hydrological Processes and Inland Waters Environmental Quality	
Rio Tinto (2016) *Mesa H Chemistry and Isotopes.* Unpublished report prepared by Rio Tinto Iron Ore, 2016.	Groundwater and surface water chemical and isotope analysis aiming to assess groundwater dependency of the Robe River pools.
Rio Tinto (2016) *Mesa H Chemistry and Isotopes.* Unpublished report prepared by Rio Tinto Iron Ore, 2016.	Groundwater and surface water chemical and isotope analysis aiming to assess groundwater dependency of the Robe River pools.
Rio Tinto (2016). *Mesa H 2016 Pre-Feasibility Study Hydrogeological Drilling Program Completion Report.* Unpublished report prepared by Rio Tinto Iron Ore, 2016.	Report detailing drilling and installation of 19 monitoring bores and 4 water bores, and test pumping of all completed water bores.
Rio Tinto (2016). *Mesa H Hydrogeological Conceptual Model Report.* Unpublished report prepared by Rio Tinto Iron Ore, 2016.	Mesa H hydrogeological conceptual model report to support the development of the groundwater numerical model.
Rio Tinto (2016). *Mesa H Dewatering, Water Supply and Impact Assessments*. Unpublished report prepared by Rio Tinto Iron Ore, 2016.	Groundwater numerical model to support the Mesa H Proposal assessing dewatering requirements, water supply strategy and impact prediction.
Rio Tinto (2016). *AMD Risk Assessment Summary for the Robe Valley.* Unpublished report prepared by Rio Tinto Iron Ore, 2016.	A review of the AMD risk assessment for the Robe Valley including Mesa H.
Rio Tinto (2016). *Mesa H Order of Magnitude Design Flood Estimation and Floodplain Mapping.* Unpublished report prepared by Rio Tinto Iron Ore, Feb 2016.	Investigation to provide design flood estimates and floodplain mapping for the Mesa H deposit to inform the development of surface water management options.
Rio Tinto (2017). *Mesa H PFS Surface Water Management.* Unpublished report prepared by Rio Tinto Iron Ore, March 2017.	Study describing the interaction between natural surface water runoff, the local environment and the Mesa H study area and proposed water management measures.
Rio Tinto (2017). *Surplus water discharge extent assessment: Mesa H*. Unpublished report prepared by Rio Tinto Iron Ore, March 2017.	Study was to estimate the extent of impact of surplus water discharge along the proposed watercourses based on discharge location options.
Rio Tinto (2017) Mesa H H3 Hydrogeological Level Assessment. Unpublished report prepared by Rio Tinto Iron Ore, 2017.	Report detailing the Mesa H and J hydrogeological conceptualisation, numerical model predictions, aquifer impact assessment, monitoring program and proposed GW management.
Other	
Various targeted surveys associated with Rio Tinto exploration and pastoral activities.	Flora/vegetation and fauna surveys conducted in localised areas subject to Native Vegetation Clearing Permit applications.

Table 4: Environmental studies relevant to the Proposed Action that are in progress

Study	Description
Flora and vegetation	
Astron Environmental Services.	Baseline Monitoring – Phase II (Monitoring transects established across riverine vegetation in the Robe River).
Rio Tinto (in prep).	Assessment of Groundwater Dependent Vegetation distribution on the Robe River - Targeted Riparian Vegetation Survey.
Subterranean fauna	
Biota Environmental Sciences (in prep).	Surveys conducted June to August 2015, August to October 2015 and January to March 2016 documenting subterranean fauna and assessing subterranean fauna habitat.
Aquatic fauna	
Streamtec Aquatic Ecosystems Study	Ongoing annual aquatic fauna monitoring as part of existing Mesa J Operations.
Wetland Research and Management (WRM)	Baseline Aquatic Fauna Monitoring – Phase II.
Visual impact assessment	
Rio Tinto (in prep).	Visual impact assessment considering vantage points along Pannawonica Road, the Robe River and sites of heritage significance.

2.6 Public consultation (including with Indigenous stakeholders)

The Proponent has undertaken consultation on the Proposed Action as summarised in Table 5. The Proponent will continue to consult with relevant stakeholders during the environmental assessment process and during project implementation. Identified key stakeholders include:

- Department of Water and Environmental Regulation - EPA Services and Compliance and Regulation;
- Department of the Environment and Energy;
- Department of Biodiversity, Conservation and Attractions - Parks and Wildlife Services;
- Department of Mines, Industry Regulation and Safety;
- Department of Jobs, Tourism, Science and Innovation;
- Department of Planning, Lands and Heritage;
- Shire of Ashburton; and
- Traditional Owners, the Kuruma Marthudunera.

Table 5: Summary of completed stakeholder consultation for the Proposed Action

Stakeholder	Date	Topics/issues raised
Department of Water and Environmental Regulation (DWER) EPA Services	15 June 2016	Scope of the Proposed Action, summary of the biological survey results and likely key environmental factors for assessment.
	25 May 2017	Update of the scope of the Proposed Action, summary of the latest biological survey results, likely key environmental factors for assessment and timeframes.
Department of Water and Environmental Regulation (DWER) EPA Services – Terrestrial Ecosystems Branch	1 May 2017	Outline of the scope of the Proposed Action. A summary of troglofauna sampling and results was provided. Conceptual proposed troglofauna habitat retention areas / approach and avoidance areas.
Department of Water and Environmental Regulation (DWER) Department of Water	14 February 2017	Presentation of the Proposed Action hydrogeological conceptualisation, approach and key assumptions undertaken in the modelling.
Department of Water and Environmental Regulation (DWER) Department of Water	11-12 April 2017	Site trip to the Robe Valley to provide context and scale of the current operations and Proposed Action. Update of current understanding and conceptualisation of the hydrology and hydrogeology for all of the Robe Valley operations and Proposed Action. The field visit also included visits to the Robe River including a number of semi-permanent pools.
Department of Water and Environmental Regulation (DWER) Department of Water	4 July 2017	Presentation of the updated results from the hydrogeological modelling and the preliminary environmental impact assessment related to modelled hydrogeological drawdown – focussing on the modelled changes to the Robe River and Jimmawurrada Creek.
Department of Mines, Industry Regulation and Safety	30 June 2016	Scope of the Proposed Action, tenure, likely key environmental factors for assessment and closure planning.
	24 January 2017	Overview of the key elements of the Closure Plan being prepared for the Proposed Action.
Department of Jobs, Tourism, Science and Innovation	30 June 2016	Brief summary of the Proposed Action and status of study. Confirmation that a Proposal requesting approval for the Proposed Action will be submitted to the Department of Jobs, Tourism, Science and Innovation following funding approval and environmental approvals.
Department of Biodiversity, Conservation and Attractions (DBCA) Parks and Wildlife Services	24 March 2017	Scope of the Proposed Action, summary of the biological survey results, and likely key environmental factors for assessment. Discussion of occurrence of listed species (Northern Quoll, Pilbara Olive Python, Pilbara Leaf-nosed Bat and Ghost Bat) and nearest Priority Ecological Community (PEC).
Kuruma Marthudunera (K&M)	4 April 2016	Robe Valley Operations update including environmental monitoring and environmental status. Update of Life of Mine Planning – to include the Mesa H study progress (Proposed Action).
	25-26 May 2016	Scope of the Proposed Action and discussion of key heritage sites and important heritage values / concerns in the Development Envelope.
	23 August 2016	Discussion of key cultural heritage sites in the Development Envelope.

Stakeholder	Date	Topics/issues raised
	5-6 October 2016	Scope of the Proposed Action, update of proposed water management, discussion of protection of a key cultural heritage site via a change to the mine plan.
	15-16 May 2017	Field trip with K&M and independent anthropologist to discuss mine plan / waste dump locations and proposed management in respect of culturally sensitive areas.
	27 June 2017	Presentation of the results from the hydrogeological modelling and the preliminary environmental impact assessment related to modelled hydrogeological changes.

2.7 A staged development or component of a larger action

Not applicable.

2.8 Related actions

The Proposed Action involves mining, ore handling, water abstraction and disposal that utilise infrastructure and share activities of the existing adjacent Mesa J Operation.

The Mesa J Operation was assessed under Part IV of the EP Act with environmental approval for the project granted in 1992 subject to the conditions of Ministerial Statement 208 (MS 208). The project pre-dated the *Environment Protection and Biodiversity Conservation Act* (1999) (EPBC Act) and hence was not referred.

3. Description of environment & likely impacts

3.1 Matters of national environmental significance

3.1 (a) World Heritage Properties

Not applicable.

3.1 (b) National Heritage Places

Not applicable.

3.1 (c) Wetlands of International Importance (declared Ramsar wetlands)

Not applicable.

3.1 (d) Listed threatened species and ecological communities

Description

An EPBC Act Protected Matters search (21 November 2016, Attachment 4) identified 10 Listed Threatened Species as potentially occurring within the Development Envelope and surrounds, of which two are migratory species. The remaining eight species are listed in Table 6 (with migratory species listed in Table 7). In addition, the Blind Cave Eel (*Ophisternon candidum)* has been recorded within 1.1 km of the Development Envelope.

Table 6: Outputs of Protected Matters search relevant to the Proposed Action

Species	Status	Type of Presence
Mammals		
Northern Quoll *Dasyurus hallucatus*	Endangered	Species or species habitat known to occur within area
Ghost Bat *Macroderma gigas*	Vulnerable	Species or species habitat likely to occur within area
Greater Bilby *Macrotis lagotis*	Vulnerable	Species or species habitat may occur within area
Pilbara Leaf-nosed Bat *Rhinonicteris aurantia* (Pilbara form)	Vulnerable	Roosting known to occur within area
Reptiles		
Pilbara Olive Python *Liasis olivaceus barroni*	Vulnerable	Species or species habitat known to occur within area
Birds		
Night Parrot *Pezoporus occidentalis*	Endangered	Species or species habitat may occur within area
Australian Painted Snipe *Rostratula australis*	Endangered	Species or species habitat may occur within area
Plants		
Hamersley Lepidium *Lepidium catapycnon*	Vulnerable	Species or species habitat likely to occur within area
Fish		
Blind Cave Eel* *Ophisternon candidum*	Vulnerable	Species or species habitat likely to occur within area

* Not an output of the EPBC Protected Matters Search.

The most recent fauna and flora/vegetation surveys (Astron 2016a, Attachment 5 and Astron 2016b, Attachment 6 respectively) assessed the likelihood of the listed species occurring in the Development Envelope as either 'Confirmed', 'High', 'Moderate' or 'Low'. The results of the assessment are summarised in Table 7.

Table 7: Likelihood of occurrence of Listed Threatened Species in the Development Envelope

Species	Status	Habitat description and distribution	Likelihood of occurrence
Plants			
Hamersley Lepidium *Lepidium catapycnon*	Vulnerable	Rocky hilltop areas and breakaway slopes. Nearest known location of this taxon is 190 km south-east of the Development Envelope.	**Low** Unlikely to occur as the Development Envelope is outside the distribution of this taxon.
Mammals			
Northern Quoll *Dasyurus hallucatus*	Endangered	In the Pilbara, ironstone ridges, scree slopes of sandstone or ironstone and granite boulders and outcrops (van Dyck and Strahan 2008). Rio Tinto has recorded the Northern Quoll over a range of approximately 345 km extending from the Mesa A mine site to the Koodaideri mine site to the east-south-east (Rio Tinto 2016). Rio Tinto has recorded the Northern Quoll over 180 times in the Robe Valley (Rio Tinto 2016), with the majority of records associated with the mesas to the east of Mesa J, many of which have been historically mined.	**Confirmed**
Ghost Bat *Macroderma gigas*	Vulnerable	Caves, rock piles and abandoned mines (Menkhorst and Knight 2014). Will travel 2 km from roost to hunt (Churchill 2008). Can disperse up to 50 km during non-breeding season. Ghost bats utilise three main types of roosts: nocturnal roosts or feeding sites; diurnal / day roosts that may be permanent or semi-permanent sites; and maternity roosts that are diurnal roosts with the range of characteristics allowing regular or permanent occupancy (Bat Call 2017b). The Ghost Bat has been recorded throughout the Pilbara with a population estimated at 1,500 – 2,000. Locally within the Robe Valley, the population has been estimated at around 150, which include current records from historically mined mesa areas (Bat Call 2017b, Attachment 12).	**Confirmed**
Greater Bilby *Macrotis lagotis*	Vulnerable	Variety of habitats on soft soils including spinifex hummock grassland, *Acacia* shrubland, open woodland and cracking clays (Burrows et al. 2012). Nearest record located >70 km east of the Development Envelope (Parks and Wildlife 2015).	**Low** Unlikely to occur due to lack of suitable habitat and distance to nearest record.

Species	Status	Habitat description and distribution	Likelihood of occurrence
Pilbara Leaf-nosed Bat *Rhinonicteris aurantia* (Pilbara form)	Vulnerable	Roost in caves with high humidity (95%) and temperature (32 °C). Forage in humid caves and along waterbodies with fringing vegetation (Armstrong 2001). Rio Tinto has recorded the Pilbara Leaf-nosed Bat over a range of approximately 360 km extending from the Warramboo mine site to the east-south-east at Koodaideri and to the south-east towards Newman. The Pilbara Leaf-nosed Bat has been recorded along the length of the Robe Valley; suitable foraging and dispersal habitat is known to be available along the length of the Robe River.	**Confirmed**
Reptiles			
Pilbara Olive Python *Liasis olivaceus barroni*	Vulnerable	Watercourses and areas of permanent water in rocky gorges, escarpments and gullies (Pearson 1993).	**Confirmed**
Birds			
Night Parrot *Pezoporus occidentalis*	Endangered	Known to inhabit treeless or sparsely wooded long unburnt spinifex hummock plains often interspersed with chenopods (Davis and Metcalf 2008, Pyke and Ehrlich 2014) (Parks and Wildlife 2017) One unpublished record within 36 km of the survey area recorded in 1967 (Department of Parks and Wildlife 2015).	**Low** Unlikely to occur due to the absence of recent records from the locality and a lack of preferred habitat. Indicated as a Medium priority for Survey (Parks and Wildlife 2017)
Australian Painted Snipe *Rostratula australis*	Endangered	Inhabits shallow terrestrial freshwater wetlands, temporary/permanent lakes, swamps and claypans with emergent grass, sedges, rushes and samphire (Astron 2016a). The nearest record is located 100km to the north of the Proposed Action (Naturemap 2011).	**Moderate**
Fish			
Blind Cave Eel* *Ophisternon candidum*	Vulnerable	Inhabits groundwater systems in subterranean caves, transmissive geological formations, fissures and wells (Humphreys 2001). Utilises a range of habitats including cave floor sediments, karst aquifers and alluvial aquifers overlying channel iron deposits in the western Pilbara (Biota 2013). The nearest records occur 1.1 km and 5 km from the eastern extent of the Proposed Action's Development Envelope, in Jimmawurrada Creek and Bungaroo Creek.	**High**

Nature and extent of likely impact

Attachment 7 shows the records of Matters of National Environmental Significance (MNES) in the Development Envelope. Species profiles relevant to the Proposed Action for species that are likely or known to occur in the Development Envelope are summarised in Table 8 to Table 12.

Assessment against the Significant Impact Criteria for each species likely or known to occur in the Development Envelope is provided in Table 13 to Table 16.

Table 8: Species profile for the Northern Quoll (*Dasyurus hallucatus*) (Endangered)

Description and context with respect to the Proposed Action
The Northern Quoll was historically common across northern Australia, occurring almost continuously from the Pilbara, Western Australia, to near Brisbane, Queensland; however, its distribution and abundance has declined over the last 50 years. The Northern Quoll now occurs in five regional populations across Queensland, the Northern Territory and Western Australia both on the mainland and on offshore islands (Department of the Environment and Energy 2016a). In the Pilbara, the species is considered to favour the Rocklea, Macroy and Robe land systems (Biota 2008). These land systems comprise basalt hills, mesas (and buttes of limonites), high and low plateaux, lower slopes, occasional tor fields and stony plains supporting either hard or soft spinifex grasslands (van Vreeswyk *et al.* 2004). The Northern Quoll has also been recorded in other land systems which comprise sandstone and dolomite hills and ridges, shrublands, sandy plains, clay plans and tussock grasslands and coastal fringes including dunes islands and beaches (Biota 2008). Factors currently thought to threaten the species include: • mortality resulting from consumption of cane toads (*Bufo marinus*) (Woinarski et al. 2014); • removal, degradation and fragmentation of habitat associated with development and pastoralism; • inappropriate fire regimes (and subsequent predation by introduced fauna following fire (Hill and Ward 2010); and • invasive species (feral cat (*Felius catus*) and European red fox (*Vulpes vulpes*)) either through direct predation or competition for food. The Robe Valley, in which the Development Envelope is located, spans a distance of over 100 km and contains 34 named mesas as well as numerous un-named minor mesa formations and breakaways (refer Attachment 9). The Robe Valley contains habitat regarded as suitable for the Northern Quoll. The escarpments of the mesas in the Robe Valley, particularly those areas with deep gullies that are associated with drainage lines and water courses, are considered to represent core habitat for the Northern Quoll. Areas potentially containing core Northern Quoll habitat in the Development Envelope are mapped as the Gorge and Breakaway Habitat (~2% of the Development Envelope) in Attachment 10. Potentially suitable foraging and dispersal habitat consisted of Riverine and Rocky Hills habitats (~4% of the Development Envelope) particularly where these habitats were in close association with the Gorge and Breakaway Habitat (Astron 2016a). Evidence of the Northern Quoll has been recorded 27 times in the vicinity of Mesa H during the most recent targeted surveys, comprising six capture records (five confirmed separate individuals), 19 remote camera location recordings and two scats, tracks and/or trace records (Astron 2016a). The majority of these records were found in the Breakaway Habitat; however some records occurred within Riverine and Gorge habitat types. All records were in close proximity to rocky substrate associated with the escarpments of Mesa H and the adjacent Robe River. No Northern Quoll records to date have been recorded within the indicative clearing footprint of the Proposed Action. The Proposed Action includes retention of the mesa escarpments at Mesa H (except where cuts through lower value habitat are required to allow vehicle access) and will ensure that core Northern Quoll habitat continues to be available. Groundwater abstraction for water supply and pit dewatering will result in localised groundwater drawdown in the Mesa H and basement aquifers that may have some connectivity to the Robe River alluvial aquifer and the Jimmawurrada creek alluvial aquifer. The modelling indicates the potential for minor reduction in water levels in the Robe River alluvial aquifer and semi-permanent and permanent pools (<1 m), with recovery of the groundwater table over time once water abstraction ceases. Groundwater abstraction for water supply from the existing Southern Cutback Borefield may potentially increase groundwater drawdown in Jimmawurrada Creek and also extend the timeframe for the predicted groundwater recovery once water abstraction ceases. This may result in localised vegetation changes; however no semi-permanent or permanent pools are known to occur in the Jimmawurrada area and the riverine ecosystem function is expected to be maintained. Numerous pools exist along the Robe River outside the potential impact area near Mesa H as presented in Attachment 14. Any temporary changes to groundwater water levels in Jimmawurrada Creek and the permanent and semi-permanent pools of the Robe River near Mesa H are, therefore, unlikely to significantly impact Northern Quoll foraging habitat.

Table 9: Species profile for the Ghost Bat (*Macroderma gigas*) (Vulnerable)

Description and context with respect to the Proposed Action
The Ghost Bat is believed to be a geographically relictual species in southern, arid landscape, present only because caves provide suitable roost microclimates (Threatened Species Scientific Committee 2016). Since European settlement, the distribution of the Ghost Bat has contracted northwards. The current range of the Ghost Bat is discontinuous, with geographically disjunct colonies occurring in the Pilbara, Kimberley, Northern Territory, the Gulf of Carpentaria, coastal and near coastal eastern Queensland and western Queensland (Threatened Species Scientific Committee 2016). Population genetic studies indicate that females appear to remain in or return to the individual's birthplace. The genetic isolation of sub-populations suggests areas are unlikely to be recolonised if local extinction occurs (Threatened Species Scientific Committee 2016). Ghost Bats move between a number of caves seasonally. Roost sites include caves, rock crevices and disused mine adits. Ghost Bats use three types of roost regularly: • Nocturnal roosts (or feeding sites) are used only at night, either habitually or for transitory visits. They are typically shallow, poorly insulated caves and shelters that are well lit during the day (Bat Call WA 2017a). Ghost Bats hunt at night and use nocturnal caves to consume prey they have captured in the surrounding area. • Diurnal roosts (or day roosts) are caves and mine adits that are deeper and more complex than nocturnal roosts. They typically have one or more large chambers at or beyond the twilight area with additional fissures or chambers at the rear in the fully dark regions. They have a minimum roof height in the chambers of 2 to 3 m providing protection from attack by terrestrial predators. They are often at mid-levels or lower in the strata making them well insulated. The stable temperature and elevated humidity of these caves relative to the ambient conditions create physiologically benign conditions (McKenzie and Bullen 2009). • Maternity roosts are diurnal roosts that usually include an interior chamber that rises toward the rear, trapping warmer, more humid air at the top. To persist in an area, Ghost Bats require a group of caves/shelters that provide diurnal and nocturnal sites and a gully or gorge system that opens onto a plain or riparian line that provides good foraging opportunities. The persistence of the species in the Pilbara is believed to depend on the availability of diurnal roosts that have stable temperature and humidity (Threatened Species Scientific Committee 2016). The current population size in the Pilbara is estimated to be between 1500 and 2000 individuals, with colonies in the Hamersley sub-region containing between five and 25 individuals (Bat Call WA 2017a). The key threat to the Ghost Bat is believed to be destruction of, or disturbance to, roost sites and nearby areas (Woinarski et al. 2014). In the Pilbara, most known breeding sites are confined to underground gold/copper mines that are now collapsing or being converted into open cut mines and to caves in banded ironstone that may be mined in the future (Threatened Species Scientific Committee 2016). Other threats to the Ghost Bat include mortality resulting from the consumption of cane toads, modification to foraging habitat, disturbance at breeding sites through human visitation and collision with barbed-wire fences. There is evidence to demonstrate that Ghost Bats will continue to use a roost despite nearby mining activities. This is reflected in Process Minerals International Poondano Iron Ore Project near Port Hedland, which originally recorded the presence of Ghost Bats in Cave 26 on Mesa 3 in 2009. A buffer zone in excess of 50 m from Cave 26 was put in place to protect the fauna habitat and mining progressed such that by September 2012, mining of Mesa 3 was well underway (Process Minerals International 2013). Ghost Bats were subsequently recorded in Cave 26 in 2012, 2013, 2014 and 2015, demonstrating a continued presence of a substantial colony of Ghost Bats in Cave 26 following during mining. Visual observations of the Ghost Bat and the presence of Ghost Bat cave middens have been recorded on the various mesas within and adjacent to the Development Envelope (Bat Call WA 2017a). A recent desktop assessment and contextual field survey (Bat Call 2017b) indicated that the Ghost Bat is common and widespread in the Robe Valley. Caves are present on the escarpments of mesas, including Mesa H and throughout the Robe Valley. Detailed characterisation of the caves at Mesa H was undertaken by Bat Call WA (2017a) (refer Attachment 11). Eleven sites in the Development Envelope were assessed as being suitable for roosting by Ghost Bats including two diurnal roost caves and nine nocturnal roost shelters. The two diurnal caves were assessed as being maternity cave candidates, although no evidence of intensive Ghost Bat use for this purpose was found during the surveys (Bat Call WA 2017a). The assessment confirmed no *permanent* Ghost Bat presence at Mesa H. Roost locations at Mesas H and contextual Ghost Bat habitat mapping are shown in Attachment 13. No Ghost Bat roosts have been found within the indicative clearing footprint of the Proposed Action. High quality habitat for Ghost Bat was defined by locations where diurnal roosts or potential maternal roosts were identified or likely to be identified. High quality habitat was assessed as being restricted to the gorge habitat in the Robe Valley, which encompasses 0.2% of the Mesa H Development Envelope (Astron 2017). The Proposed Action includes retention of

Description and context with respect to the Proposed Action
the mesa escarpments and these associated gorges, where this high quality habitat occurs. Mine pits and waste dumps / infrastructure have been designed to avoid the highest value habitat for the Ghost Bat. The Proposed Action includes retention of the mesa escarpments (except where cuts through lower value habitat are required to allow vehicle access) to retain nocturnal and potential diurnal/maternal roost caves. The depths of the diurnal/potential maternal caves at Mesas H are up to 30m. The conceptual mine designs incorporate a 40 m mining exclusion zone between the back of each diurnal/potential maternal roost cave and the proposed mine pit to protect the integrity of the diurnal/potential maternal roosts. The Proposed Action also includes retention of the nocturnal roost caves. Nocturnal roost caves that form part of roost complexes (i.e. nocturnal roost caves that are in the same gullies as the diurnal/ potential maternal roosts) are considered to be an important factor in the persistence of Ghost Bats in an area, and range from 5 – 19 m in depth at Mesa H (Bat Call WA 2017). For each nocturnal cave that is part of a roost complex, the mine designs will incorporate a mining exclusion zone of 40 m from the cave entry to the proposed mine pit. The Proponent operates within a blast management framework underpinned by the best practice approaches identified in AS 2187.2 (the prescribed standard for use of explosives in Western Australia) to protect environmental and cultural heritage values. The Proponent has an established record of successfully managing drill and blast operations to minimise harm to sensitive sites (including bat roosts). Current and previous blasting programmes for sensitive sites across Pilbara mines provide a baseline for future work. Drill and blast management plans for specific areas will be risk-based and may prescribe one or more of the following additional controls: • a blast vibration monitoring and control programme; • reduced drill hole size, reduced charge weights and modified blast timing to minimise ground vibrations and 'air-blast' disturbance; and • use of leading-edge technology such as 'seed hole' analysis and modelling supported by electronic initiation systems to control vibrations. The Ghost Bat forages across the Development Envelope as well as more widely in the Robe Valley, particularly along the Riverine Habitat. The Proposed Action will involve clearing of up to 2,200 ha with the majority of this occurring on the surface of the mesas and on the plain adjacent to Mesa H. However, the mesa escarpments and associated major gullies will be retained and no significant clearing will be undertaken along the Robe River under the Proposed Action. The potential increase in water availability in the Robe River due to surplus water discharge may locally increase available foraging habitat for the duration of the discharge. Groundwater abstraction for water supply and pit dewatering will result in localised groundwater drawdown in the Mesa H and basement aquifers that may have some connectivity to the Robe River alluvial aquifer and the Jimmawurrada creek alluvial aquifer. The modelling indicates the potential for minor reduction in water levels in the Robe River alluvial aquifer and semi-permanent and permanent pools (<1 m), with recovery of the groundwater table over time once water abstraction ceases. Groundwater abstraction for water supply from the existing Southern Cutback Borefield may potentially increase groundwater drawdown in Jimmawurrada Creek and also extend the timeframe for the predicted groundwater recovery once water abstraction ceases. This may result in localised changes to structure and composition of riparian vegetation in the Jimmawurrada area; however no semi-permanent or permanent pools are known to occur in the Jimmawurrada locality and the riverine ecosystem function is expected to be maintained. Numerous pools exist along the Robe River outside the potential impact area near Mesa H as presented in Attachment 14. Any temporary changes to groundwater water levels in Jimmawurrada Creek and the permanent and semi-permanent pools of the Robe River near Mesa H are considered unlikely to significantly impacts on Ghost Bat foraging habitat. The Proponent requires personnel to comply with strict guidelines regarding cave entry for safety reasons as well as protection of heritage and environmental values. The Proponent will continue to apply these guidelines. Disturbance to Ghost Bats resulting from human visitation to caves is, therefore, unlikely to result in any significant changes to the Ghost Bat populations in the Robe Valley. Barbed-wire fences will only be installed under the Proposed Action where there is a statutory requirement to do so (e.g. *Electricity (Licensing) Regulations 1991* (WA)). Where barbed-wire is necessary, reflectors will be installed to deter the bats. The Proponent has several decades of experience mining adjacent to environmentally sensitive areas, including at the West Angelas mine site, where the use of barbed wire is strictly limited (only when there is a statutory requirement) specifically to protect Ghost Bats. Dust controls will be in place in the Development Envelope as part of standard management practices. Dust and light are unlikely to have a significant impact on the Ghost Bat as the aspect of the diurnal/potential maternal caves is such that they face away from the mining areas, into protected gullies, and thus are protected from direct dust ingress into the caves.

Table 10: Species profile for the Pilbara Leaf-nosed Bat (*Rhinonicteris aurantia*) (Pilbara form) (Vulnerable)

Description and context with respect to the Proposed Action
The Pilbara Leaf-nosed Bat is restricted to caves and mine adits (horizontal shafts) with stable, warm and humid microclimates because of its poor ability to thermoregulate and retain water (Armstrong 2001). Roosts are usually over pools of water in deeper mines, or deep within the mine or cave structure in an area that maintains elevated temperature and humidity. Simple vertical shafts are not used and shallow caves beneath mesa bluffs are also unlikely roost sites (Armstrong 2001). Colonies of the Pilbara Leaf-nosed Bat are found in three distinct areas: in the mines of the eastern Pilbara; scattered throughout the Hamersley Range in smaller colonies; and in sandstone formations south of the Hamersley Range in a small number of significant colonies (Armstrong 2001). Habitat favoured by the Pilbara Leaf-nosed Bat for foraging is diverse, ranging from *Triodia* hummock grasslands to eucalypt woodlands along watercourses (Armstrong 2001). Typically, they exhibit a preference for foraging in the open spaces in watercourses and gorges, and over *Triodia* grassland, with a usual foraging range up to 20 km from the primary roost cave (Bullen 2013). It also appears that the Pilbara Leaf-nosed Bat spreads from primary roosts to satellite roosts when wet season conditions allow and consolidates back to permanent sites during dry periods (Bat Call WA 2016). Threats to the persistence of the Pilbara Leaf-nosed Bat are mainly related to the susceptibility of the species to dehydration and hypothermia which limits the availability of suitable roosts in the Pilbara. Many roost sites comprise old mine workings, which can degrade over time with collapses and flooding rendering them unusable. Disturbance factors associated with human activities include mine development and rehabilitation of old mine sites where roost sites are disturbed. The species is also vulnerable to collisions with vehicles as it tends to fly relatively low and displays a curiosity for light sources; a busy road located close to a roost or foraging site could contribute to a local population decline (Department of the Environment and Energy 2016b). Astron (2016a) completed 27 systematic and targeted bat recording nights in the Development Envelope. In addition, Rio Tinto completed 61 targeted bat recording nights in the vicinity of the Development Envelope. Echolocation records of the Pilbara Leaf-nosed Bat in the Development Envelope indicate that this species forages generally across the Development Envelope with the Robe River providing the main foraging habitat. The echolocation records also indicate that the Pilbara Leaf-nosed Bats foraging in the area originate from a roost located approximately 10 km to the south of Mesa H, outside the Development Envelope (Bat Call 2017a). Detailed characterisation of the caves on Mesas H (Rio Tinto 2016, Bat Call WA 2017a) showed no evidence of Pilbara Leaf-nosed Bat presence in any cave or shelter on these mesas. The Pilbara Leaf-nosed Bat forages across the Development Envelope as well as more widely in the Robe Valley, particularly along the Riverine Habitat. The Proposed Action will involve clearing of up to 2,200 ha and the majority of this clearing will be on the surface of the mesas and on the plain adjacent to Mesa H. The mesa escarpments and associated major gullies will be retained (except where cuts through lower value habitat are required to allow vehicle access) and no significant clearing will be undertaken along the Robe River and Jimmawurrada Creek under the Proposed Action. The potential increase in water availability in the Robe River may locally increase available foraging habitat for the duration of the discharge. Groundwater abstraction for water supply and pit dewatering will result in localised groundwater drawdown in the Mesa H and basement aquifers that may have some connectivity to the Robe River alluvial aquifer and the Jimmawurrada creek alluvial aquifer. The modelling indicates the potential for minor reductions in water levels in the Robe River alluvial aquifer and semi-permanent and permanent pools (<1 m), with recovery of the groundwater table over time once water abstraction ceases. Groundwater abstraction for water supply from the Southern Cutback Borefield may potentially extend drawdown in Jimmawurrada Creek and extend the timeframe for the predicted groundwater recovery once water abstraction ceases. This may result in localised changes to structure and composition of riparian vegetation; however no semi-permanent or permanent pools are known to occur in this area and the riverine ecosystem function is expected to be maintained. Attachment 14 shows numerous pools that are present along the Robe River within the 20 km foraging range of the Pilbara Leaf-nosed Bat. The Proposed Action is, therefore, unlikely to significantly impact Pilbara Leaf-nosed Bat foraging habitat. Dust controls will be in place in the Development Envelope so dust is unlikely to have a significant impact on any roosts located to the south-east of the Development Envelope. It is also considered that, given that the closest permanent roost is estimated to be located approximately 10 km away, that light, noise and vibration from the Proposed Action are unlikely to have an impact on the roost.

Table 11: Species profile for the Pilbara Olive Python (*Liasis olivaceus barroni*) (Vulnerable)

Description and context with respect to the Proposed Action
The Pilbara Olive Python has a known distribution that coincides roughly with the Pilbara bioregion, where it is widespread. The species is considered stable and is present in sizable numbers at some sites (Pearson 2003). A large portion of the Pilbara Olive Python habitat is conserved in Karijini National Park (Pearson 1993). The Pilbara Olive Python prefers escarpments, gorges and water holes in the ranges of the Pilbara region (Pearson 1993; Wilson and Swan 2003). Radio-telemetry has shown that individuals are usually in close proximity to water and rock outcrops that attract suitable sized prey species (Pearson 2003). The range of the male Pilbara Olive Python is approximately 4 km (Department of the Environment and Energy 2016c). Factors recognised as threats to the Pilbara Olive Python include major fire events, predation by foxes, declines in prey species and habitat destruction associated with mining developments (Department of the Environment and Energy 2016c). Major gullies at Mesa H contain breeding habitat for the Pilbara Olive Python and the Robe River and Jimmawurrada Creek provides foraging habitat and a potential dispersal route (Astron 2016a). One Pilbara Olive Python was recorded in the Riverine Habitat of the Robe River during the 2015 surveys and numerous records of the species exist within 50 km of the Development Envelope in similar riverine habitats (Astron 2016a). The Proposed Action includes retention of the mesa escarpments (except where cuts through lower value habitat are required to allow vehicle access). The proposed cuts through the escarpments will impact only a small proportion (<5%) of the escarpment on each mesa and have been designed to avoid the highest value habitat for the Pilbara Olive Python. Retention of the escarpments will ensure that Pilbara Olive Python habitat continues to be available. The potential increase in water availability in the Robe River due to surplus water discharge may locally increase available foraging habitat for the duration of the discharge. Groundwater abstraction for water supply and pit dewatering will result in localised groundwater drawdown in the Mesa H and basement aquifers that may have some connectivity to the Robe River alluvial aquifer and the Jimmawurrada Creek alluvial aquifer. The modelling indicates the potential for limited reduction in water levels in the Robe River alluvial aquifer and semi-permanent and permanent pools (<1 m), with recovery of the groundwater table over time once water abstraction ceases. Groundwater abstraction for water supply from the Southern Cutback Borefield may potentially further extend drawdown in the Jimmawurrada Creek and will extend the timeframe for the predicted groundwater recovery once water abstraction ceases. This may result in localised changes to structure and composition of riparian vegetation; however no semi-permanent or permanent pools are known to occur in the Jimmawurrada area and the riverine ecosystem function is expected to be maintained. The area of potential disturbance in the vicinity of Mesa H due to dewatering is a small proportion of the Pilbara Olive Python foraging habitat available along the Robe River and Jimmawurrada Creek. There are a number of pools present in the Robe River the vicinity of Mesa H that are within the individual range of the Pilbara Olive Python (refer Attachment 14), so individuals may relocate to nearby suitable habitat if necessary.

Table 12: Species profile for the Blind Cave Eel (Ophisternon candidum) (Vulnerable)

Description and context with respect to the Proposed Action
The Blind Cave Eel (*Ophisternon candidum*) is a depigmented, subterranean fish growing up to 40 cm in length and is the world's longest cavefish with a long slender body, no eyes, and a thin rayless membrane around the tip of the tail (DSEWPaC 2008). The Blind Cave Eel is one of only three vertebrate animals known from Australia that are restricted to subterranean waters (Humphreys 2001). The Blind cave eel inhabits groundwater systems in subterranean caves, transmissive geological formations, fissures and wells (Humphreys 2001). It is known to utilise cave floor sediments at Cape Range, Karstic Aquifers on Barrow Island, and alluvial aquifers in association with Channel Iron Deposits (Biota 2013). They are also known to occur in a range of water qualities at Cape Range, ranging from fresh to brackish (0-16 ppt) and generally neutral pH (6.8-7.6) (Biota 2013). Two records of the Blind Cave Eel have been recorded in the Pilbara region, both from the Jimmawurrada Creek aquifer in the Bungaroo area, approximately 1.1 km and 5 km from the Development Envelope. Given these specimens were obtained from the major aquifer system of this area, this implies the presence of a population in this system (Biota 2013). Genetic analysis has also demonstrated that the species present at Bungaroo is the same as that on Cape Range, suggesting that it is likely that the species occurs further downstream, and is probably also associated with the regional aquifer of the Robe River (to which Jimmawurrada Creek is a tributary). This is supported by distribution patterns in other stygofauna species, with some taxa known from Cape Range and Barrow Island also present in the headwaters of the Robe River (Biota 2013). Factors presenting threats to the Blind Cave Eel include sedimentation from mining; water abstraction; and point source pollution (Humphreys 2001). The Robe River and Jimmawurrada Creek alluvial aquifers provide subterranean habitat and provide a potential dispersal route. The Proposed Action includes retention of the Robe River and Jimmawurrada Creek subterranean habitat by avoiding excavation of the primary alluvial habitat. Retention of the alluvial substrate and flow paths of the river systems will ensure that the Blind Cave Eel habitat connectivity is maintained. The potential increase in water availability in the Robe River due to surplus water discharge may locally increase available dispersal habitat for the duration of the discharge. Groundwater abstraction for water supply and pit dewatering will result in localised groundwater drawdown in the Mesa H and basement aquifers that may have some connectivity to the Robe River alluvial aquifer and the Jimmawurrada Creek alluvial aquifer. The modelling indicates the potential for limited reduction in water levels in the Robe River alluvial aquifer and semi-permanent and permanent pools (<1 m), with recovery of the groundwater table over time once water abstraction ceases. Groundwater abstraction for water supply from the Southern Cutback Borefield may potentially extend drawdown in Jimmawurrada Creek and extend the timeframe for the predicted groundwater recovery once water abstraction ceases. This will result in localised changes to groundwater levels across a ~9 km stretch of Jimmawurrada Creek, which encompasses the area of one of the Blind Cave Eeel records (1.1 km from the Development Envelope), however the alluvials will continue to be seasonally recharged following large rainfall events and the area of potential disturbance in the vicinity of Mesa H due to dewatering is a limited proportion (<7%) of the potential Blind Cave Eel habitat available along the Robe River and Jimmawurrada Creek.

Table 13: Assessment against the significant impact criteria for the Northern Quoll

Significant impact criteria	Comment
Is there a real chance or possibility the action will lead to a long-term decrease in the size of a population	**No.** Management strategies for avoiding and reducing impacts to the Northern Quoll will be implemented as outlined in Section 5.1. The escarpments of the mesas in the Robe Valley, particularly those areas with deep gullies that are associated with drainage lines and water courses, are considered to represent core habitat for the Northern Quoll. The mesa escarpments will be retained and the continued presence of the Northern Quoll has been observed in both historical and currently active mining areas where mesa escarpments have been retained (e.g. Mesa A, Middle Robe and East Deepdale). There are also numerous other mesas in the Robe Valley (refer Attachment 9) that provide core habitat for the Northern Quoll. The Proposed Action is unlikely to have a significant impact on Northern Quoll foraging habitat as proposed clearing will impact only a small proportion of available foraging habitat.
Is there a real chance or possibility the action will reduce the area of occupancy of the species	**No**. The escarpments of the mesas in the Robe Valley, particularly those areas with deep gullies that are associated with drainage lines and water courses, are considered to represent core habitat for the Northern Quoll. The mesa escarpments will be retained (except where cuts through lower value habitat are required to allow vehicle access).
Is there a real chance or possibility the action will fragment an existing population into two or more populations	**No.** Core habitat connectivity will be maintained by retention of the escarpments, particularly along the Robe River. The Proposed Action minimise impacts by utilising existing Mesa J linear infrastructure (e.g. road, rail) which will not prevent passage of individuals.
Is there a real chance or possibility the action will adversely affect habitat critical to the survival of a species	**No.** The escarpments of the mesas in the Robe Valley, particularly those areas with deep gullies that are associated with drainage lines and water courses, are considered to represent core habitat for the Northern Quoll. The mesa escarpments will be retained. There are also numerous other mesas in the Robe Valley (refer Attachment 9) that provide core habitat for the Northern Quoll.
Is there a real chance or possibility the action will disrupt the breeding cycle of a population	**No.** Denning habitat is contained within the escarpments of the mesas in the Robe Valley, particularly those areas with deep gullies that are associated with drainage lines and water courses. The mesa escarpments will be retained (except where cuts through lower value habitat are required to allow vehicle access). There are also numerous other mesas in the Robe Valley (refer Attachment 9) that provide core habitat for the Northern Quoll.
Is there a real chance or possibility the action will modify, destroy, remove, isolate or decrease the availability or quality of habitat to the extent that the species is likely to decline	**No.** The escarpments of the mesas in the Robe Valley, particularly those areas with deep gullies that are associated with drainage lines and water courses, are considered to represent core habitat for the Northern Quoll. The mesa escarpments will be retained (except where cuts through lower value habitat are required to allow vehicle access). There are also numerous other mesas in the Robe Valley (refer Attachment 9) that provide core habitat for the Northern Quoll. Temporary minor reduction in water levels in a number of adjacent semi-permanent and permanent pools may seasonally affect individuals but would not result in species decline due to the continued presence of the pools and presence of other nearby pools on the Robe River.

Significant impact criteria	Comment
Is there a real chance or possibility the action will result in invasive species that are harmful to a critically endangered or endangered species becoming established in the endangered or critically endangered species' habitat	**No.** The cane toad is considered to be the main invasive species that poses a threat to the Northern Quoll. The cane toad is not currently established in the Pilbara. Discharge to the Robe River may result in additional water being present which may locally increase suitable habitat for cane toads for the duration of the discharge, should the cane toad spread to the Pilbara. However, permanent water is already available in the locality (permanent pools on the Robe River). The Proposed Actions will not, therefore, alter the possibility of cane toads becoming established in the area. The feral cat is also considered to pose a threat to the Northern Quoll. There is little opportunity for the Proposed Action to result in increases to the feral cat population. Feral cat control will continue to be undertaken by the Proponent in the areas where the Proponent operates.
Is there a real chance or possibility the action will introduce disease that may cause the species to decline	**No.**
Is there a real chance or possibility the action will interfere with the recovery of the species	**No.** Offset actions are being undertaken as part of the approved Yandicoogina Threatened Species Offset Plan (TSOP) on parts of Yarraloola Pastoral Station. Yarraloola Pastoral Station underlies and surrounds the Development Envelope. The TSOP specifically recognises that mineral resources in the offset area will be developed and accounts for this through selection of a land management area that is much larger than the area of habitat to be impacted by the Yandicoogina Project. The Proposed Action will, therefore, not interfere with the offset actions of the TSOP. The EPBC Act referral guideline for the Northern Quoll (Department of the Environment 2016) includes in the definition of 'populations important for the long-term survival of the Northern Quoll' populations which are, 'being monitored by government agencies or universities or subject to reintroductions or translocations.' The TSOP is implementing landscape-scale land management to improve habitat for Matters of National Environmental Significance through de-stocking and cat baiting. The Yarraloola area was selected as an area that would benefit from improved land management and as an area where it is logistically feasible to undertake land management; the selection was not based on an assessment of the importance of the Northern Quoll population. Although the TSOP was developed in partnership with the WA Department of Biodiversity, Conservation and Attractions - Parks and Wildlife Service and includes some monitoring of Northern Quoll, it does not specifically include monitoring of the Northern Quoll population by government agencies or universities, nor is the population subject to reintroductions or translocations. The monitoring at Yarraloola is focused on monitoring of land condition with monitoring of Northern Quolls used as a tool to validate the land condition gains achieved through implementation of the land management actions. It is, therefore, considered that the Northern Quoll population in the Development Envelope does not meet the definition of a population important for the long-term survival of the Northern Quoll.

Table 14: Assessment against the significant impact criteria for the Ghost Bat

Significant impact criteria	Comment
Is there a real chance or possibility the action will lead to a long-term decrease in the size of an important population of the species	**No**. Management strategies for avoiding and reducing impacts to the Ghost Bat will be implemented as outlined in Section 5.2. The Robe Valley Ghost Bat population occurs towards the western extent of the Ghost Bat's range so may be considered an 'important population' as defined by the Department of the Environment (2013). The key threat to the Ghost Bat is believed to be destruction of, or disturbance to, roost sites and nearby areas (Woinarski *et al*. 2014). As the Proposed Action will retain the two diurnal roosts (which contain potential features for maternal roosts), it is considered unlikely to lead to a long-term decrease in the size of the Ghost Bat population in the Robe Valley. There are also four confirmed maternal Ghost Bat roosts and > 10 confirmed diurnal Ghost Bat roosts elsewhere in the Robe Valley. Given that potential changes to foraging habitat associated with the Robe River will be temporary and represent only a small proportion of Ghost Bat foraging habitat available in the Robe Valley, the Proposed Action is unlikely to result in a long-term decrease in the size of the Ghost Bat population in the Robe Valley.
Is there a real chance or possibility the action will reduce the area of occupancy of an important population	**No.** There may be a minor, temporary reduction in the area of occupancy if Ghost Bats vacate the retained roosts due to noise and vibration while mining operations are underway. There are, however, other roosts and roost complexes available throughout the Robe Valley (including a large maternal roost approximately 20 km west). The retention of diurnal (and potential maternal) roosts, availability of alternative roosts and the evidence of continued Ghost Bat presence in the roost at the Poondano mine site and in historical mining areas of Robe Valley (including the Deepdale area) indicate that it is unlikely that the Proposed Action will permanently reduce the area of occupancy of the Robe Valley population.
Is there a real chance or possibility the action will fragment an existing important population into two or more populations	**No.** The Proposed Action will not alter the movement of individuals so will not cause any fragmentation of the Ghost Bat population in the vicinity of the Development Envelope.
Is there a real chance or possibility the action will adversely affect habitat critical to the survival of the species	**No.** The Proposed Action includes retention of all nocturnal roosts and all potential diurnal/maternal roosts with appropriate mining exclusion zones to protect the integrity of the roosts.
Is there a real chance or possibility the action will disrupt the breeding cycle of an important population	**No.** There may be a temporary disruption to the breeding cycle of individuals in the Development Envelope if Ghost Bats vacate the retained diurnal (potential maternal) roosts due to noise and vibration while mining operations are underway. There are, however, other roosts available throughout the Robe Valley (including a large maternal roost approximately 20 km west). The retention of diurnal/maternal roosts, availability of alternative roosts and the evidence of continued Ghost Bat presence in the roost at the Poondano mine site and in historical mining areas of Robe Valley (including the Deepdale area) indicate that it is unlikely that the Proposed Action will disrupt the breeding cycle of the Ghost Bat population in the Robe Valley.

Significant impact criteria	Comment
Is there a real chance or possibility the action will modify, destroy, remove, isolate or decrease the availability or quality of habitat to the extent that the species is likely to decline	**No.** The Proposed Action includes retention of all nocturnal roosts and all potential diurnal/maternal roosts with appropriate mining exclusion zones to protect the integrity of the roosts. Given that potential changes to foraging habitat associated with the Robe River will be temporary and represent only a small proportion of Ghost Bat foraging habitat available in the Robe Valley, the Proposed Action is unlikely to result in a long-term decrease in the size of the Ghost Bat population in the Robe Valley.
Is there a real chance or possibility the action will result in invasive species that are harmful to the vulnerable species becoming established in the vulnerable species' habitat	**No.** The cane toad is considered to be an invasive species that poses a threat to Ghost Bats as Ghost Bats may prey on cane toads. The cane toad is not currently established in the Pilbara. Discharge to the Robe River may result in permanent water being present which may locally increase suitable habitat for cane toads for the duration of the discharge, should the cane toad spread to the Pilbara. However, permanent water is already available in the locality (permanent pools on the Robe River). The Proposed Action will not, therefore, alter the possibility of cane toads becoming established in the area.
Is there a real chance or possibility the action will introduce disease that may cause the species to decline	**No.**
Is there a real chance or possibility the action will interfere substantially with the recovery of the species	**No.**

Table 15: Assessment against the significant impact criteria for the Pilbara Leaf-nosed Bat

Significant impact criteria	Comment
Is there a real chance or possibility the action will lead to a long-term decrease in the size of an important population of the species	**No.** Management strategies for avoiding and reducing impacts to the Pilbara Leaf-nosed Bat will be implemented as outlined in Section 5.3. Survey data indicate that a permanent Pilbara Leaf-nosed Bat roost is not present in the Development Envelope. Given that potential changes to foraging habitat will be temporary and represent only a small proportion of foraging habitat available in the Robe Valley within the range of the Pilbara Leaf-nosed Bat, the Proposed Action is unlikely to result in a long-term decrease in the size of the Pilbara Leaf-nosed Bat population in the Robe Valley.
Is there a real chance or possibility the action will reduce the area of occupancy of an important population	**No.** Survey data indicate that a permanent Pilbara Leaf-nosed Bat roost is not present in the Development Envelope.
Is there a real chance or possibility the action will fragment an existing important population into two or more populations	**No**. The Proposed Action will not alter the movement of individuals so will not cause any fragmentation of the Pilbara Leaf-nosed Bat population in the vicinity of the Development Envelope.
Is there a real chance or possibility the action will adversely affect habitat critical to the survival of the species	**No.** Survey data indicate that a permanent Pilbara Leaf-nosed Bat roost is not present in the Development Envelope. Given that potential changes to foraging habitat represent only a small proportion of foraging habitat available in the Robe Valley within the range of the Pilbara Leaf-nosed Bat, the Proposed Action is unlikely to adversely affect habitat critical to the survival of the species.
Is there a real chance or possibility the action will disrupt the breeding cycle of an important population	**No.** Survey data indicate that a permanent Pilbara Leaf-nosed Bat roost is not present in the Development Envelope (Astron 2016a, Bat Call 2017a). Given that the closest permanent roost is estimated to be approximately 10 km from the Proposed Action and that dust controls will be in place, the effects of dust, light, noise and vibration are unlikely to have a significant impact on the roost or the breeding cycle of Pilbara Leaf-nosed Bats in the roost.
Is there a real chance or possibility the action will modify, destroy, remove, isolate or decrease the availability or quality of habitat to the extent that the species is likely to decline	**No** Survey data indicate that a permanent Pilbara Leaf-nosed Bat roost is not present in the Development Envelope.
Is there a real chance or possibility the action will result in invasive species that are harmful to the vulnerable species becoming established in the vulnerable species' habitat	**No.**

Significant impact criteria	Comment
Is there a real chance or possibility the action will introduce disease that may cause the species to decline	**No.**
Is there a real chance or possibility the action will interfere substantially with the recovery of the species	**No.**

Table 16: Assessment against the significant impact criteria for the Pilbara Olive Python

Significant impact criteria	Comment
Is there a real chance or possibility the action will lead to a long-term decrease in the size of an important population of the species	**No.** Management strategies for avoiding and reducing impacts to the Pilbara Olive Python will be implemented as outlined in Section 5.4. The Robe Valley Pilbara Olive Python population occurs towards the western extent of the python's range so may be considered an 'important population' as defined by the Department of the Environment (2013). Major gullies contain breeding habitat for the Pilbara Olive Python. The Proposed Action will retain the escarpments and associated gullies (except where cuts through lower value habitat are required to allow vehicle access). The Robe River provides foraging habitat and a potential dispersal route for the Pilbara Olive Python (Astron 2016a). The Proposed Action may disturb foraging habitat due to abstraction of groundwater which is modelled to result in localised groundwater drawdown in the Mesa H and basement aquifers that may have some connectivity to the Robe River alluvial aquifer and the Jimmawurrada creek alluvial aquifer. However modelling indicates that the potential drawdown impacts to the semi-permanent and permanent pools of the Robe River is expected to be <1 m, with recovery of the groundwater table over time once water abstraction ceases. Groundwater abstraction for water supply from the Southern Cutback Borefield may potentially further extend drawdown in the Jimmawurrada Creek and will extend the timeframe for the predicted groundwater recovery once water abstraction ceases, however no semi-permanent or permanent pools are known to occur in this area – refer to Attachment 14. The potential disturbance to foraging habitat would, however, be temporary and would represent only a small proportion of the foraging habitat available in the Robe Valley. Given retention of the escarpments and the wider availability of foraging habitat in the Robe Valley it is unlikely that the Proposed Action will lead to a long-term decrease in the size of the Robe Valley Pilbara Olive Python population.
Is there a real chance or possibility the action will reduce the area of occupancy of an important population	**No.** The Proposed Action will retain the escarpments and associated gullies (except where cuts through lower value habitat are required to allow vehicle access). Given that potential disturbance to foraging habitat will be temporary and represents only a small proportion of foraging habitat available in the Robe Valley, it is unlikely that the Proposed Action will reduce the area of occupancy of the Robe Valley Pilbara Olive Python population.
Is there a real chance or possibility the action will fragment an existing important population into two or more populations	**No.** Proposed infrastructure will not prevent passage of individuals.

Significant impact criteria	Comment
Is there a real chance or possibility the action will adversely affect habitat critical to the survival of the species	**No.** The Proposed Action will retain the escarpments and associated gullies (except where cuts through lower value habitat are required to allow vehicle access). Given that potential disturbance to foraging habitat will be temporary and represents only a small proportion of foraging habitat available in the broader Robe Valley, it is unlikely that the Proposed Action will adversely affect habitat critical to the survival of the species.
Is there a real chance or possibility the action will disrupt the breeding cycle of an important population	**No.** The Proposed Action will retain breeding habitat through retention of the escarpments and associated gullies (except where cuts through lower value habitat are required to allow vehicle access).
Is there a real chance or possibility the action will modify, destroy, remove, isolate or decrease the availability or quality of habitat to the extent that the species is likely to decline	**No.** The Proposed Action will retain breeding habitat through retention of the escarpments and associated gullies (except where cuts through lower value habitat are required to allow vehicle access). Any disturbance to foraging habitat would be temporary and would represent only a small proportion of the foraging habitat available in the broader Robe Valley.
Is there a real chance or possibility the action will result in invasive species that are harmful to the vulnerable species becoming established in the vulnerable species' habitat	**No.** The cane toad is considered to be an invasive species that poses a threat to Pilbara Olive Pythons as Pilbara Olive Pythons may prey on cane toads. The cane toad is not currently established in the Pilbara. Discharge to the Robe River may result in permanent water being present which may locally increase suitable habitat for cane toads for the duration of the discharge, should the cane toad spread to the Pilbara. However, permanent water is already available in the locality (permanent pools on the Robe River). The Proposed Actions will not, therefore, alter the possibility of cane toads becoming established in the area. The feral cat is also considered to pose a threat to juvenile Pilbara Olive Pythons. There is little opportunity for the Proposed Action to result in increases to the feral cat population. Feral cat control will continue to be undertaken by the Proponent in the areas where the Proponent operates.
Is there a real chance or possibility the action will introduce disease that may cause the species to decline	**No.**
Is there a real chance or possibility the action will interfere substantially with the recovery of the species	**No.** Offset actions are being undertaken as part of the TSOP on parts of Yarraloola Pastoral Station. Yarraloola Pastoral Station underlies and surrounds the Development Envelope. The TSOP recognises that mineral resources in the offset area will be developed and accounts for this through selection of a land management area that is much larger than the area of habitat impacted by the Yandicoogina Project. The Proposed Action will, therefore, not interfere with the offset actions under the TSOP.

Table 17: Assessment against the significant impact criteria for the Blind Cave Eel

Significant impact criteria	Comment
Is there a real chance or possibility the action will lead to a long-term decrease in the size of an important population of the species	**No.** Management strategies for avoiding and reducing impacts to the Blind Cave Eel will be implemented as outlined in Section 5.5. The alluvial aquifers overlying CID formation in Jimmawurrada Creek contains known habitat for the Blind Cave Eel. Jimmawurrada Creek forms an upstream tributary which intersects the Robe River to the east of the Proposed Action. These creek systems are interconnected and provide a potential dispersal route for the Blind Cave Eel. The Proposed Action will retain the alluvial aquifer habitat and flow paths of the creeks, however may result in a localised reduction in habitat due to the lowering of the groundwater table due to abstraction of groundwater for water supply and mine pit dewatering. The hydrogeological modelling indicates the potential for minor reduction in water levels in the Robe River alluvial aquifer and semi-permanent and permanent pools (<1 m), with recovery of the groundwater table over time once water abstraction ceases. Groundwater abstraction for water supply from the Southern Cutback Borefield may potentially extend groundwater drawdown in Jimmawurrada Creek over a 9 km section, which would encompass a known Blind Cave Eel record (located 1.1 km from the Development Envelope) and extend the timeframe for the predicted groundwater recovery once water abstraction ceases. However wet season flows are expected to continue to provide seasonal connectivity of the alluvial habitat through these creek systems. Any temporary changes to groundwater levels in the alluvial aquifer of Jimmawurrada Creek and the Robe River near Mesa H are, therefore, unlikely to significantly impact habitat for the Blind Cave Eel and would represent only a small proportion of the habitat available in the broader Robe Valley. Given that the creek flow lines and alluvial substrate will remain largely physically undisturbed, and the interconnected nature of Jimmawurrada creek and the Robe River, the availability of core habitat remains extensive in the broader Robe Valley. The potential impact from reduction in habitat due to groundwater drawdown is considered temporary. In any case, mitigation options for groundwater drawdown, such as supplementary water supply to the river ecosystems via controlled discharge would be considered for the Proposed Action should monitoring indicate a requirement to protect significant values. Therefore it is considered unlikely that the Proposed Action will lead to a long-term decrease in the size of the Blind Cave Eel population.
Is there a real chance or possibility the action will reduce the area of occupancy of an important population	**No.** The Proposed Action will retain core subterranean habitat through retention of the alluvial aquifers and connectivity of these aquifers. Given that potential disturbance to habitat via groundwater drawdown will be temporary and represents only a small proportion of habitat available in the broader Robe Valley it is unlikely that the Proposed Action will significantly reduce the area of occupancy of the Blind Cave Eel population.
Is there a real chance or possibility the action will fragment an existing important population into two or more populations	**No.** Proposed surface infrastructure will not prevent passage of individuals.
Is there a real chance or possibility the action will adversely affect habitat critical to the survival of the species	**No.** The Proposed Action will retain core subterranean habitat through retention of the alluvial aquifers and connectivity of these aquifers. Given that potential disturbance to habitat via groundwater drawdown will be temporary and represents only a small proportion of habitat available in the broader Robe Valley it is unlikely that the Proposed Action will adversely affect habitat critical to the survival of the species.

Significant impact criteria	Comment
Is there a real chance or possibility the action will disrupt the breeding cycle of an important population	**No.** The Proposed Action will retain breeding habitat through retention of the subterranean alluvial aquifer habitat.
Is there a real chance or possibility the action will modify, destroy, remove, isolate or decrease the availability or quality of habitat to the extent that the species is likely to decline	**No.** The Proposed Action will retain core subterranean habitat through retention of the alluvial aquifers and connectivity of these aquifers. Impacts to groundwater levels are modelled to be minor along the Robe River and localised to a 9km section of Jimmawurrada Creek. The habitat will continue to be seasonally connected following rainfall events. Any disturbance to habitat would be temporary and would represent only a small proportion of the habitat available in the broader Robe Valley.
Is there a real chance or possibility the action will result in invasive species that are harmful to the vulnerable species becoming established in the vulnerable species' habitat	**No.** The Proposed Action manages surface and groundwater from the same connected catchments and aquifers. As the Blind Cave Eel habitat is subterranean, and the environment subject to significant natural flooding events which would support broad catchment connectivity, it is unlikely that the Proposed Action could result in the introduction of invasive species.
Is there a real chance or possibility the action will introduce disease that may cause the species to decline	**No.**
Is there a real chance or possibility the action will interfere substantially with the recovery of the species	**No.**

3.1 (e) Listed migratory species

Description

An EPBC Act Protected Matters search (21 November 2016, Attachment 4) identified nine Listed Migratory Species as potentially occurring within the Development Envelope and surrounds. Four additional species that potentially occur in the Development Envelope (Astron 2016a) are listed in Table 18 with their likelihood of occurrence in the Development Envelope.

Table 18: Likelihood of occurrence of Listed Migratory Species in the Development Envelope

Species	Likelihood of occurrence
Rainbow Bee-eater *Merops ornatus*	**Confirmed** Recorded from all habitats in the Proposal Area including loamy/stony plains, riverine, drainage lines, low hills and slopes, and breakaways
Eastern Great Egret *Ardea modesta*	**Confirmed** Recorded from riverine habitat within the Development Envelope
Cattle Egret *Ardea ibis*	**Moderate** May occur along watercourses in the Development Envelope
Oriental Pratincole *Glareola maldivarum*	**Moderate** May occur along watercourses in the Development Envelope
Common Sandpiper *Actitis hypoleucos*	**Moderate** May occur along watercourses in the Development Envelope during periods of flood

Species	Likelihood of occurrence
Wood Sandpiper *Tringa glareola*	**Moderate** May occur along watercourses in the Development Envelope during periods of flood
Common Greenshank *Tringa nebularia*	**Moderate** May occur along watercourses in the Development Envelope during periods of flood
Fork-tailed Swift *Apus pacificus*	**Moderate** Has the potential to overfly the Development Envelope
Eastern Osprey *Pandion cristatus*	**Low** May occur along watercourses in the Development Envelope during periods of flood
Barn Swallow *Hirundo rustica*	**Low** No regional records and no preferred habitat in the Development Envelope.
Oriental Plover *Charadrius veredus*	**Low** No regional records within 50 km of the Development Envelope but the species may occur intermittently in plains habitat in the Development Envelope
Curlew Sandpiper *Calidris ferruginea*	**Low** No regional records within 50 km of the Proposal Area and no preferred habitat present in the Proposal Area
Eastern Curlew, Far Eastern Curlew *Numenius madagascariensis*	**Low** No regional records within 50 km of the Proposal Area and no preferred habitat present in the Proposal Area
Grey Wagtail *Motacilla cinerea*	**Low** No regional records within 50 km of the Development Envelope and no preferred habitat present in the Development Envelope
Yellow Wagtail *Motacilla flava*	**Low** No regional records within 50 km of the Development Envelope and no preferred habitat present in the Development Envelope

Nature and extent of likely impact

The Proposed Action is not expected to have any significant impacts on the species listed in Table 18 for the following reasons:

- The Loamy/Stony Plain and Riverine habitats potentially used by the migratory species extend well beyond the Development Envelope; only a small proportion of available habitat is located within the Development Envelope.
- All of the species have extensive distributions across Western Australia (i.e. are not spatially restricted).
- The presence of the species in the Development Envelope is expected to be transitory only.
- All of the species are mobile, with the capacity to avoid mining disturbances such as vegetation clearing activities.
- Despite extensive fauna surveys conducted in and near the Development Envelope over a 20 year period, significant populations of these species have not been recorded in the locality.

3.1 (f) Commonwealth marine area

Not applicable

3.1 (g) Commonwealth land

Not applicable

3.1 (h) The Great Barrier Reef Marine Park

Not applicable

3.1 (i) A water resource, in relation to coal seam gas development or large coal mining development

Not applicable

3.2 Nuclear actions, actions taken by the Commonwealth (or Commonwealth agency), actions taken in a Commonwealth marine area, actions taken on Commonwealth land, or actions taken in the Great Barrier Reef Marine Park

3.2 (a)	**Is the proposed action a nuclear action?**	✓	No
3.2 (b)	**Is the proposed action to be taken by the Commonwealth or a Commonwealth agency?**	✓	No
3.2 (c)	**Is the proposed action to be taken in a Commonwealth marine area?**	✓	No
3.2 (d)	**Is the proposed action to be taken on Commonwealth land?**	✓	No
3.2 (e)	**Is the proposed action to be taken in the Great Barrier Reef Marine Park?**	✓	No

3.3 Description of the project area and affected area for the proposed action

3.3 (a) Flora and fauna

Flora

The Development Envelope is located in the Pilbara bioregion as defined by the Interim Biogeographic Regionalisation for Australia (IBRA) (DSEWPaC 2013). The Development Envelope is located within the Hamersley sub-region (refer Attachment 9).

Numerous flora and vegetation surveys have been undertaken across the Development Envelope and surrounds since the early 1990's.

There were 310 vascular flora species from 53 families and 150 genera recorded in the Development Envelope. The most represented families were Fabaceae, Poaceae and Malvaceae. No Threatened flora were recorded during the survey or are expected to occur. Three State-listed Priority flora were identified:

- *Indigofera* sp. Bungaroo Creek (S. van Leeuwen 4301) P3,
- *Triodia* sp. Robe River (M.E. Trudgen et al. MET 12367) P3; and
- *Rhynchosia bungarensis* P4.

These Priority flora are also represented in the surrounding landforms and vegetation, outside the Development Envelope. *Rhynchosia bungarensis* has been recorded from National Parks and/or Nature Reserves in protected habitat. *Triodia* sp. Robe River (M.E. Trudgen *et al*. MET 12367) has been recorded by Rio Tinto over a range of approximately 125 km extending south-east and 25 km north-west from Mesa H (Rio Tinto 2016) and floristic composition was found to be typical of the Hamersley and Roebourne sub-regions.

During the more recent two phase seasonal survey effort (2015-2016 (Astron 2016b)) across the Development Envelope, 38 vegetation associations were described, none of which represent a Threatened Ecological Community (TEC). All but three vegetation associations recorded are well represented beyond the Development Envelope and do not support assemblages of species that are unique, on restricted landforms, or of high conservation significance:

- Priority 3 Priority Ecological Community (PEC) '*Triodia sp. Robe River assemblages of mesas of the West Pilbara'*. Vegetation representing this PEC accounted for 14.6 ha (0.3%) within the Development Envelope.
- Vegetation association (ChAsppGOrGsppPlSsTeTw) contained all three of the recorded Priority flora species. This vegetation was associated with drainage lines comprising approximately 135 ha (3%) of the Development Envelope. Similar vegetation has been recorded from other regional surveys.
- Riparian vegetation association containing MaEcCv, represents approximately 174 ha (3%) of the Development Envelope, and is considered a groundwater dependent ecosystem as it is characterised by the obligate phreatophyte *Melaleuca argentea*. MaEcCv was mapped on the fringes of permanent and semi-permanent water pools both in and outside the Development Envelope and the main flow channels of the Robe River, and as such supported a number of species that were unique to this habitat.

The families and genera recorded in the Riverine and Drainage lines are typical of what would be expected in riparian vegetation of major drainage lines in the Pilbara. No Threatened taxa were recorded. There were 23 weed species recorded within the riparian habitats. None of the weed species recorded is listed as a declared pest for the Shire of Ashburton or a Weed of National Significance.

Vegetation condition ranged from 'very poor' to 'excellent' with approximately 67% of the Development Envelope classified as being in 'excellent' condition. The area is also subject to a history of pastoral activity with cattle grazing evident on the plains, floodplains and drainage lines.

Fauna

Astron undertook a multi-seasonal terrestrial fauna survey in 2015 and 2016 including systematic, targeted, and opportunistic sampling for terrestrial vertebrate fauna and potential short-range endemic (SRE) invertebrates. Seven broad fauna habitat types were recorded in the Development Envelope:

- Riverine;
- Drainage Line; Gorge;
- Breakaway;
- Rocky Hills;
- Low Hills and Slopes; and
- Loamy/Stony Plain.

The Gorge, Riverine and Breakaway habitats in the Development Envelope are considered important for fauna due to the microhabitats they provide such as caves and water pools. The Gorges and Breakaway habitats represent an important site of refuge due to their location close to the Robe River and as habitat for conservation significant fauna.

There were 169 vertebrate fauna species recorded within the Development Envelope including: two amphibian species: 55 reptile species: 85 bird species; and 27 mammal species (including four introduced species). The faunal assemblage recorded is considered typical of the Hamersley Range subregion extending from near Pannawonica to Mt Brockman.

Eight conservation significant fauna species have been recorded in the Development Envelope: Pilbara Olive Python (VU; S3) (*Liasis olivaceus barroni*); Northern Quoll (EN; S2) (*Dasyurus*

hallucatus); Pilbara Leaf-nosed Bat (VU; S3) (*Rhinonicteris aurantia*); Ghost Bat (VU; S3) (*Macroderma gigas*); Rainbow Bee-eater (Mi; S5) (*Merops ornatus*); Eastern Great Egret (Mi; S5) (*Ardea modesta*); Lined Soil-crevice Skink (P4) (*Notoscincus butleri*); and Western Pebble-mound Mouse (P4) (*Pseudomys chapmani*). These are listed in Table 19.

The Development Envelope was systematically trapped for vertebrates for a total of 3,493 trap nights across eight sites including targeted searching. Forty person hours were spent conducting avifauna surveys and 30 person hours were spent spotlighting. Motion-sensor cameras were deployed for 247 camera trap-nights and SM2 Bat detectors were deployed for 27 recording-nights. In addition, Rio Tinto personnel deployed SM2 Bat detectors for 61 recording nights in and near the Development Envelope.

Four of the eight recorded conservation significant species are classified under the EPBC Act as MNES species: the Pilbara Olive Python; Northern Quoll; Ghost Bat; and Pilbara Leaf-nosed Bat.

The following recordings were made of these species:

- A single juvenile Pilbara Olive Python and two Pilbara Olive Python scats were recorded within the Riverine and the Breakaway habitat type within the Development Envelope. All records were outside the indicative clearing footprint of the Proposed Action.

- The Northern Quoll was recorded 27 times comprising: six capture records; 19 remote camera location records; and from two scats within the Breakaway, Riverine and Gorge habitat types in and immediately outside the Development Envelope. All records were outside the indicative clearing footprint of the Proposed Action.

- The Ghost Bat was recorded twice through scat collections and acoustic recordings. Eleven caves were identified within the Development Envelope during the surveys during detailed assessments undertaken by Bat Call WA (2017a), including two potential diurnal roost caves and nine nocturnal roost shelters based on their size, complexity and the presence of Ghost Bats and /or scats. All records and caves were outside the indicative clearing footprint of the Proposed Action.

- The two diurnal caves were assessed as being maternity cave candidates although no evidence of intensive Ghost Bat use for this purpose was found during the survey.

- The Pilbara Leaf-nosed Bat was recorded at eight of the 14 SM2 bat detector locations, all at low activity levels apart from one location (BAT 14) located outside the Development Envelope which recorded 257 calls. Further data and analysis of the BAT 14 sites confirmed that the Pilbara Leaf-nosed Bats originated from a known roost site approximately 10 kms south of the Development Envelope.

Table 19: Conservation listed fauna species recorded in the Development Envelope*

Common name (*Scientific name*)	Status	
	EPBC Act	In Western Australia
Northern Quoll (*Dasyurus hallucatus*)	Endangered	Schedule 2
Ghost Bat (*Macroderma gigas*)	Vulnerable	Schedule 3
Pilbara Leaf-nosed Bat (*Rhinonicteris aurantia*)	Vulnerable	Schedule 3
Pilbara Olive Python (*Liasis olivaceus barroni*)	Vulnerable	Schedule 3
Rainbow Bee-eater (*Merops ornatus*)	Migratory	Schedule 5
Eastern Great Egret (*Ardea modesta*)	Migratory	Schedule 5
Lined Soil-crevice Skink (*Notoscincus butleri*)	-	Priority 4
Western Pebble-mound Mouse (*Pseudomys chapmani*)	-	Priority 4

The Blind Cave Eel (Vulnerable) was also recorded approximately 1.1 km outside of the Development Envelope*, but within the area of modelled groundwater drawdown impact.

3.3 (b) Hydrology, including water flows

The Hamersley sub-region experiences an arid to tropical climate characterised by hot summers, warm winters, high potential evaporation and intermittent intense rainfall, often associated with cyclones and thunderstorms. The region experiences climatic extremes where severe droughts and major floods can follow each other in close succession.

The Robe River is the major river system in the region and covers a linear distance in excess of 190 km. The majority of the Development Envelope lies within the Robe River catchment which has a catchment area of approximately 7,500 km^2. Major watercourses occurring within the catchment include the Robe River and the Jimmawurrada, Bungaroo and Mungarathoona Creek's. The major water courses generally flow from the southeast to the northwest through high relief areas of the Hamersley Ranges on to the more gently sloping areas of the coastal plain before discharging into the ocean approximately 150 km south of Dampier. For the majority of its course, the Robe River is ephemeral with a wide, shallow flood plain. During the dry season water is often restricted to a series of permanent pools that are maintained by sub-surface flow (Bowman *et al*. 1991).

The eastern part of the Development Envelope lies within the Jimmawurrada Creek catchment which has a catchment area of approximately 400 km^2. Jimmawurrada is an ephemeral creek containing numerous braided dry creek beds subject to flooding during the wet season and converges into the Robe River immediately to the east of Mesa J and the Development Envelope.

3.3 (c) Soil and vegetation characteristics

The Development Envelope is located in the Hamersley IBRA sub-region, the characteristics of which are described in Table 20 (Environment Australia 2000).

Soils of the Development Envelope are typically shallow and of poor quality; the river landform is characterised by sand, gravel, pebbles and stones. The surrounding drainage zones are red shallow loams (Van Vreeswyk *et al*. 2004).

Table 20: Description of the Hamersley IBRA sub-region

Sub-region	Description
Hamersley	Mountainous area of Proterozoic sedimentary ranges and plateaux with Mulga low woodland over bunch grasses on fine textured soils and Snappy Gum over *Triodia brizoides* on skeletal sandy soils of the ranges.

Van Vreeswyk *et al*. (2004) classified and mapped the land systems of the Pilbara region according to similarities in landform, soil, vegetation, geology and geomorphology. The Development Envelope intersects six land systems as described in Table 21. The Development Envelope incorporates low plateaux and mesas associated with the Robe Land System, and the Robe River itself as a component of the River Land System. The surrounding plains supporting spinifex are predominantly associated with the Boolgeeda Land System.

Table 21: Land systems in the Development Envelope

Land system	Land system description
Boolgeeda	Stony lower slopes and plains below hill systems supporting hard and soft spinifex grasslands and mulga shrublands.
McKay	Hills, ridges, plateaux remnants and breakaways of meta sedimentary and sedimentary rocks supporting hard spinifex grasslands.
Newman	Rugged jaspilite plateaux, ridges and mountains with hard spinifex.
River	Seasonally active flood plains and major river channels supporting grassy eucalypt woodlands, tussock grasslands and soft spinifex grasslands.
Robe	Low plateaux, mesas and buttes of limonite supporting soft spinifex and occasionally hard spinifex grasslands.
Urandy	Stony plains, alluvial plains and drainage lines supporting shrubby soft spinifex grasslands

3.3 (d) Outstanding natural features

The Development Envelope does not include any areas with outstanding natural features.

3.3 (e) Remnant native vegetation

The Development Envelope consists almost entirely of native vegetation, much of which has a history of pastoral land use. Apart from the adjacent active mining area (Mesa J and Mesa K), only a small proportion of the area has been cleared in association with mining exploration activities (i.e. tracks, drill pads, temporary workforce camps).

3.3 (f) Gradient (or depth range if action is to be taken in a marine area)

The Proposed Action will occur on a mesa landform and the surrounding plains. The plains in the Development Envelope occur at an elevation of approximately 122 mAHD, with the top of the mesa rising to a maximum elevation of approximately 55 m above the plain (177 mAHD). The mesa escarpments have variable gradients ranging from approximately 5º to 25º.

3.3 (g) Current state of the environment

The Development Envelope and surrounds has been subject to pastoral land use activities for over a century and iron ore mining since 1992 when productive mining commenced at Mesa J. Beyond the Development Envelope, iron ore mining has been undertaken in the Robe Valley in the Deepdale Area since the late 1960s.

The majority of the vegetation in the Development Envelope has been assessed as in Excellent or Very Good condition. Exceptions include areas cleared for the adjacent mine operations, infrastructure, vehicle tracks, rail line and drill pads as well as areas with high weed infestations and areas that have been heavily grazed or trampled by cattle.

3.3 (h) Commonwealth Heritage Places or other places recognised as having heritage values

The Development Envelope does not include Commonwealth Heritage Places or other places recognised as having heritage values.

3.3 (i) Indigenous heritage values

The Proposal lies within the Kuruma Marthudunera (K&M) Native Title Claim (WCD2016/006). The Proponent has a Participation Agreement and Indigenous Land Use Agreement with the K&M that includes an established consultation framework and ongoing engagement on processes such as: land access; tenure acquisition; heritage surveys and environmental management relating to the Proponent's operations.

All of the archaeological survey work and the majority of the ethnographic survey work has been completed for the Proposal. Heritage sites of high significance in the vicinity of the Development Envelope are ethnographic sites (including mythological locations, named pools and places of importance due to current use); the Robe River, and the mesa profiles which are used as landmarks within the landscape. The Proposal has been specifically designed to avoid significant impact and to protect key identified heritage sites in consultation with the K&M. Disturbance to less significant heritage sites will be avoided where practicable. Where these less significant heritage sites cannot be avoided, it is anticipated that potential impacts will be managed through the processes contained within the Participation Agreement and under the *Aboriginal Heritage Act 1972* (WA).

3.3 (j) Other important or unique values of the environment

The Development Envelope does not have other known important or unique environmental values.

3.3 (k) Tenure of the action area (e.g. freehold, leasehold)

The Robe Valley mining operations, including this Proposed Action, are predominantly located within the State Agreement Mineral Lease ML248SA granted pursuant to the *Iron Ore (Robe River) Agreement Act 1964* (WA). ML248SA is appropriate tenure for mining and mining related infrastructure.

The main co-existing Land Administration Act 1997 (WA) (LAA) tenure in the Development Envelope includes the Yarraloola Pastoral Station (Lease N49500) and the Yalleen Pastoral Station (Lease N49492). These pastoral leases are held by entities associated with members of the RRIA.

Existing tenure in and near the Development Envelope is shown in Attachment 2. The Proposal pits, dumps and the majority of infrastructure are located within ML248SA (section 104 and a portion of section 103). A powerline to the east of Mesa J in the eastern part of the Development Envelope will require grant of new tenure under the *Mining Act 1978*.

3.3 (l) Existing uses of area of proposed action

The Proposal is located in the Shire of Ashburton, approximately 16 km south west of the township of Pannawonica. Existing land uses in the Development Envelope include: pastoral activities (Yarraloola and Yalleen Stations); mineral exploration; mining activities; and cultural / recreational activities (predominantly by Traditional Owners) such as camping, fishing and hunting. The mesa landform / profiles of the Robe Valley are also used by Traditional Owners as landmarks when travelling though the countryside (refer Attachment 2).

3.3 (m) Any proposed uses of area of proposed action

It is anticipated that the Yarraloola and Yalleen pastoral leases will continue to support pastoral activities both during mining activities and post-mining.

The Proponent will prepare a Mine Closure Plan (MCP) for the entire Mesa J Hub Operation (which includes the Proposed Action) in accordance with the Western Australian *Guidelines for Preparing Mine Closure Plans* (Department of Mines and Petroleum and Environmental Protection Authority 2015). The MCP will be regularly updated over the life of the project in consultation with relevant government agencies. Closure activities will also conform to the global Rio Tinto Closure Standard.

4. Environmental outcomes

Based upon project design and biological assessment (Astron 2016a) - Attachment 5 and Bat Call WA (2017a & b) – Attachment 11 & 12), the Proposed Action is not anticipated to have any significant impacts upon MNES. Specifically, the Proposed Action includes the following environmental outcomes:

- Clearing of up to 2,200 ha in the Development Envelope of 4,930 ha. The majority of clearing will be on the top of the mesa and the surrounding plains. These areas do not represent core habitat for the MNES which may be impacted by the Proposed Action. All MNES records to date have been sampled outside the indicative Proposed Action clearing footprint.
- Retention of approximately 95% of the escarpments and associated gullies to ensure retention of core habitat for MNES to avoid impact by the Proposed Action.
- Continued retention of the escarpments, except for areas required to provide vehicle access to the mesa.
- Retention of the attributes of the diurnal (with potential to be maternity) Ghost Bat roost caves and associated roost complexes:
    - A mining exclusion zone of 40 m between the back of each diurnal / potential maternal roost cave and the proposed mine pit.
    - A mining exclusion zone of 50 m from the entry to each cave that is part of a roost complex (i.e. the caves in the same gullies as the diurnal / potential maternal roost caves) to the proposed mine pit.
- Retention of all recorded nocturnal Ghost Bat roosts.
- Ongoing availability of foraging habitat for the Northern Quoll, Ghost Bat, Pilbara Leaf-nosed Bat and Pilbara Olive Python both inside and outside the Development Envelope.
- No impact to the Pilbara Leaf-nosed Bat roost located approximately 10 km away to the south.
- Limited impact to core Pilbara Olive Python habitat along the Robe River and Jimmawurrada Creek from road access and groundwater drawdown. Potential extension of habitat in areas of surplus water discharge.
- Localised impact to the Blind Cave Eel habitat from groundwater drawdown.

5. Measures to avoid or reduce impacts

5.1 Northern Quoll

Potential impacts

Northern Quoll individuals may be impacted by:

- Minor reduction in denning habitat where cuts are made through the escarpments to allow access to the mesas.
- Minor clearing or modification of foraging habitat, including habitat associated with the Robe River (<5 ha) and indirect impact to Jimmawurrada Creek.
- Noise and vibration from mining activities.
- Increased risk of vehicle strike on roads.
- Increased predation from feral predators.

Management strategies

Strategies for avoiding and reducing impacts to the Northern Quoll include:

- **Designing the Proposed Action to minimise the proposed footprint.**
- **Designing the Proposed Action to avoid areas of core habitat:**
    - retain mesa escarpments; and
    - limited / minimal disturbance to the Robe River and Jimmawurrada Creek – minimal clearing within the Robe River (facilities in the Robe River limited to low impact crossing points); avoidance of direct disturbance to associated pools; and avoidance of clearing within Jimmawurrada Creek.
- **Delineating disturbance footprint and adhering to disturbance boundaries** to minimise disturbance and to avoid inadvertent disturbance to areas of significance.
- **Maintaining appropriate speed limits** for light vehicles by ensuring all roads are sign-posted and vehicle speeds are monitored.
- **Implementing programs for education of the workforce** with respect to fauna protection and management, specifically in relation to the Northern Quoll.
- **Implementing feral animal control.**

Anticipated residual impacts

The Proposed Action is not expected to result in significant impacts to the Northern Quoll as approximately 95% of Northern Quoll core habitat (mesa escarpments, particularly areas with deep gullies that are associated with drainage lines and water courses) within the Development Envelope will be retained. The Proposed Action is not expected to result in a significant impact to Northern Quoll foraging habitat as only a small proportion of available foraging habitat in the development envelope will be disturbed.

5.2 Ghost Bat

Potential impacts

Ghost Bat individuals may be impacted by:

- Minor loss of nocturnal roosts through cuts in the escarpments to allow vehicle access to the mesa.

- Minor clearing or modification of foraging habitat, including habitat associated with the Robe River and Jimmawurrada Creek.
- Dust, noise and vibration from mining activities.

Management strategies

Strategies for avoiding and reducing impacts to the Ghost Bat include:

- **Designing the Proposed Action to minimise the proposed footprint.**
- **Designing the Proposed Action to avoid areas of core habitat:**
    - retain escarpments at Mesa H;
    - establish mining exclusion zones around diurnal roosts and their associated cave complexes;
    - design the haul roads to avoid diurnal roosts and their associated cave complexes; and
    - limited / minimal disturbance to the Robe River and Jimmawurrada Creek – minimal clearing within the Robe River (facilities in the Robe River limited to low impact crossing points); avoidance of direct disturbance to associated pools; and avoidance of clearing within Jimmawurrada Creek.
- **Delineating disturbance footprint and adhering to disturbance boundaries** to minimise disturbance and to avoid inadvertent disturbance to areas of significance.
- **Ensuring barbed-wire fences are not installed** unless there is a statutory requirement to do so. Where barbed-wire is necessary, ensuring reflectors are installed to deter bats.
- **Controlling dust.**
- **Implementing programs for education** of the workforce with respect to fauna protection and management, specifically in relation to the Ghost Bat.

Anticipated residual impacts

The Proposed Action is not expected to result in significant impacts to the Ghost Bat as diurnal roosts will be retained with adequate buffer zones to protect the integrity of the caves. Most nocturnal roosts will also be retained. Nor is the Proposed Action expected to result in a significant impact to Ghost Bat foraging habitat given that any changes to foraging habitat associated with the Robe River would be temporary and would represent only a small proportion of the foraging habitat available in the Robe Valley.

5.3 Pilbara Leaf-nosed Bat

Potential impacts

Pilbara Leaf-nosed Bat individuals may be impacted by:

- Minor clearing or modification of foraging habitat, including habitat associated with the Robe River and Jimmawurrada Creek.
- Dust, noise, vibration and light from the mining operation.
- Increased risk of vehicle strike on roads.

Management strategies

- **Designing the Proposed Action to minimise the proposed footprint.**
- **Designing the Proposed Action to limit direct disturbance and limit indirect disturbance associated with water to the primary foraging areas**, the Robe River and Jimmawurrada Creek.

- **Delineating disturbance footprint and adhering to disturbance boundaries** to minimise disturbance and to avoid inadvertent disturbance to areas of significance.
- **Maintaining appropriate speed limits for light vehicles** by ensuring all roads are sign-posted and vehicle speeds are monitored.
- **Implementing programs for education** of the workforce with respect to fauna protection and management, specifically in relation to the Pilbara Leaf-nosed Bat.

Anticipated residual impacts

The Proposed Action is not expected to result in significant impacts to the Pilbara Leaf-nosed Bat given that the nearest roost is located well outside (>10 km south) of the Development Envelope.

5.4 Pilbara Olive Python

Potential impacts

Pilbara Olive Python individuals may be impacted by:

- Minor clearing or modification of habitat, including habitat associated with the Robe River and Jimmawurrada Creek.
- Minor reduction in lower quality habitat where cuts are made through the escarpments to allow access to the mesa.
- Potential extension of habitat in the Robe River via surplus water discharge.
- Noise and vibration from the mining operation.
- Increased risk of vehicle strike on roads.
- Increased predation from feral predators.

Management strategies

- **Designing the Proposed Action to minimise the proposed footprint.**
- **Designing the Proposed Action to avoid areas of core habitat:**
    - retain escarpments at Mesa H;
    - limited / minimal disturbance to the Robe River and Jimmawurrada Creek – minimal clearing within the Robe River (facilities in the Robe River limited to low impact crossing points); avoidance of direct disturbance to associated pools; and avoidance of clearing within Jimmawurrada Creek; and
    - maintaining pools in the Robe River via supplementary water supply should monitoring indicate significant pool level changes resulting from groundwater drawdown.
- **Delineating disturbance footprint and adhering to disturbance boundaries** to minimise disturbance and to avoid inadvertent disturbance to areas of significance.
- **Maintaining appropriate speed limits** for light vehicles by ensuring all roads are sign-posted and vehicle speeds are monitored.
- **Implementing programs for education of the workforce** with respect to fauna protection and management, specifically in relation to the Pilbara Olive Python.
- **Implementing feral animal control.**

Anticipated residual impacts

The Proposed Action is not expected to result in significant impacts to the Pilbara Olive Python as the mesa escarpment will be retained and any impact to foraging habitat along the Robe River

would be minor or temporary, with pools in the Robe River being maintained, and would represent only a small proportion of the foraging habitat available in the Robe Valley.

5.5 Blind Cave Eel

Potential impacts

Blind cave eel individuals may be impacted by:

- Modification of habitat through:
    - reduction of habitat via groundwater drawdown, including habitat associated with the Robe River and Jimmawurrada Creek alluvial aquifers; and
    - potential extension of habitat in the Robe River via surplus water discharge.
- Localised reduction in habitat quality from pollutants and sedimentation being transported into the surface water and groundwater systems.

Management strategies

- **Designing the Proposed Action to minimise the proposed footprint.**
- **Designing the Proposed Action to avoid direct removal of core habitat:**
    - direct physical disturbance to the Robe River and Jimmawurrada Creek will be limited to vehicle crossing points and no direct physical disturbance to the pools; and
    - creekline flood flows and flow paths will be maintained which will support retention of habitat connectivity.
- **Maintaining areas of viable habitat:**
    - limiting area of habitat subject to groundwater drawdown;
    - managing surface water discharge quality by managing erosion and sedimentation;
    - maintain groundwater and surface water quality by managing contaminants (e.g. Hydrocarbon spills);
    - maintaining alluvial habitat and connectivity; and
    - implementing a precautionary mitigation option such as supplementary water supply to alluvial ecosystems via controlled discharge to minimise localised impacts of groundwater drawdown should monitoring indicate significant groundwater level changes.
- **Delineating disturbance footprint and adhering to disturbance boundaries** to minimise disturbance and to avoid inadvertent disturbance to areas of significance.
- **Implementing programs for education of the workforce** with respect to fauna protection and management, specifically in relation to the Blind Cave Eel.

Anticipated residual impacts

The Proposed Action is not expected to result in significant impacts to the Blind Cave Eel as potential habitat impacts along the Robe River and Jimmawurrada Creek would be temporary and localised – with subterranean habitat substrate and connectivity retained, and thus the impacts are constrained to only a small proportion of the habitat available in the broader Robe Valley.

6. Conclusion on the likelihood of significant impacts

6.1 Do you THINK your Proposed Action is a Controlled Action?

No. Refer to Section 6.2.

6.2 Proposed action IS NOT a controlled action.

As detailed in Section 3.1, based on extensive flora/vegetation and fauna surveys in and near the Development Envelope:

- The Northern Quoll has been recorded in the Development Envelope as well as numerous times throughout the broader Robe Valley and occur outside the indicative Proposed Action clearing footprint.
- The Ghost Bat and Ghost Bat roosts have been recorded in the Development Envelope as well as numerous times throughout the Robe Valley. No confirmed maternal roots have been located in the Development Envelope and all known roosts are located outside the indicative clearing footprint of the Proposed Action.
- The Pilbara Leaf-nosed Bat has been recorded foraging in the Development Envelope as well as numerous times throughout the broader Robe Valley. Based on acoustic records, the nearest Pilbara Leaf-nosed Bat roost is estimated to be approximately 10 km south of Mesa H, well outside the Development Envelope.
- The Pilbara Olive Python has been recorded in the Development Envelope as well as numerous times throughout the broader Robe Valley and were located outside the indicative clearing footprint of the Proposed Action.
- Nine migratory bird species (refer Table 18) have been recorded or are likely to occur in the Development Envelope as well as more broadly in the Robe Valley.
- The Blind Cave Eel has been recorded in the groundwater approximately 1.1 km outside the Development Envelope, but within the modelled groundwater drawdown cone of depression. Another record exists 5km from the Development Envelope, outside the predicted impact area. The same species has also been recorded from 11 localities in the subterranean waters of Cape Range.

The potential impacts of the Proposed Action on MNES have been assessed against:

- The general significance test required under the EPBC Act, whether there is ‘a real chance or possibility’ of an impact that is ‘important, notable or of consequence, having regard to its context or intensity’ (Department of the Environment 2013).
- The criteria specified by Department of the Environment (2013) regarding significant adverse impacts to Listed Threatened Species.

Based on the assessment of the Proposed Action against the above criteria, the Proposed Action is **not** considered to be a controlled action as:

- The Proposed Action will protect and avoid mining of the Mesa H escarpments which contain denning habitat for the Northern Quoll. The Proposed Action will disturb only a small proportion of the available primary foraging habitat for the Northern Quoll in the vicinity of the Development Envelope.
- The Proposed Action will retain the diurnal Ghost Bat roosts and associated roost complexes with buffer zones between the proposed mine pits and the caves. The availability of diurnal roosts is believed to be a key factor in the persistence of the Ghost Bat in the Pilbara. The Proposed Action avoids disturbance to the diurnal Ghost Bat roosts (mining, habitat removal and roads). Any impact to Ghost Bat foraging habitat would be temporary and limited to a very small proportion of the available foraging habitat along the Robe River.

- The Proposed Action will not impact on any Pilbara Leaf-nosed Bat roosts as the nearest roost is estimated to be approximately 10 km south from Mesa H, outside the Development Envelope. The availability of suitable roosts is key to the persistence of the Pilbara Leaf-nosed Bat.
- The Proposed Action will retain the Mesa H escarpments which potentially contains breeding habitat for the Pilbara Olive Python. The Proposed Action will disturb only a small proportion of the available foraging habitat for the Pilbara Olive Python in the vicinity of the Development Envelope and the disturbance will be temporary.
- The Proposed Action will impact only a small proportion of the available Plains and Riverine habitats used by migratory bird species in the Robe Valley. The presence of the migratory species in the Development Envelope is expected to be transitory only and all of the migratory species likely to occur in the Development Envelope have extensive distributions across Western Australia.
- The Proposed Action will potentially impact on a 9 km portion of the Blind Cave Eel habitat from groundwater drawdown and minor surface clearing for road access. However, the functioning of the creekline alluvial aquifer systems, which are understood to form the core habitat for the Blind Cave Eel, will be retained and seasonal rainfall will ensure that the aquifer is periodically recharged to retain habitat connectivity.

7 Environmental record of the person proposing to take the action

		Yes	No
7.1	**Does the party taking the action have a satisfactory record of responsible environmental management?**	✓	
	Rio Tinto's iron ore business has over 50 years of experience in mining iron ore successfully and responsibly in the Pilbara region of Western Australia. With a network of 15 mines (including joint ventures), four port facilities, a 1,700 km rail network and related infrastructure, the group produces more than 300 million tonnes of iron ore annually. Rio Tinto has developed and refined environmental management policies, systems and procedures over decades of operational mining experience in the Pilbara region. These are successfully applied at the group's numerous existing Pilbara iron ore mine sites. The key components of Rio Tinto's environmental management approach that are applicable to the Proposed Action include: • Rio Tinto's Iron Ore Health, Safety, Environment, Communities and Quality Policy (HSECQ Policy). The HSECQ Policy is the guiding document for environmental management and provides context and direction for continuous improvement. • Rio Tinto's Environmental Management System (EMS) - The EMS is a continuous improvement model that covers key elements including systematic assessment of environmental risk and legal requirements and the development of objectives and targets for improvement, as well as systems for training, operational control, communication, emergency response, corrective actions, audits and review. • a Construction Environmental Management Plan (CEMP) will be prepared to address environmental factors potentially subject to impacts arising from construction activities. For each factor, the CEMP will identify potential impacts, management controls, monitoring, reporting and contingency actions. This will include clear identification of roles and responsibilities associated with the implementation of the CEMP. • an Environmental Management Plan (EMP) will be prepared and implemented for the operational phase of the project. The EMP will be interfaced with the EMS, and address all relevant environmental aspects of the project. No proceedings have been taken against the Proponent, or known to be in the process of being taken against the Proponent, under the EPBC Act.		
7.2	**Provide details of any proceedings under a Commonwealth, State or Territory law for the protection of the environment or the conservation and sustainable use of natural resources against:** **a) the person proposing to take the action, or** b) **if a permit has been applied for in relation to the action - the person making the application.**		✓
7.3	**If the person taking the action is a corporation, please provide details of the corporation's environmental policy and planning framework and if and how the framework applies to the action.**	✓	
	The Rio Tinto Iron Ore HSECQ Policy is the guiding document for environmental management and provides context and direction for continuous improvement. Rio Tinto's iron ore mines in the Pilbara region operate under an EMS which is a continuous improvement model covering systematic assessment of environmental risk and legal requirements and the development of objectives and targets for improvement; as well as systems for training, operational control, communication, emergency response, corrective actions, audits and review. The Proposed Action will be undertaken in accordance with both the HSECQ Policy and the EMS.		

7.4	**Has the party taking the action previously referred an action under the EPBC Act, or been responsible for undertaking an action referred under the EPBC Act?** Yes, Robe River Mining Co. Pty. Limited has previously referred three other iron ore mining projects in the Pilbara under the EPBC Act: • Mesa A/Warramboo Iron Ore Project (2006/2698) • Bungaroo Iron Ore Trial Mining Operation (2006/2771) • Extension of Mesa A Warramboo Iron Ore Project (2016/7843)	✓	

8 Information sources and attachments

8.1 References

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8.2 Reliability and date of information

All information sources discussed in Section 3 are included in the reference list. The key survey reports for the Development Envelope (Astron 2016a, Astron 2016b, Bat Call WA 2017a) are included as Attachments. These surveys were undertaken by suitably qualified ecologists with extensive experience in surveys of this type in the Pilbara region. Each survey report includes a discussion of survey limitations and uncertainties. The Proponent considers that the information presented has a high level of reliability and that limitations associated with the information have been explicitly appraised in the survey report.

8.3 Attachments

Attachment 1	Regional location
Attachment 2	Land Tenure
Attachment 3	Indicative Conceptual Mine Layout
Attachment 4	Protected Matters Search report
Attachment 5	Astron Mesa H Level 2 Fauna Assessment (Astron 2016a)
Attachment 6	Astron Mesa H Level 2 Vegetation and Flora Assessment (Astron 2016b)
Attachment 7	MNES (Non-Migratory) Records in and near the Development Envelope
Attachment 8	MNES (Migratory) Records in and near the Development Envelope
Attachment 9	Development Envelope in the Context of the Robe Valley
Attachment 10	Fauna Habitat Mapping in the Development Envelope
Attachment 11	Bat Call WA Mesa H Ghost Bat roost cave assessment report (Bat Call WA 2017a)
Attachment 12	Bat Call WA Robe Valley Mesa A to Mesa 2405A, impact of mining on Ghost bat presence and activity (Bat Call WA 2017b)
Attachment 13	Ghost Bat Roosts and Contextual Ghost Bat Habitat Mapping
Attachment 14	Pools in and near the Development Envelope
Attachment 15	GIS file of the Development Envelope

		✓ attached	Title of attachment(s)
You must attach	figures, maps or aerial photographs showing the locality of the proposed action (section 1)	✓	Attachment 1: Regional location Attachment 2: Land tenure Attachment 3: Indicative conceptual mine layout Attachment 9: Development Envelope in the context of the Robe Valley Attachment 15: GIS file of the Development Envelope
	GIS file delineating the boundary of the referral area (section 1)		
	figures, maps or aerial photographs showing the location of the proposed action in respect to any matters of national environmental significance or important features of the environments (section 3)	✓	Attachment 7: MNES (Non-Migratory) Records in and near the Development Envelope Attachment 8: MNES (Migratory) Records in and near the Development Envelope Attachment 10: Fauna habitat mapping in the Development Envelope Attachment 13: Ghost Bat roosts on Mesas H and Ghost Bat habitat mapping Attachment 14: Pools in and near the Development Envelope
If relevant, attach	copies of any state or local government approvals and consent conditions (section 2.5)		Not relevant
	copies of any completed assessments to meet state or local government approvals and outcomes of public consultations, if available (section 2.6)		Not relevant
	copies of any flora and fauna investigations and surveys (section 3)	✓	Attachment 5: Mesa H Level 2 Fauna Assessment (Astron 2016a) Attachment 6: Astron Mesa H Level 2 Vegetation and Flora Assessment (Astron 2016b) Attachment 11: Bat Call WA Mesa H Ghost Bat roost cave assessment report (Bat Call WA 2017a) Attachment 12: Bat Call WA Robe Valley Mesa A to Mesa 2405A, impact of mining on Ghost bat presence and activity (Bat Call 2017b)
	technical reports relevant to the assessment of impacts on protected matters that support the arguments and conclusions in the referral (section 3) conclusions in the referral (section 3 and 4)	✓	Attachment 5: Astron Fauna Survey Report (Astron 2016a) Attachment 6: Astron Flora Survey Report (Astron 2016b) Attachment 11: Bat Call WA Mesa H Ghost Bat roost cave assessment report (Bat Call WA 2017a) Attachment 12: Bat Call WA Robe Valley Mesa A to Mesa 2405A, impact of mining on Ghost bat presence and activity (Bat Call 2017b)
	report(s) on any public consultations undertaken, including with Indigenous stakeholders (section 3)		Not relevant

9. Contacts, signatures and declarations

Proposed action title:		Mesa H Proposal
9.1	**Person proposing to take action**	
	Name and Title:	IVAN VELLA Director
	Organisation (if applicable): Trust deed (if applicable):	Robe River Mining Co. Pty. Limited Not applicable
	ACN / ABN (if applicable):	ACN 008 694 246
	Postal address:	GPO Box A42, Perth WA 6837
	Telephone:	(08) 9327 2000
	Email:	
	I qualify for exemption from fees under section 520(4C)(e)(v) of the EPBC Act because I am:	Not applicable
	If you are small business entity you must provide the Date/Income Year that you became a small business entity:	Not applicable
	I would like to apply for a waiver of full or partial fees under regulation 5.21A of the EPBC Regulations. Under regulation 5.21A(5), you must include information about the applicant (if not you) the grounds on which the waiver is sought and the reasons why it should be made:	Not applicable
	Declaration:	I declare that to the best of my knowledge the information I have given on, or attached to this form is complete, current and correct. I understand that giving false or misleading information is a serious offence. I declare that I am not taking the action on behalf of or for the benefit of any other person or entity.
	Signature:	Date: 15/08/2017
9.2	**Designated proponent**	
	Name of proposed proponent:	Robe River Mining Co. Pty. Limited
	ACN / ABN (if applicable):	As above
	Postal address:	As above
	Telephone:	As above
	Email:	As above

	Declaration by the proposed proponent: Declaration by the person proposing to take the action:	Robe River Mining Co. Pty. Limited, as manager and agent of the Robe River Iron Associates joint venture, being the proposed proponent, consent to the proposed designation of itself as the proponent for the purposes of the action described in this referral. I, IVAN VELLA, the person proposing to take the action, consent to the proposed designation of Robe River Mining Co. Pty. Limited as Proponent for the purposes of the action described in this referral.
	Signature:	
	Date:	15/08/2017

9.3	**Person preparing the referral information (if different from section 9.1)**		
	Name:	Ms Melinda Brand	
	Title:	Principal Advisor Environmental Approvals, Rio Tinto	
	Organisation:	Robe River Mining Co. Pty. Limited (member of the Rio Tinto Group)	
	ACN / ABN (if applicable):	ACN 008 694 246	
	Postal address:	GPO Box A42, Perth WA 6837	
	Telephone:	0419 481 682	
	Email:	melinda.brand@riotinto.com	
	Declaration:	I declare that to the best of my knowledge the information I have given on, or attached to this form is complete, current and correct. I understand that giving false or misleading information is a serious offence.	
	Signature:		Date: 8/8/17

REFERRAL CHECKLIST

HAVE YOU:	
✓	Completed all required sections of the referral form?
✓	Included accurate coordinates (to allow the location of the proposed action to be mapped)?
✓	Provided a map showing the location and approximate boundaries of the project area for the proposed action?
✓	Provided a map/plan showing the location of the action in relation to any matters of NES?
✓	Provided a digital file (preferably ArcGIS shapefile, refer to guidelines at Attachment A) delineating the boundaries of the referral area?
❑	Provided complete contact details and signed the form?
❑	Provided copies of any documents referenced in the referral form?
❑	Ensured that all attachments are less than three megabytes (3mb)?
❑	Sent the referral to the Department (electronic and hard copy preferred)

Ass # 590

Bull # 574

State # 208

WESTERN AUSTRALIA

MINISTER FOR THE ENVIRONMENT

STATEMENT THAT A PROPOSAL MAY BE IMPLEMENTED (PURSUANT TO THE PROVISIONS OF THE ENVIRONMENTAL PROTECTION ACT 1986)

MESA J IRON ORE DEVELOPMENT, PANNAWONICA (590)

ROBE RIVER IRON ASSOCIATES

This proposal may be implemented subject to the following conditions:

1 Proponent Commitments

In implementing the proposal, the proponent shall fulfil the commitments (which are not inconsistent with the conditions or procedures contained in this statement) made in the proponent's Consultative Environmental Review (a copy of the commitments is attached).

2 Implementation

Subject to these conditions, the manner of detailed implementation of the proposal shall conform in substance with that set out in any designs, specifications, plans or other technical material submitted by the proponent to the Environmental Protection Authority with the proposal. Where, in the course of that detailed implementation, the proponent seeks to change those designs, specifications, plans or other technical material in any way that the Minister for the Environment determines on the advice of the Environmental Protection Authority, is not substantial, those changes may be effected.

3 Environmentally Significant Areas

The Robe River - Jimmawurrada Creek environment, its vegetation, water levels and water quality, and particularly the permanent pools of the Robe River, are to be protected from unacceptable direct and indirect impacts by this project during the life of the project, recognising the requirements of mining and ore transport. This includes but is not necessarily limited to the following requirements:

1. Mining and other activities associated with the project shall be excluded from those areas of the Mesa J escarpment along the Robe River as delineated on the sketch plan of September 1991 prepared by the proponent and attached to this Statement; and

2. The alignment of the rail route from Mesa K to Mesa J shall utilise the Jimmawurrada Creek escarpment and not the creek bed, and accordingly shall be rail alignment option 2 as identified by the proponent in Addendum "A" to the Consultative Environmental Review.

4 Drainage Management

The Robe River - Jimmawurrada Creek system needs to be protected from pollution and unacceptable sedimentation, recognising the requirements of mining and ore transport.

Published on

15 JAN 1992

18th FLOOR, ALLENDALE SQUARE, 77 ST GEORGE'S TERRACE, PERTH, W.A. 6000 TELEPHONE 325 9422 FAX. 325 5621

4-1 Prior to construction at the site, the proponent shall prepare a Drainage Management Programme, to protect the Robe River - Jimmawurrada Creek system from the deleterious impacts of sedimentation and pollution from the project, to the satisfaction of the Minister for the Environment on advice of the Environmental Protection Authority, the Department of Conservation and Land Management and the Water Authority of Western Australia. The plan is to include but is not necessarily limited to:

1. a monitoring programme to detect impacts;
2. procedures for protecting the ecology of the system;
3. procedures for reporting on the programme; and
4. a commitment to ameliorate environmental impacts to the satisfaction of the Environmental Protection Authority if impacts are detected which are deemed unacceptable by the Environmental Protection Authority.

4-2 Subsequent to condition 4-1, the proponent shall implement the approved Drainage Management Programme to the satisfaction of the Environmental Protection Authority on advice of the Water Authority of Western Australia and the Department of Conservation and Land Management.

5 Dewatering Management

The permanent pools and vegetation of the Robe River - Jimmawurrada Creek system are to be protected from unacceptable environmental impacts, recognising the requirements of mining and ore transport.

5-1 Prior to the commencement of dewatering, the proponent shall prepare a Dewatering Management Programme, to protect the Robe River - Jimmawurrada Creek system, to the satisfaction of the Environmental Protection Authority on advice of the Department of Conservation and Land Management and the Water Authority of Western Australia. The plan is to include but is not necessarily limited to:

1. a monitoring programme to detect impacts;
2. procedures for protecting the ecology and water quality of the permanent pools and associated vegetation;
3. procedures for reporting on the programme; and
4. a commitment to ameliorate environmental impacts to the satisfaction of the Environmental Protection Authority if impacts are detected which are deemed unacceptable by the Environmental Protection Authority.

5-2 Subsequent to condition 5-1, the proponent shall implement the approved Environmental Management Programme to the satisfaction of the Environmental Protection Authority on advice of the Water Authority of Western Australia and the Department of Conservation and Land Management.

6 Rehabilitation

Rehabilitation is an integral part of the project and requires management throughout the life of the project.

6-1 Within 12 months of the date of this statement, the proponent shall prepare a Rehabilitation Management Programme to the satisfaction of the Environmental Protection Authority on advice of the Department of Mines and the Department of Conservation and Land Management. The programme shall include but not necessarily be limited to:

1. proposals for rehabilitation of the project area; and
2. a monitoring programme to determine success of the rehabilitation.

6-2 The initial programme shall be submitted to the Environmental Protection Authority, with subsequent programmes for the project to be updated annually in conjunction with reporting requirements under the Iron Ore (Robe River) Agreement Act.

6-3 At least twelve months prior to decommissioning, the proponent shall prepare a plan for decommissioning and rehabilitating the site, to the satisfaction of the Environmental Protection Authority on advice of the Department of Mines and the Department of Conservation and Land Management.

6-4 Subsequent to conditions 6-1 and 6-3, the proponent shall implement the approved programmes for rehabilitating and decommissioning the site, to the satisfaction of the Environmental Protection Authority on advice of the Department of Mines and the Department of Conservation and Land Management.

7 Environmental Management Programme

A comprehensive management programme for the project should be prepared to integrate the various components referred to in conditions 4, 5 and 6 above. This will allow reporting for the various aspects of the project to be done in one document.

7-1 Prior to construction, the proponent shall prepare an interim report outlining the key components of a comprehensive environmental management programme to the satisfaction of the Minister for the Environment on advice of the Environmental Protection Authority. The programme shall include but not necessarily be limited to:

1. drainage;
2. rehabilitation; and
3. dewatering.

7-2 Subsequent to condition 7-1 and prior to the commencement of mining, the proponent shall prepare a comprehensive environmental management programme to the satisfaction of the Minister for the Environment on advice of the Environmental Protection Authority. Whilst initial reporting would be to the Environmental Protection Authority, future reporting could be done under the Iron Ore (Robe River) Agreement Act. The programme shall include but not necessarily be limited to:

1. the plan for drainage management required by condition 4-1;
2. the plan for rehabilitation required by condition 6-1; and
3. a status report on the plan for dewatering management as per condition 5-1.

8 Proponent

Prior to any transfer of ownership, control or management of the project being effected which would give rise to the need for the replacement of the proponent, the Minister for the Environment shall be advised of the name and details of the transferee and invited to nominate a replacement proponent.

If the Minister nominates a replacement proponent, a copy of this statement endorsed with an undertaking by the replacement proponent to carry out the project in accordance with the conditions and procedures set out in the statement shall be

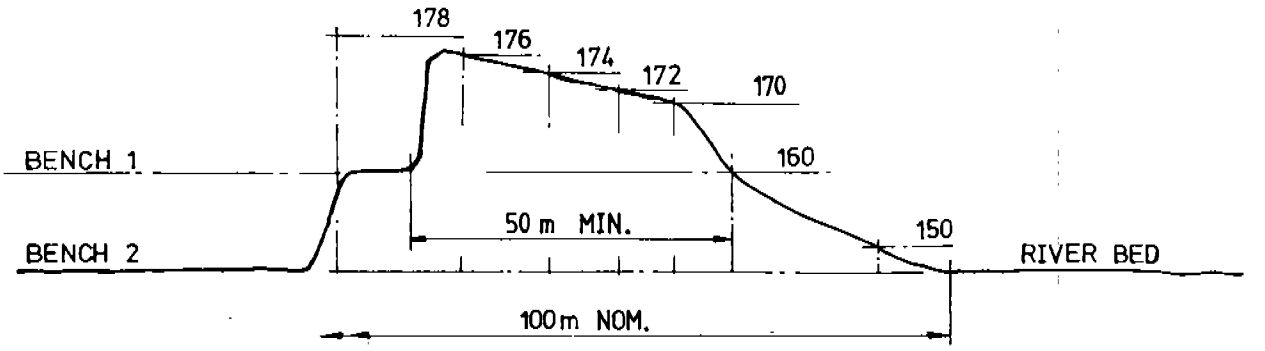
delivered to the Minister and thereupon the former proponent shall be released from the conditions of this statement to the extent of its interest transferred.

9 Time limit on approval

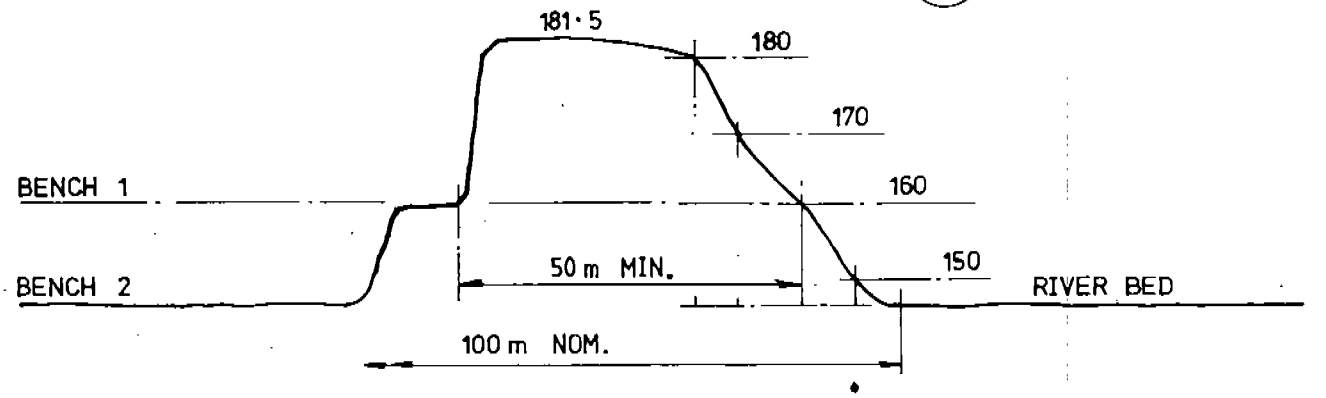
If the proponent has not substantially commenced the project within five years of the date of this statement, then the approval to implement the proposal as granted in this statement shall lapse and be void. The Minister for the Environment shall determine any question as to whether the project has been substantially commenced. Any application to extend the period of five years referred to in this condition shall be made before the expiration of that period, to the Minister for the Environment by way of a request for a change in the condition under Section 46 of the Environmental Protection Act. (On expiration of the five year period, further consideration of the proposal can only occur following a new referral to the Environmental Protection Authority).

Bob Pearce, MLA
MINISTER FOR THE ENVIRONMENT

14 JAN 1997



NOMINAL LEVELS THROUGH SECTION (A)



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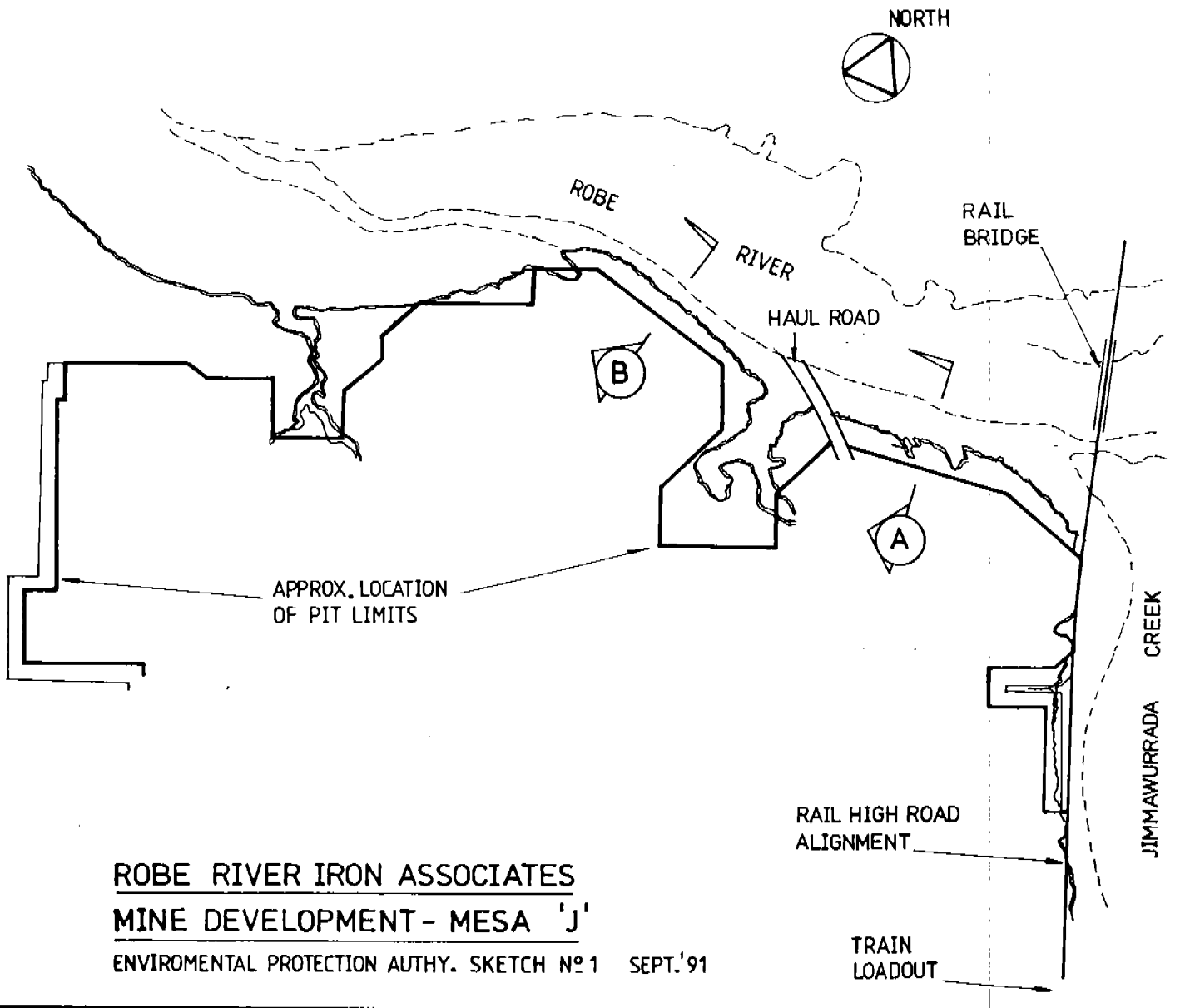


ROBE RIVER IRON ASSOCIATES

MINE DEVELOPMENT - MESA 'J'

ENVIROMENTAL PROTECTION AUTHY. SKETCH Nº 1 SEPT.'91

PROPONENT'S COMMITMENTS (CONSOLIDATED)

MESA J IRON ORE DEVELOPMENT, PANNAWONICA (590)

The proponent has made the following environmental commitments:

1. The proponent will develop and implement environmental monitoring and management programmes for the mining operation and associated activities in the course of project implementation.

2. The proponent will assign environmental monitoring and management responsibilities to appropriate personnel for the duration of the project.

3. The proponent will develop and implement an environmental awareness programme for all construction and operational workforce at the implementation phase of the project, and will continue it during ensuing years.

4. The proponent will minimise as far as practicable, recognising the requirements of mining and ore transfer, direct and indirect alteration of the physical environment for the duration of the project.

5. The proponent will control and monitor and manage noise, occupational and ambient dust, erosion, stormwater discharge, and sewage disposal for the duration of the project.

6. The proponent will implement landform stabilization and revegetation programs in the project area for the duration.

7. The proponent will monitor and manage dewatering of the mining area, and discharge of excess water to adjacent watercourses.

8. The proponent will take appropriate steps to protect, monitor and manage hydrology and vegetation within the adjacent riverine environment.

9. The proponent will monitor and manage any scour or siltation in the Robe River and Jimmawurrada Creek adjacent to the project, and will implement remedial works if deemed necessary by expert opinion.

10. The proponent will minimise, as far as practical, disturbance to culturally significant sites for the duration of the project.

11. At the completion of the project, the proponent will prepare the site for abandonment in accordance with the requirements of the Mines Department and in recognition of the requirements of the Iron Ore (Robe River) Agreement Act, 1964, including, as applicable:

1. Re-establishment of pre-existing drainage patterns as far as can be practicably achieved;
2. The initiation of stabilisation and revegetation activities to stabilise structures and communities; and
3. The mining plan will be modified to incorporate the return of as much waste rock to the mined out pit as can be practically achieved during the life of the project.

Attachment to Statement 208

Change to Description of Proposal

Proposal: Mesa J Iron Ore Development

Proponent: Robe River Mining Co. Pty. Ltd.

Change: Mesa J Mine Pit Extension

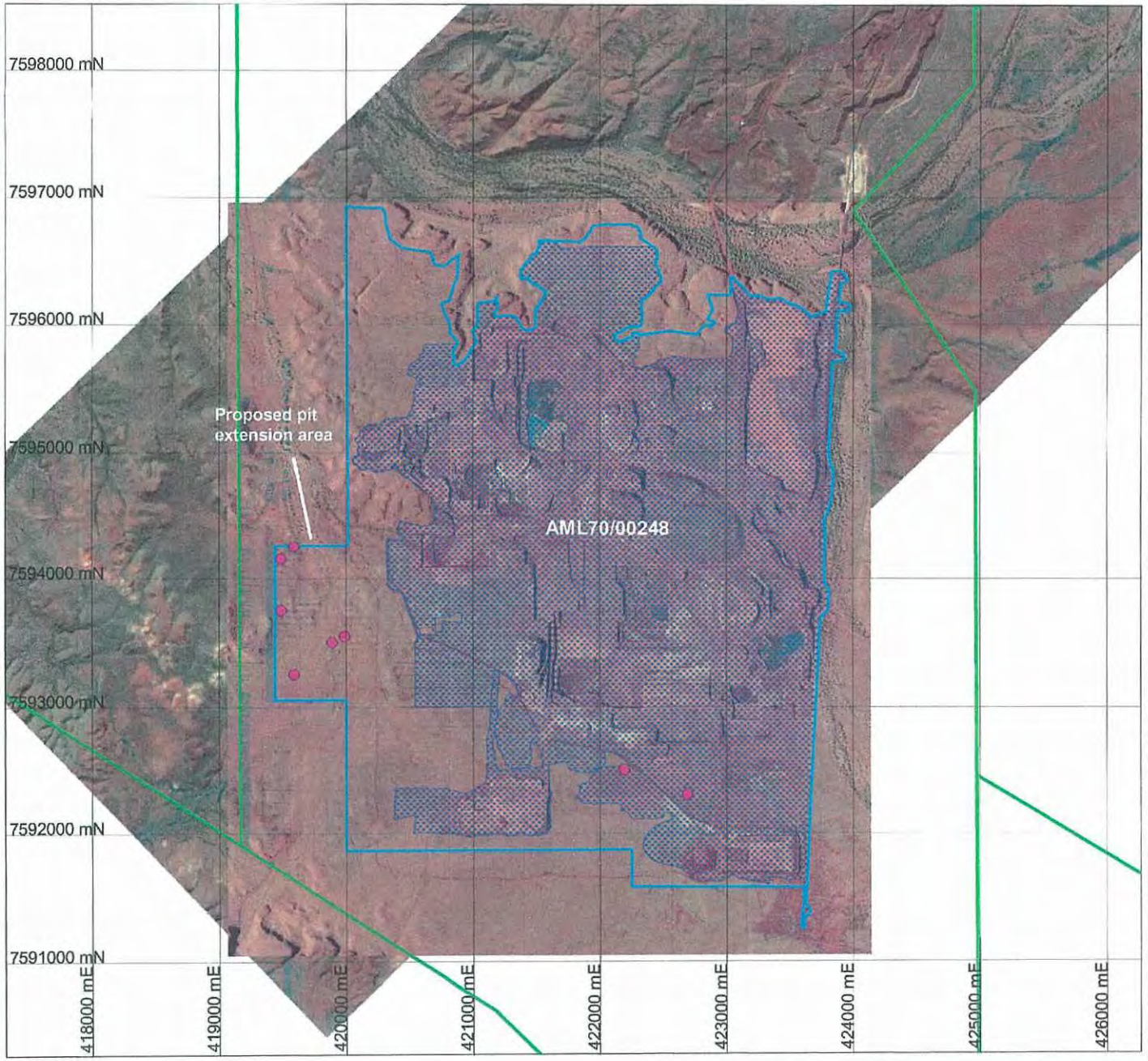
From:

To:

Element	Quantities/Description
Project life	18 - 25 years
Ore reserve	Approximately 600 million tonnes (Mt)
Percentage mining below water table and depth of mining	Approximately 42 per cent (%), to depth of approx. 120mRL
Total disturbance area (vegetation clearing)	1800 hectares (ha)

Figure 1. Proposed Pit Extension and Improved Boundary Definition

Approval Date: 20/12/05



Area disturbed to end December 2004

Proposed improved boundary definition

Troglobitic fauna sampling location

N

500 0 500 1000 1500 2000

Meters

Scale: 1:48,000

Pilbara Iron

Figure 1
Proposed Pit Extension and Improved Boundary Definition

Author: Fiona Bell	Date: 22/8/05
Drawn:	Revised:
Dwg No.:	Report No.:
Projection: MGA Zone 50 (GDA94)	Scale: 1:48,000

Attachment to Statement 208

Change to Description of Proposal

Proposal: Mesa J Iron Ore Development, Pannawonica

Proponent: Pilbara Iron Pty Ltd for Robe River Mining Co. Pty. Ltd.

Change: New rail siding at Green Pool

Features of currently approved Proposal:

Element	Quantities/Description
Railway	Single standard railway line

Features of approved change to Proposal:

Element	Quantities/Description
Railway	Single standard railway line with a passing station at Green Pool, centre at 63km and a passing track, backtrack and spur.

Figure 1. Location

Approval Date: 13/11/06

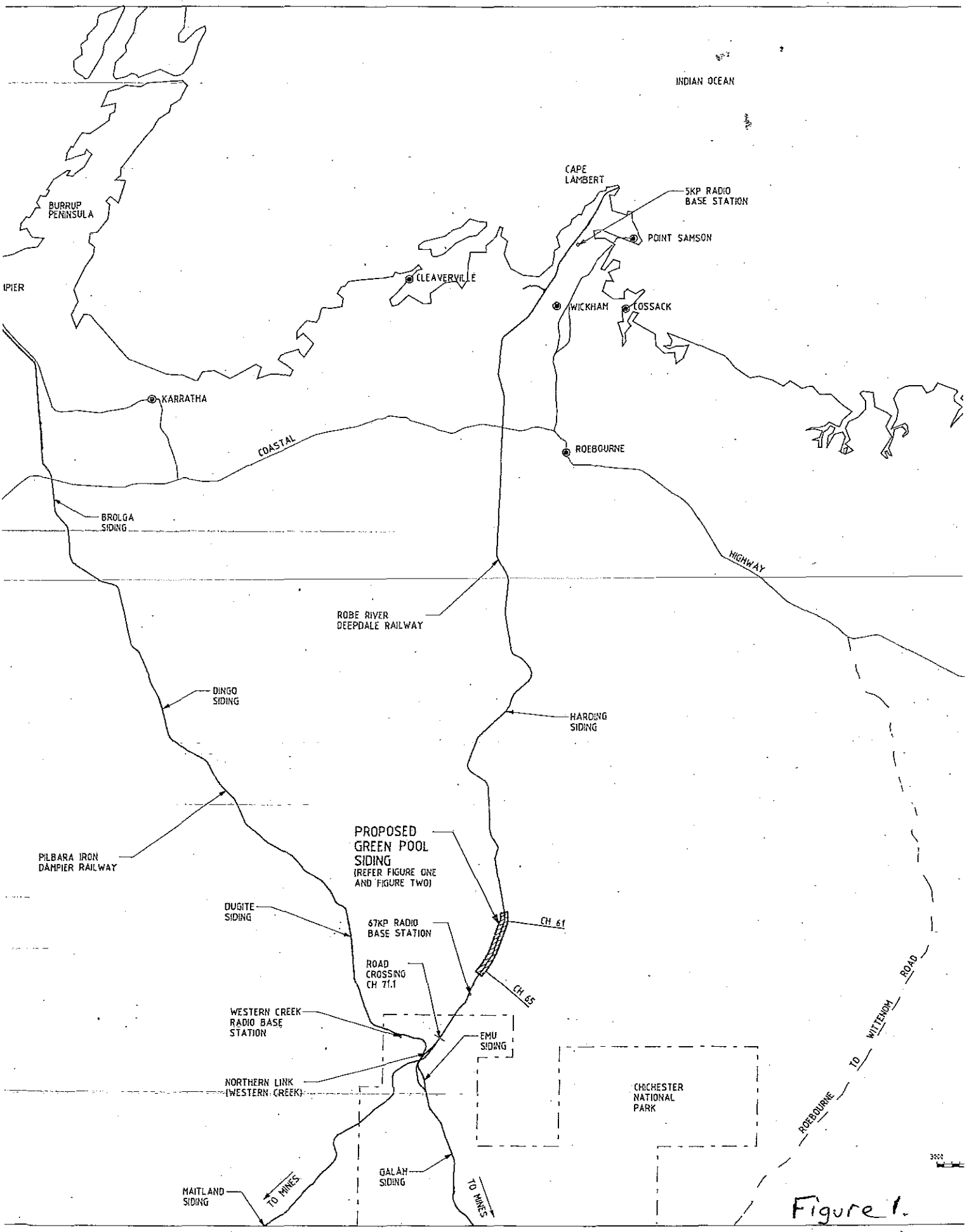


Figure 1.

REVISIONS														
REV	BY	DATE	DESCRIPTION	CKD	APP	REV	BY	DATE	DESCRIPTION	CKD	APP	DRAWN	TRANSMIRC
												TRACED	
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												APPROVED	
												APP. FOR CONST	

Attachment to Statement 208

Change to description of Proposal

Proposal: Mesa J Iron Ore Development, Pannawonica

Proponent: Pilbara Iron (on behalf of Robe River Mining Co Pty Ltd)

Change: Installation of Fibre Optic Cable for railway communications system

Features of currently approved Proposal:

Element	Quantities/Description
Railway communications system	Single standard gauge railway line with a voice and data radio communications system.
Vegetation disturbance from railway communications construction	Unspecified in original approval.

Features of approved change to Proposal:

Element	Quantities/Description
Railway communications system	Single standard gauge railway line with a voice and data radio communications system with a Fibre Optic Cable from the 5 kilometre peg near Cape Lambert to the 71 kilometre peg near Western Creek.
Vegetation disturbance from railway communications construction	Unspecified plus 11 hectares permanent and 48 hectares temporary.

Approved: 6 March, 2007

Attachment 2 to Statement 208

Change to Proposal

Proposal: Mesa J Iron Ore Development, Pannawonica

Proponent: Robe River Iron Associates

Change: Installation of Fibre Optic Cable for railway communications system from the Cape Lambert administration offices to the 5 kilometre peg and from the 71 kilometre peg to the Mesa J mine operations at Pannawonica (known as "the Deepdale Fibre Optic Cable").

Features of previously approved Proposal:

Element	Quantities/Description
Railway communications system	Single standard gauge railway line with a voice and data radio communications system.
Vegetation disturbance from railway communications construction	Unspecified in original approval.

Features of changed Proposal:

Element	Quantities/Description
Railway communications system	Single standard gauge railway line with a voice and data radio communications system with a Fibre Optic Cable from the Cape Lambert administration offices to the 5 kilometre peg, and from the 71 kilometre peg to the Mesa J mine operations at Pannawonica (a total of approximately 130 kilometres).
Vegetation disturbance from railway communications construction	Unspecified plus 0.3 hectares permanent disturbance for construction of three 'communication shelters', and 68 hectares temporary disturbance.

Approved under delegation from the Minister for the Environment:

EPA Chairman

Approval Date: 26/10/07

RioTinto

Draft Environmental Management Plan

Mesa J Hub

February 2019

RTIO-HSE-0325684

Robe River Mining Co. Pty. Limited

152-158 St Georges Terrace, Perth

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RioTinto

Disclaimer and Limitation

This Environmental Management Plan has been prepared by Rio Tinto's Iron Ore group (Rio Tinto), on behalf of Robe River Mining Co. Pty. Limited (the Proponent), specifically for the Mesa H and J Project (Mesa J Hub). Neither the report nor its contents may be referred to without the express approval of Rio Tinto, unless the report has been released for referral and assessment of proposals.

Document Status					
Rev	Author	Reviewer/s	Date	Approved for Issue	
				To Whom	Date
A-B	Rio Tinto	Approvals Ops Environment	July 2018		
1	Rio Tinto	GM West Angelas and Robe Valley	July 2018	EPA Services	July 2018
2	Rio Tinto		September 2018	EPA Services	September 2018
3	Rio Tinto	Rio Tinto HSES	February 2019	EPA Services	February 2019

Summary

This Mesa H and J Environmental Management Plan (Mesa J Hub EMP) is submitted by Rio Tinto on behalf of Robe River Mining Co. Pty. Limited (the Proponent) in accordance with Ministerial Statement xxxx (MS xxxx).

Summary Table 1 below presents the environmental criteria to measure achievement of the environmental outcomes that must be met through implementation of this EMP.

Summary Table 1: Environmental criteria to measure achievement of environmental outcomes and objectives

Proposal title		Mesa H (Revision to Mesa J Iron Ore Development)
Proponent		Robe River Mining Co. Pty. Ltd.
Ministerial Statement		MS xxxx
Purpose of this EMP		This EMP fulfils the requirements of the Mesa H (Revision to Mesa J Iron Ore Development) Environmental Scoping Document and Conditions x – x of MS xxxx.
Mesa J and Mesa H **Inland Waters; Vegetation; and Aquatic Fauna** - abstraction of groundwater; surface water discharge; riparian vegetation and groundwater dependent ecosystems of the Robe River and Jimmawurrada Creek. **EPA Objective:** *To protect flora and vegetation so that biological diversity and ecological integrity are maintained* *To maintain the hydrological regimes and quality of groundwater and surface water so that environmental values are protected.*		
Outcome Based Provisions	**Condition environmental outcome**	The Proponent shall ensure there is no irreversible impact to the semi-permanent and permanent pools of the Robe River, aquatic fauna of the Robe River pools, and health of riparian vegetation communities of the Robe River and Jimmawurrada Creek as a result of groundwater abstraction and discharge for the Revised Proposal (Figure 1-3). The Proponent shall ensure that groundwater abstraction and surplus dewater discharge does not cause long term impacts to the Aboriginal heritage values linked to the physical and/or biological surroundings of the Robe River.

	Trigger criteria	1. The mean vegetation index for the riparian upper canopy (*E. victrix, E. camaldulensis* and *M. argentea*) of Zones 1 & 2 of Jimmawurrada Creek and the Robe River declines by ≥ 2 standard deviations from baseline. 2. A statistically significant decline from baseline ($p<0.05$) in the number and/or cover of native perennial species of Zones 1 & 2 of Jimmawurrada Creek and the Robe River. 3. Detection of new introduced species at a potential impact site, previously not detected within the Development Envelope. 4. Decline of >0.5m between paired Alluvial Aquifer bores in the Robe River near targeted pools. 5. Yeera Bluff (Gnieroora) Pool drops below 2m depth. 6. Water quality in pools exceeds rolling quarterly median measured against the operational guideline SSTV equivalent of 95%ile value of baseline or the ANZECC/ARMCANZ (2000) default TV for toxicants for protection of 95% of species, whichever is higher (except for pH).
	Threshold criteria	1. The mean vegetation index for the riparian upper canopy (*E. victrix, E. camaldulensis* and *M. argentea*) of Zones 1 & 2 of Jimmawurrada Creek and the Robe River declines by ≥ 2 standard deviations from baseline over two consecutive monitoring events. 2. A statistically significant decline from baseline ($p<0.05$) in the number and/or cover of native perennial species over two consecutive monitoring events of Zones 1 & 2 of Jimmawurrada Creek and the Robe River. 3. Detection of new introduced species rated high or very high management priority (by the Department of Biodiversity, Conservation and Attractions) at a potential impact site, previously not detected within the Development Envelope and a significant increase in cover or abundance over successive monitoring events. 4. Decline of ≥1 m between paired Alluvial Aquifer bores in the Robe River near targeted pools. 5. Yeera Bluff (Gnieroora) Pool drops below 1m depth. 6. Three (3) or less species of fish recorded during a sampling event.
Mesa H **Terrestrial fauna – Ghost Bat (*Macroderma gigas*)** **EPA Objective:** *To protect terrestrial fauna so that biological diversity and ecological integrity are maintained.*		
Outcome Based Provisions	**Condition environmental outcome**	The Proponent shall ensure there is no irreversible impact, as a result of the Mesa H Project, to Breakaways and Gullies habitat retained in the escarpments of the Mesa H Mining Exclusion Zone (MEZ), other than exiting and authorised disturbance.
	Trigger criteria	1. Vibration levels exceed 50mm/s peak particle velocity at the potential diurnal/maternal Ghost Bat roost caves. 2. Disturbance, other than approved clearing, within 50m of the recorded back of the potential diurnal/maternal Ghost Bat roost caves.
	Threshold criteria	1. Significant damage to diurnal/maternal Ghost Bat roost caves as shown in Figure 1-4. 2. Disturbance, other than approved than approved clearing, within 40m of the recorded back of the potential diurnal/maternal Ghost Bat roost caves.

Management Based Provisions	**Condition environmental objective**	The Proponent shall improve knowledge of the Ghost Bat population and utilisation of high value habitat in the Robe Valley in order to assist in maintaining biological diversity and ecological integrity.
	Management targets	1. Estimate the local population of Ghost Bats in the central part of the Robe Valley. 2. Indicate how Ghost Bats use caves within the central part of the Robe Valley (e.g. diurnal versus maternal), including the degree of utilisation of caves by pregnant females.
Mesa H **Terrestrial fauna – Northern Quoll (*Dasyurus hallucatus*)** **EPA Objective:** *To protect terrestrial fauna so that biological diversity and ecological integrity are maintained.*		
Outcome based Provisions	**Condition environmental outcome**	The Proponent shall ensure there is no irreversible impact, as a result of the Mesa H Project, to Breakaways and Gullies habitat retained in the escarpments of the Mesa H MEZ (Figure 1-4) other than existing and authorised disturbance.
	Trigger criteria	1. Disturbance of ≥ 5% of potential Northern Quoll denning habitat on the retained escarpment (MEZ) of Mesa H.
	Threshold criteria	1. Disturbance of > 10% of potential denning Northern Quoll habitat on the retained escarpment (MEZ) of Mesa H.
Mesa H **Subterranean Fauna – Troglofauna** **EPA Objective:** *To protect subterranean fauna so that biological diversity and ecological integrity are maintained.*		
Outcome Based Provisions	**Condition environmental outcome**	The Proponent shall ensure there is no irreversible impact, as a result of the Mesa H Project, to the troglofauna habitat retained within the Mesa H MEZ (Figure 1-5).
	Trigger criteria	1. Operational error **during mining** resulting in removal of greater than 0.01% by volume annually of the MEZ at Mesa H.
	Threshold criteria	1. Net loss of the MEZ at Mesa H, at the **completion of mining**.
Management Based Provisions	**Condition environmental objective**	The Proponent shall protect the biological diversity and ecological integrity of the troglofauna assemblages of Mesa H by minimising impacts as far as practicable
	Management targets	1. Total clearing of native vegetation across the surface of the Mesa H MEZ is less than 30% of the MEZ surface area. 2. Troglofauna specimen capture rate is not below the baseline minimum for three (3) consecutive sampling events at Mesa H.
Mesa H and Mesa J **Subterranean Fauna – Stygofauna** **EPA Objective:** *To protect subterranean fauna so that biological diversity and ecological integrity are maintained.*		

Outcome Based Provisions	**Condition environmental outcome**	The Proponent shall ensure there is no irreversible impact, as a result of the Revised Proposal's water management activities, to stygofauna habitat within the CID aquifers and stygofauna / Blind Cave Eel habitat within the alluvial aquifer habitats of Jimmawurrada Creek and the Robe River shown in Figure 1-6.
	Trigger criteria	1. Groundwater levels drop three (3) m below predicted water table heights in the Jimmawurrada Creek alluvial aquifer. 2. Diversity of stygofauna Orders collected during annual survey events reduced to three (3) or less.
	Threshold criteria	1. Alluvial aquifer bores in the margins of Jimmawurrada are dry for two (2) consecutive years. 2. Absence of Blind Cave Eel recorded for two (2) consecutive annual sampling events. 3. Absence of stygofauna specimens for two (2) consecutive annual sampling events.
Management Based Provisions	**Condition environmental objective**	The Proponent shall protect the biological diversity and ecological integrity of the stygofauna assemblages within the CID and Alluvial aquifer habitats shown in Figure 1-6 by minimising impacts as far as practicable.
	Management target	5. Understand the distribution and ecology of key stygofauna taxa within the Robe Valley area.

Corporate endorsement

I hereby certify that to the best of my knowledge, the provisions within this Mesa H and J Environmental Management Plan are true and correct and address the legal requirements of MS xxxx.

Name: **Signed:**

Designation: GM Robe Valley **Date:**

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1. CONTEXT, SCOPE AND RATIONALE

1.1 Mesa H and J Project (Mesa J Hub)

Robe River Mining Co. Pty. Limited (the Proponent) manages and operates the Robe Valley mining operations, which includes iron ore mines at Mesa J and H as approved by MS XXXX under Part IV of the *Environmental Protection Act 1986* (EP Act). Mesa H is an extension of the existing Mesa J operation and for the purposes of this Environmental Management Plan (EMP) both are referred to as the Mesa J Hub.

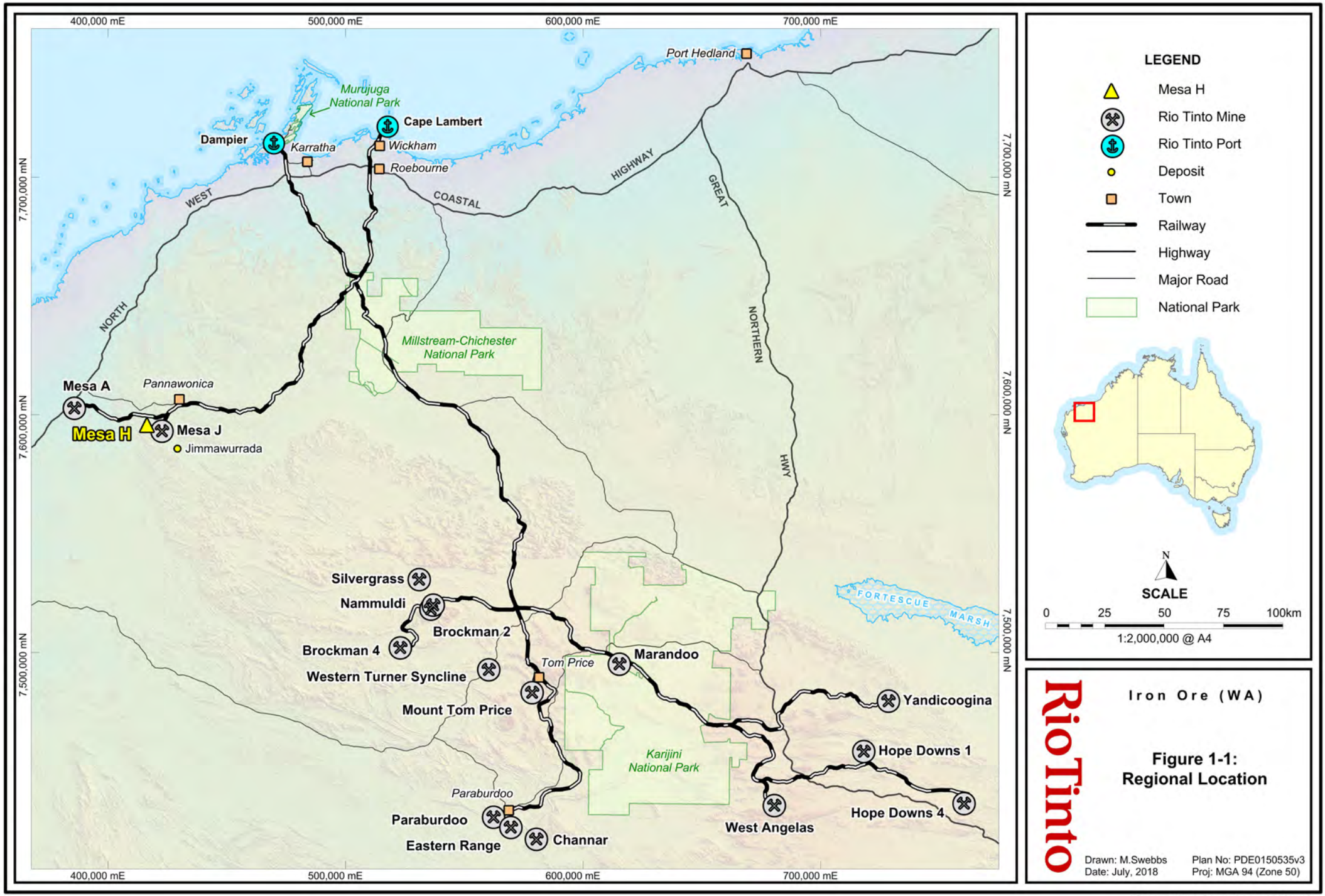
The Mesa J Hub is located approximately 16 km south west of Pannawonica in the Pilbara region of Western Australia (Figure 1-1) and consists of the following:

- Mine Pits:
  - Mesa J – open cut above and below water table pit; and
  - Mesa H - new open cut above and below water table pits.
- Ore processing supported by existing processing facilities at Mesa J, but may require other processing facilities, including, but not limited to waste fines storage facilities.
- Mineral waste management including backfilling, ex-pit waste dumps, low grade ore dumps, topsoil and sub-soil stockpiles.
- Infrastructure including but not limited to the following:
  - Dewatering and surplus water management infrastructure such as bores, pipelines, and discharge outlets, for use in processing, on-site use and controlled discharge to the Robe River and tributaries.
  - Surface water management infrastructure, including surface water diversion drains, levees and culverts.
  - Linear infrastructure, including heavy vehicle and light vehicle access roads, upgrades to existing vehicle access roads, pipelines and power (including sub-stations) and communications distribution networks.
  - Support facilities, including the workshops, power supply infrastructure, hydrocarbon storage, laydown areas, offices and waste water treatment plants.
  - Water supply utilising groundwater abstracted for dewatering, surface water that reports to pits, an expansion to the existing Mesa J borefield (Southern Cutback Borefield).

The Mesa J Hub Development Envelope and the conceptual layout for the Mesa H Project is shown in Figure 1-2.

This EMP will supersede the existing Mesa J Operation Environmental Management Plan (December 2012, RTIO-HSE-0162720).

This EMP has been developed in accordance with the EPA's *Instructions on how to prepare Environmental Protection Act 1986 Part IV Environmental Management Plans.*



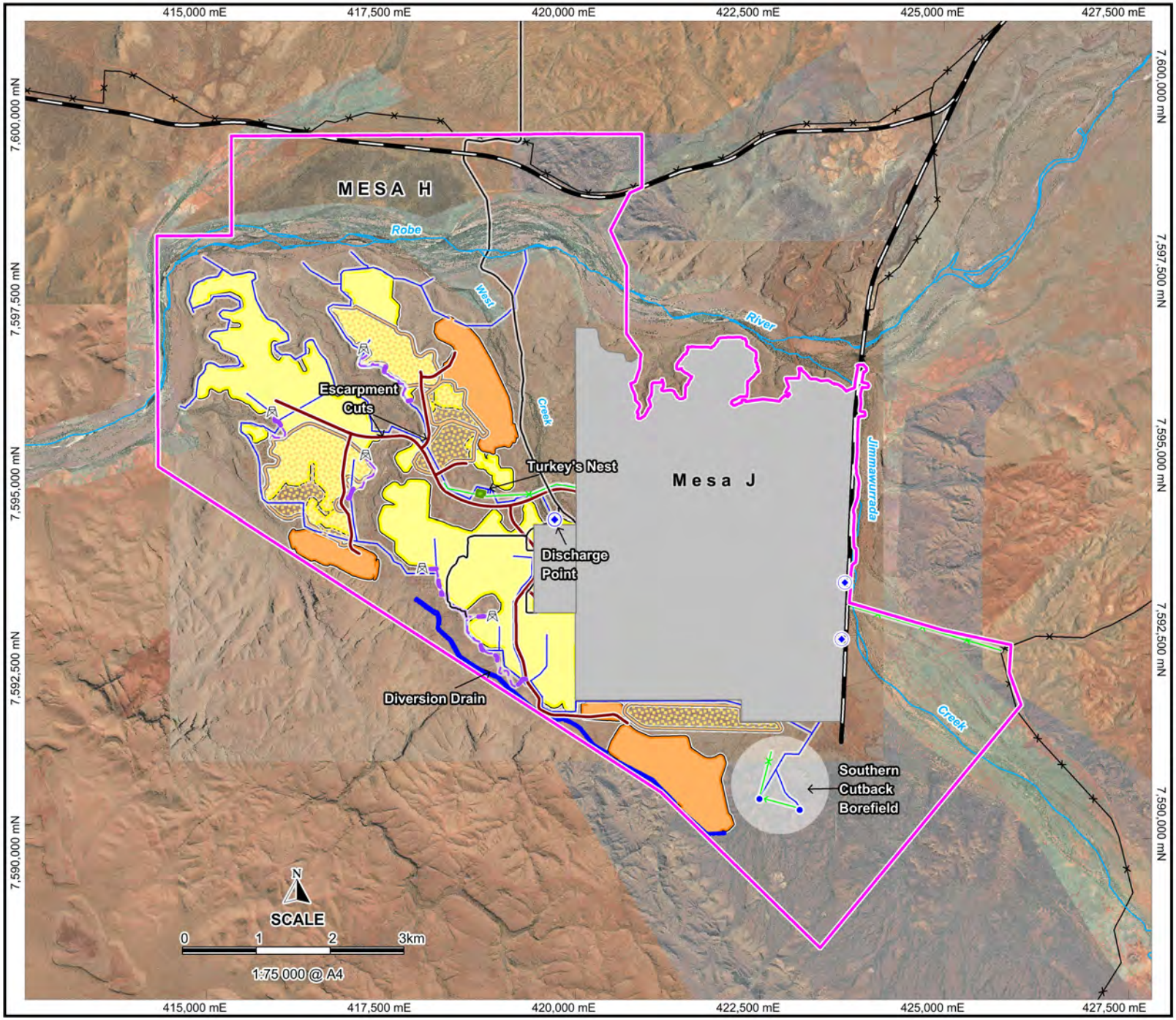
Iron Ore (WA)

Figure 1-1: Regional Location

Drawn: M.Swebbs
Date: July, 2018

Plan No: PDE0150535v3
Proj: MGA 94 (Zone 50)

Geospatial Information and Mapping



LEGEND

- Development Envelope
- Ministerial Statement 208
- Railway
- Powerline
- LV Road
- Major Watercourse
- Existing Discharge Point

Conceptual Mine Layout

- Mine Pit
- Waste Dump
- Topsoil / Subsoil Stockpile
- Turkey's Nest
- Diversion Drain
- Haul Road
- Discharge Pipeline
- Electrical Services
- Communicaiton Route
- Communication Tower
- Water Bore

Disclaimer

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Iron Ore (WA)

Figure 1-2: Mesa J Hub Development Envelope and Conceptual Layout

Drawn: M.Swebbs
Date: Aug, 2018

Plan No: PDE0152228v8
Proj: MGA94 Zone50

Geospatial Information and Mapping

1.2 Key Environmental Factors

Management of the following key aspects of the Mesa J Hub are incorporated in this EMP:

- **Inland Waters; Flora and Vegetation; and Aquatic Fauna** - abstraction of groundwater; surface water discharge; riparian vegetation and groundwater dependent ecosystems of the Robe River and Jimmawurrada Creek.
- **Terrestrial fauna** – conservation significant fauna species (Ghost Bat and Northern Quoll).
- **Subterranean fauna** – troglofauna and stygofauna.

Inland Waters

Pools and Aquatic fauna

The Robe River is predominantly an ephemeral river which carries a significant base-flow in its alluvial bed, which maintains permanent and semi-permanent pools, a number of which are contained within the Development Envelope. These pools are maintained by groundwater in the absence of surface water inputs, with a range in seasonal groundwater variability of up to 3m, as recorded in alluvial bores within the Study Area. These pools along the Robe River support “River Pool Ecosystem” type GDEs. These ecosystems are an important component of the river ecosystem, supporting a diverse range of aquatic fauna and specialised flora, and rely on consistent surface expressions of groundwater. The fringing vegetation surrounding the pools generally support a high diversity of flora species and the pools themselves were found to have elevated to high macrophyte (including sedges) and ephemeral taxa diversity

Groundwater abstraction for pit dewatering will result in localised groundwater drawdown in CID aquifers that may have some connectivity to the Robe River alluvial aquifer. Modelling indicates the potential for a reduction in water levels in the Robe River alluvial aquifer and the Robe River semi-permanent and permanent pools may be up to 1m. This is not anticipated to change the permanent or semi-permanent nature of any of the pools, but shallow pools (<1m) have the potential to dry out as a result.

Riparian Vegetation

Riparian ecosystems occur along the Robe River and along and Jimmawurrada Creek, supporting woodlands comprising silver cadjeput (*Melaleuca argentea*) and eucalypt species (*Eucalyptus camaldulensis, E. victrix*).

The riparian vegetation of Jimmawurrada Creek predominantly comprises facultative phreatophytic species (i.e. species that utilise groundwater for a portion of their water requirements, but can also satisfy their water requirements through stored soil water reserves). Riparian vegetation of the Robe River differs from Jimmawurrada Creek due to the dominance of obligate phreatophytic species, which are considered groundwater dependent.

The Mesa J Hub operations require groundwater abstraction to facilitate mining of the CID ore located below the water table, which has the potential to lower groundwater levels in the adjacent sections of the Robe River. Additional groundwater abstraction for water supply (predominantly for wet ore processing) is sourced from the Southern Cutback Borefield. The additional abstraction will result in further lowering of the groundwater table around the borefield. Combined with the cumulative effects of the Coastal water Supply Project and mine pit dewatering, the drawdown cone of depression is modelled to extend below Jimmawurrada Creek and further lower the water table between 1 – 9 m below a 12 km section of Jimmawurrada Creek.

This may reduce the availability of water to GDV occurring within the Development Envelope and adjacent sections of Jimmawurrada Creek immediately upstream of the Development Envelope, potentially resulting in health decline of these riparian communities and in some cases death of obligate phreatophytes.

All abstracted water is planned to be used on site for operational requirements however during wet season or significant rainfall events when storage capacity is exceeded, surplus water will be periodically discharged. Discharge of surplus water will be via a number of existing Mesa J discharge outlets into Jimmawurrada Creek and / or West Creek, and may intermittently result in a surface water expression extending up to 8 km from the discharge outlet(s) depending on seasonal water availability and processing plant water demand. Given the intermittent nature of discharge and discharge continuing within the existing Mesa J operational discharge footprint, no additional significant impact to riparian communities are expected.

Discharge directly into the Robe River is not proposed unless required as a mitigation strategy for maintaining the pools.

Terrestrial fauna

The most important habitat types for the Ghost Bat and Northern Quoll within the Development Envelope includes Gorge and Breakaway habitat for their cave forming characteristics providing potential shelter and foraging habitat and Riverine and Drainage Line habitats for foraging and dispersal.

Potential impacts of the Project on the Ghost Bat and the Northern Quoll are loss or fragmentation of habitat, including breeding, foraging and dispersal habitat, due to clearing; indirect disturbance to critical habitat (potential diurnal/maternal Ghost Bat roosts) via blast vibrations; and indirect impacts to foraging habitat in the Major River/Creek habitat due to groundwater drawdown and surplus water discharge.

Subterranean Fauna – troglofauna and stygofauna

The target ore body in the Mine Development Envelope comprises Robe Pisolite which is considered to be high prospectivity habitat for troglofauna and stygofauna. Most species of obligate troglofauna are considered to be Short Range Endemic (SRE) with many species believed to be endemic to individual mesas in the Robe Valley. Stygofauna are also commonly considered to be SRE's however species' distribution is linked to aquifer extent. Mine pit excavation to be conducted as part of the Project will result in direct loss of troglofauna and stygofauna habitat and a loss of individuals, which in turn has the potential to result in changes to community assemblages. Groundwater abstraction for mine pit dewatering and water supply will also result in direct loss of stygofauna habitat, loss of individuals and potential changes in community assemblages. Clearing of vegetation may lead to a reduction in organic inputs into the subterranean environment which may reduce the quality of troglofauna and stygofauna habitat.

1.3 Condition Requirements

The proposed EMP condition and the associated proposed environmental objectives for the Mesa J Hub are detailed below in Table 1-1.

Table 1-1 Proponent proposed conditions for the Mesa J Hub

Condition		Section in EMP
5	**Condition Environmental Management Plans**	
5-1	The proponent shall prepare and submit a Condition Environmental Management Plan to the satisfaction of the CEO. This plan shall demonstrate that the environmental outcomes specified in in condition 6-1, condition 7-1, condition 8-1, and condition 9-1 will be met.	
5-2	The Condition Environmental Management Plan shall: (1) specify the environmental outcomes to be achieved, as specified in condition 5-1;	Table 2-1 to Table 2-5

	Condition	Section in EMP
	(2) specify trigger criteria that must provide an early warning that the threshold criteria may not be met; (3) specify threshold criteria to demonstrate compliance with the environmental outcomes specified in condition 5-1. Exceedance of the threshold criteria represents non-compliance with these conditions; (4) specify monitoring to determine if trigger criteria and threshold criteria are exceeded; (5) specify trigger level actions to be implemented in the event that trigger criteria have been exceeded; (6) specify threshold contingency actions to be implemented in the event that threshold criteria are exceeded; and (7) provide the format and timing for the reporting of monitoring results against trigger criteria and threshold criteria to demonstrate that condition 5-1 has been met over the reporting period in the Compliance Assessment Report required by condition 3-6. For management based provisions, the Condition Environmental Management Plan shall: (8) specify the environmental objectives to be achieved, as specified in condition 5-1; (9) specify management actions to meet the environmental objective; (10) specify management targets; (11) specify monitoring to determine if management targets are being met (12) provide the format and timing for the reporting of monitoring results against management targets to demonstrate that condition 5-1 has been met over the reporting period in the Compliance Assessment Report required by condition 3-6.	
5-3	After receiving notice in writing from the CEO that the Condition Environmental Management Plan satisfies the requirements of condition 5-2 the proponent shall: (1) implement the Condition Environmental Management Plan, or any subsequent approved versions; and (2) continue to implement the Condition Environmental Management Plan until the CEO has confirmed by notice in writing that the proponent has demonstrated the objectives specified in condition 5-1 have been met.	N/A

	Condition	Section in EMP
5-4	In the event that the monitoring indicates an exceedance of the threshold criteria specified in the Condition Environmental Management Plans, the proponent shall: (1) report the exceedance in writing to the CEO within seven (7) days of the exceedance being identified; (2) implement the threshold level contingency actions specified in the Condition Environmental Management Plans within 24 hours and continue implementation of those actions until the CEO has confirmed by notice in writing that it has been demonstrated that the threshold criteria are being met and the implementation of the threshold contingency actions is no longer required; (3) investigate to determine the cause of the threshold criteria being exceeded; (4) investigate to provide information for the CEO to determine potential environmental harm that occurred due to the threshold criteria being exceeded; and (5) provide a report to the CEO within twenty one (21) days of the exceedance being reported as required by condition 5-6(1). The report shall include: a. details of threshold contingency actions implemented; b. the effectiveness of the threshold contingency actions implemented, against the threshold criteria; c. the findings of the investigations required by condition 5-5(3) and 5-5(4); d. measures to prevent the threshold criteria being exceeded in the future; e. measures to prevent, control or abate the environmental harm which may have occurred; and f. justification of the threshold remaining, or being adjusted based on better understanding, demonstrating that outcomes would continue to be met.	Table 2-1 to Table 2-5
5-5	The proponent: (1) may review and revise the Condition Environmental Management Plan, or (2) shall review and revise the Condition Environmental Management Plan as and when directed by the CEO.	N/A
5-6	The proponent shall implement the latest revision of the Condition Environmental Management Plan, which the CEO has confirmed by notice in writing, satisfies the requirements of condition 5-1 and condition 5-2.	

	Condition	Section in EMP
6	**Mesa H and J Inland Waters** **Dewatering of groundwater and groundwater dependent ecosystems of the Robe River and Jimmawurrada Creek; surface discharge of surplus water and riparian vegetation of the Robe River and Jimmawurrada Creek.**	
6-1	The proponent shall manage the implementation of the Proposal to meet the following environmental outcomes: (1) No irreversible impact, as a result of the proponent's water abstraction, to the health of groundwater dependent vegetation within the Robe River. (2) No irreversible impact, as a result of the proponent's water abstraction, to the health of riparian vegetation communities within Jimmawurrada Creek. (3) No irreversible impact, as a result of the Proponent's discharge of surplus water, to the health of riparian vegetation communities of Jimmawurrada Creek and the Robe River. (4) No irreversible impact, as a result of the Proponent's drawdown and discharge, to the pool ecosystems of the Robe River.	Table 2-1
7	**Mesa H Terrestrial Fauna** **Conservation significant fauna species; Ghost Bat (*Macroderma gigas*) and Northern Quoll (*Dasyurus hallucatus*)**	
7-1	The proponent shall manage the implementation of the Proposal to meet the following environmental outcome: (1) No irreversible impact, as a result of the proponent's activities, to Breakaways and Gullies habitat retained in the escarpments of Mesa H.	Table 2-2 Table 2-3
7-2	The proponent shall manage the implementation of the Proposal to meet the following environmental objective: (1) The proponent shall improve knowledge of the Ghost Bat population and utilisation of high value habitat in the Robe Valley in order to assist in maintaining biological diversity and ecological integrity.	Table 2-3
8	**Mesa H Subterranean fauna – Troglofauna**	
8-1	The proponent shall manage the implementation of the Proposal to meet the following environmental outcome: (1) No irreversible impact, as a result of the proponent's activities, to the troglofauna habitat retained within the Mesa H MEZ.	Table 2-4
8-2	The proponent shall manage the implementation of the Proposal to meet the following environmental objective: (1) The Proponent shall protect the biological diversity and ecological integrity of the troglofauna assemblages of Mesa H by minimising impacts as far as practicable.	Table 2-4
9	**Mesa H and Mesa J Subterranean fauna – Stygofauna**	
9-1	The proponent shall manage the implementation of the Proposal to meet the following environmental outcome: (1) No irreversible impact, as a result of the proponent's water management activities to the stygofauna habitat within the CID aquifer and stygofauna and Blind Cave Eel habitat within the alluvial aquifer habitat of Jimmawurrada Creek and the Robe River.	Table 2-5
9-2	The proponent shall manage the implementation of the Proposal to meet the following environmental objective:	Table 2-5

Condition			Section in EMP
	(1)	The Proponent shall protect the biological diversity and ecological integrity of the stygofauna assemblages within the Robe River and Jimmawurrada Creek alluvial aquifer habitats by minimising impacts as far as practicable.	

1.4 Rationale and Approach

This EMP addresses environmental factors (and relevant environmental outcomes and objectives) which were determined by the Department of Water and Environmental Regulation – EPA Services (EPA Services) as being relevant to the management of groundwater abstraction, surface water discharge, conservation significant vegetation communities and fauna species associated with the Mesa J Hub.

This EMP identifies:

- The environmental criteria that the Proponent will use to monitor performance of the management measures to ensure environmental objectives are met.
- The management actions that will be implemented in response to monitoring results.

Results of baseline surveys, monitoring and a number of assumptions and uncertainties inform the management approach for meeting the environmental outcomes and objectives stated in conditions 6, 7, 8 and 9 of MS xxxx.

The identified trigger criteria, threshold criteria, management targets and response actions are aligned with the overall management approach.

Monitoring data is used to evaluate compliance with the trigger and threshold criteria to achieve the environmental outcomes and management targets are used to assess whether the management actions are effective in meeting the environmental objectives.

1.4.1 Survey and Study Findings

a) Inland Waters – Pools and Aquatic Fauna

Permanent and semi-permanent pools exist along the Robe River due to the significant subsurface flow in the coarse channel gravels of the Robe River alluvial aquifer. There is potentially a strong hydraulic correlation between the Robe River alluvium and the underlying aquifer, the direction of interaction changes seasonally in response to stream flow events and evapotranspiration. Streamflow events also recharge groundwater, causing the groundwater level to rise, creating large and continuous pools. After a period of no flow, the hydraulic gradient between the groundwater and the pools reverse and groundwater discharges into the pools. Ephemeral pools eventually become disconnected from intermittent pools and as surface water evaporates, these pools reduce in size or disappear.

Drought conditions and declining groundwater levels result in shallower pool depths and semi-permanent pools becoming disconnected from the groundwater. Permanent pools have long-term connectivity to the groundwater and are expected to be maintained by natural groundwater discharge during drought periods.

The history of isolation of river systems of the Pilbara results in a low biodiversity of freshwater fish being recorded from the Pilbara (12 species) (Allen *et al*. 2002 cited in Streamtec 2017). A total of ten species have been recorded in the Robe River during aquatic surveys since 1991 (Streamtec 2017).

The baseline aquatic survey in 2016 (WRM 2017) recorded a total of 3,515 fish in the Development Envelope including seven true freshwater taxa. There was no significant difference in abundance of fish upstream and downstream of the Jimmawurrada-Robe confluence; however, there was a significant difference in mean species richness between upstream and downstream, with significantly higher richness downstream of the Jimmawurrada-Robe confluence, adjacent to the Mesa J Hub.

b) Inland Waters - Riparian Vegetation

Robe River

The Robe River is an ephemeral river with significant base-flow in its alluvial aquifer, which maintains permanent and semi-permanent pools; a number of which are within the Development Envelope. These pools are maintained by groundwater in the absence of surface water inputs, with a range in seasonal groundwater levels of up to 3m, as recorded in alluvial bores. As groundwater levels drop during prolonged dry periods, the semi-permanent pools may dry out.

Key features of the vegetation associated with the Robe River in the Development Envelope (as summarised by Astron 2018) include:

- No Threatened or Priority Ecological Communities (TECs/PECs) and no Threatened flora; however does contain Priority flora (primarily *Rhynchosia bungarensis* P4).
- Permanent and semi-permanent pools - these pools generally support high species diversity. Vegetation surrounding these pools is typically dominated by dense *Melaleuca argentea* and *Eucalyptus camaldulensis* subsp. *refulgens* over sedge, grass and herbaceous species.
- Pools and main channels support Groundwater Dependant Ecosystems including groundwater dependant vegetation dominated by *M. argentea.*
- Vegetation condition varies from 'Very Poor' to 'Excellent' in the Robe River and its tributaries. Poorer condition is generally as a result of weed proliferation, grazing and trampling. **Cenchrus* species (spp.) (Buffel and Birdwood Grasses) are a common component of the vegetation in some areas.

Jimmawurrada Creek

Jimmawurrada Creek is an ephemeral system with negligible base-flow, and possesses stretches of riparian vegetation which has been modified by changes to drainage lines; drawdown associated with the Mesa J Project, the Southern Cutback Borefield and the Coastal Water Supply; and mine dewatering discharge through existing licensed outlets.

Key features of the vegetation associated with Jimmawurrada Creek in the Development Envelope and within the extent of the modelled groundwater drawdown include:

- No TECs or PECs and no Threatened flora.
- No permanent and semi-permanent pools.
- Vegetation is dominated by *Eucalyptus camaldulensis* subsp. *refulgens* and *E. victrix*
- Vegetation condition varies from 'Very Poor' to 'Excellent' with poorer condition generally as a result of weed proliferation, grazing and trampling. **Cenchrus* species (Buffel and Birdwood Grasses) are a common component of the vegetation in some areas.

Refined Riparian Mapping

Given the local and sub-regional significance of the riparian zone vegetation, a refined riparian mapping program was undertaken across both the Robe River and Jimmawurrada Creek (Rio Tinto 2017a, 2017b) in order to attribute an impact 'risk rating' to each vegetation association. This involved an interpretation of the degree of sensitivity (or vulnerability) of each community to hydrological change and the risk that "measurable" impact/change to a community could result from significant hydrological changes.

Within the Development Envelope, Astron (2016a) mapped two riparian communities which they identified as potential GDE's: MaEcCv (representing the obligate phreatophytic (OPV) or generally "high risk" type communities mapped by Rio Tinto (2017a); and EcEvAtrApyPlTw) (representing the

facultative phreatophytic (FPV) or generally “moderate risk” type communities mapped by Rio Tinto (2017a)).

Vegetation association MaEcCv was considered a GDE due to the dominant species being *Melaleuca argentea* (an obligate phreatophyte) and *E. camaldulensis var. refulgens* (a facultative phreatophyte). *M. argentea* and *E. camaldulensis* var. *refulgens*, and therefore the vegetation in which they predominate, is highly likely to be sensitive to changes in groundwater depth and availability. These two vegetation associations are typical of riparian vegetation that occurs along minor and major channels within the River Land System in the Pilbara.

The two riparian vegetation units identified by Astron (2016a, 2016b) as GDE’s equate to ten ‘refined’ units mapped by Rio Tinto (2017a, 2017b), only three of which are considered to contain obligate phreatophytes (Table 1-2). The differentiation by Rio Tinto (2017a, 2017b) is a result of differences in canopy structure, the dominance or co-dominance of *E. camaldulensis* versus *E. victrix*, and differences in mesic understorey composition observed through detailed field mapping (Rio Tinto 2017a, 2017b).

The three key vegetation associations identified by Rio Tinto (2017a, 2017b) as representing GDE communities and dominated by obligate phreatophytes comprise: C1AA (a&b); C1A; and C1B. The C1AA (a&b) and C1A communities possess relatively mature OPV, while the C1B community comprises relatively immature OPV. The mature community was generally uniform in its presence and spatial extent in the environment, indicating more consistent groundwater access, whereas the immature community is likely to be more transient in nature, have less consistent groundwater access and likely to have established in response to dewatering discharge. The C1AA communities have a canopy dominated by *Melaleuca argentea,* which generally form an open forest overstorey, whereas C1A and C1B communities had an overstory only co-dominated by *Melaleuca argentea (*and *Eucalyptus* spp.*)*.

Table 1-2: Significant riparian vegetation units in the Development Envelope

Astron (2016a, 2016b) vegetation association	Equivalent (or associated) Rio Tinto (2017a, 2017b) units*	Broad Rio Tinto (2017) GDE classification type	Rio Tinto (2017) Residual Significance
MaEcCv	**C1AA (a&b), C1A, C1B**	OPV-A, B and C (vegetation at least co-dominated by the obligate phreatophyte *Melaleuca argentea* of varying age structure)	High to Moderate (locally and sub-regionally significant)
EcEvAtrApyPITw	**C2AA**, C2AACr, C2A, C2B, C2A-B, C2B-B, C3A	FPV-A and FPV-B (vegetation at least co-dominated by the facultative phreatophyte *Eucalyptus camaldulensis*)	Moderate to Minor (locally restricted but common regionally to common locally and regionally)

*Bold and underlined units indicate significant vegetation

Of the Rio Tinto (2017a) refined riparian vegetation units, only the *Melaleuca argentea* dominated and co-dominated communities (C1AA(a&b), C1A, and C1B) are considered locally and sub-regionally significant as potential GDE’s (Rio Tinto 2017a, 2017b). Unit C2AA (*Eucalyptus camaldulensis* open forest) is considered to be locally and potentially sub-regionally significant and similar to Astron’s (2016a) EcEvAtrApyPITw community.

Unit C2A (*Eucalyptus camaldulensis* woodland-open forest) mapped on Jimmawurrada Creek is broadly similar to the significant C2AA community but the conservation significance was reduced based on it being restricted to creek landforms, possessing lower species diversity, having reduced condition due to grazing pressure and alteration of the community from discharge. The remaining units are typically found in mesic riparian environments and are widely represented in creek and river systems in the Pilbara (Rio Tinto 2017a).

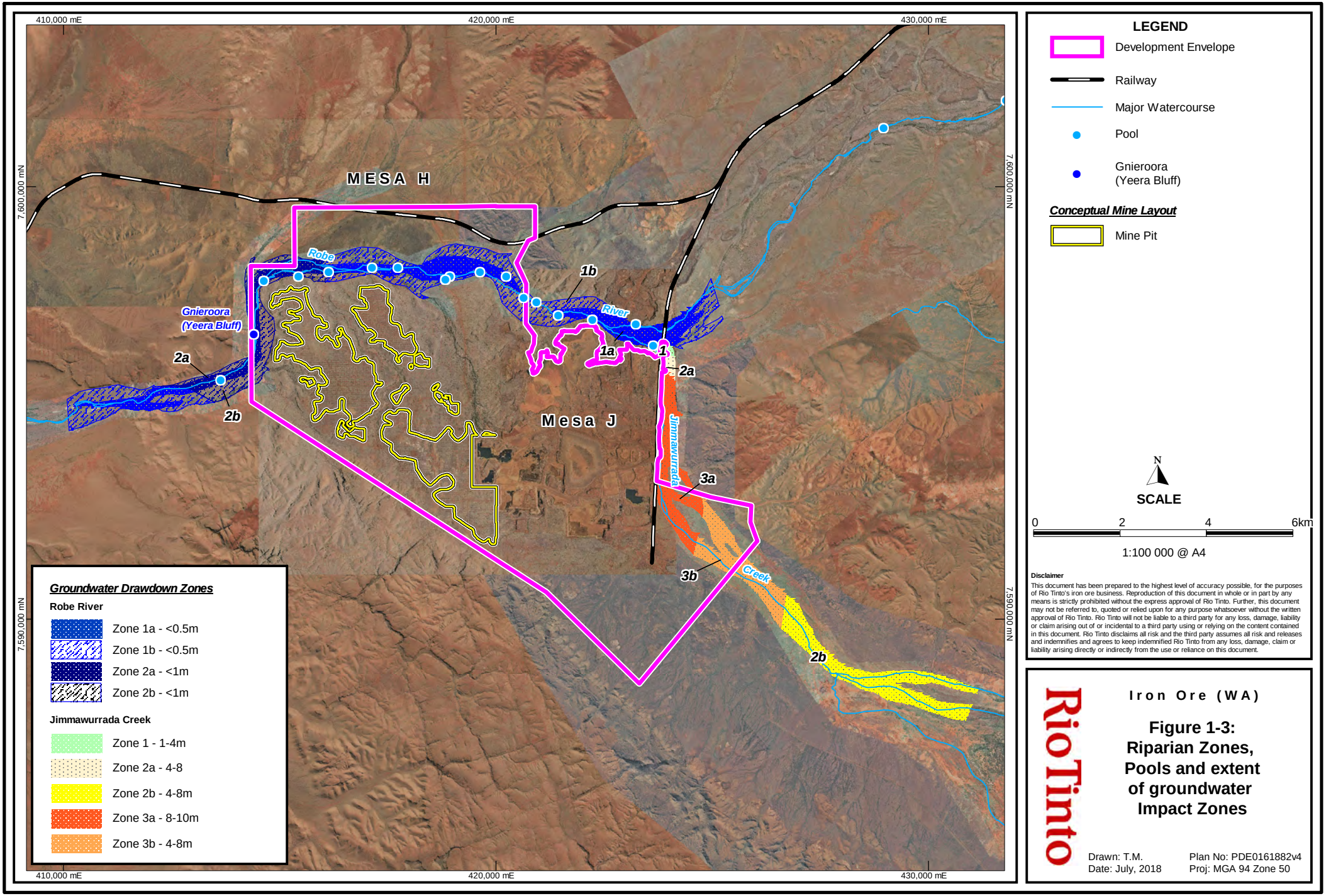
Based on the refined riparian mapping and likely sensitivity of the riparian vegetation units to changes in groundwater levels, combined with predicted extent and depth of groundwater drawdown, a number of impact 'Zones' have been defined along Jimmawurrada Creek and the Robe River as provided in

Table 1-3 and shown in Figure 1-3.

Table 1-3: Riparian vegetation Zones in the Development Envelope and extent of modelled groundwater drawdown

Zone	Max water table depth - (bgl)		Magnitude of Drawdown	Mitigating factors	Presence/Absence of OPV or FPV in the Riparian Zone
Jimmawurrada Creek					
JIM 1	*<7		*1-4	Discharge and Robe River alluvial aquifer; large scale influence. Surface water flows; moderate to large scale influence (due to creek attenuation by range).	Some OPV present, although FPV broadly dominant. Potential baseline OPV restricted to low flow channels skirting the west bank within this zone. The remainder of OPV in this zone appears to have established post mining. Single riparian corridor present.
JIM 2	A	*7-11	*4-8	Discharge; large scale Influence. Robe River alluvial aquifer; moderate to large scale influence. Surface water flows; moderate to large scale influence (due to creek attenuation by the range).	Some pre and post-mining (augmented) OPV present, however creek broadly dominated by FPV. OPV generally restricted to a strip surrounding the low flow channel skirting the west boundary of the creek. Single riparian corridor present.
	B			Discharge; low to negligible influence. Surface water flows; moderate scale influence.	OPV absent. Creek dominated by FPV. Single riparian corridor present in the west, dual corridors (Channel splits to Bungaroo and Jimmawurrada Creeks) in the eastern end of polygon.
JIM 3	A	*11-14	*8-10	Discharge; minor to moderate scale influence. Surface water flows; moderate to large scale influence.	Some post-mining (augmented) OPV present, however creek broadly dominated by FPV. OPV generally restricted to a thin strip surrounding the low flow channel skirting the west boundary of the creek. Single riparian corridor present in the north, dual corridors in the southern 1/3 of polygon.
	B		*4-8	Discharge; low to negligible scale influence. Surface water flows; moderate scale influence.	No OPV present; area dominated by FPV. Dual riparian corridor present in two sections, with a central section where a single corridor is present.
Robe River					
RR-1A	Zone A*: Low flow and secondary	~1.5-3m	~<0.5m	Discharge; minor to moderate scale influence. Surface water flows and subsurface base-flow; large scale influence.	OPV represents the dominant riparian vegetation present. FPV is also common and relatively widespread.

Zone	Max water table depth - (bgl)		Magnitude of Drawdown	Mitigating factors	Presence/Absence of OPV or FPV in the Riparian Zone
	channel Zones.				
RR-1B	Zone B*: Outer/flanking, and generally more elevated cobbled bed zones – includes minor channels.	~3 - 5.5m	<0.5m	Discharge; minor scale influence. Surface water flows and subsurface base-flow; large to moderate scale influence.	FPV represents the dominant riparian vegetation present. OPV is also common throughout.
RR-2A	Zone A*: Low flow and secondary channel Zones.	2 - 3.5m	*<1m	Discharge; minor to moderate scale influence. Surface water flows and subsurface base-flow; large scale influence.	OPV represents the dominant riparian vegetation present. FPV is also common and relatively widespread.



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Iron Ore (WA)

Figure 1-3: Riparian Zones, Pools and extent of groundwater Impact Zones

Drawn: T.M.
Date: July, 2018

Plan No: PDE0161882v4
Proj: MGA 94 Zone 50

Geospatial Information and Mapping

c) Terrestrial fauna – Ghost Bats

Roost sites used permanently by Ghost Bats are generally deep natural caves with a relatively stable temperature of 23-28^{o}C and humidity above 50%. Individuals require a range of cave sites and move between roosts seasonally or according to weather conditions. The most significant habitats in the Development Envelope for the species are the Breakaways and Gullies (including the mesa escarpments) and the Major River/Creek habitat (Figure 1-4); these areas represent potential roosting and foraging habitat. Habitat loss through impact or disturbance to roost sites, specifically caves that play a role in breeding activities (maternal roosts), and nearby areas is seen as a key risk to this species conservation status.

Previous assessments of caves in the Mesa H Survey Area and Development Envelope (Astron 2014; Bat Call 2017a) have collectively identified two diurnal roosts (with maternity roost potential) and ten nocturnal feeding roosts (two were part of the one system) (Astron 2017a) Figure 1-4.

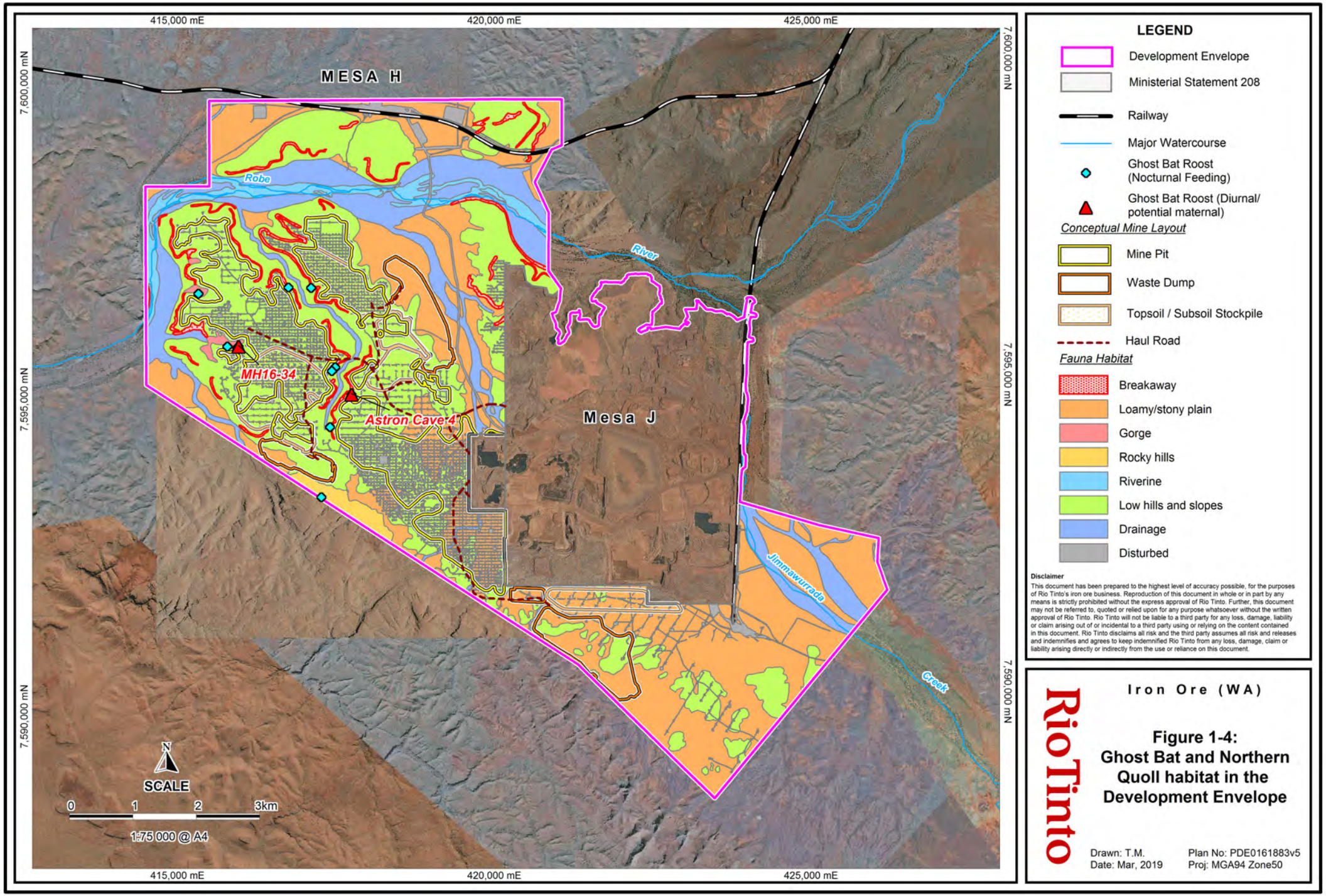
An assessment of the conservation value of caves associated with Ghost Bats at Mesa H indicated that Ghost Bat presence at the mesa is intermittent, with the mesa being used for nocturnal foraging and occasional diurnal roosting (Bat Call 2017a). The Ghost Bats at Mesa H likely originate from Buckland Hills to the south, Yeera Bluff (Gnieroora) between Mesa's G and H or the Three Peak hills to the north-west (Bat Call 2017a).

d) Terrestrial fauna - Northern Quoll

In the Pilbara, the Northern Quoll favours rocky gorges, breakaways and hills, usually of high relief and often along drainage lines for denning purposes. Adjacent plains and vegetated areas provide habitat suitable for foraging and dispersal of young (Van Dyck and Strahan 2008), but are considered to be of less importance for the species' conservation (DSEWPaC 2011). The rocky facades of the mesa landforms are important sources of shelter, food and moisture for species of conservation significance.

The Northern Quoll was recorded in the Development Envelope, with the majority of records occurring in Breakaway habitat with some in Riverine and Gorge habitat types; however, the species is also likely to utilise Rocky Hills habitat (Astron 2017a). Historical surveys have also recorded the Northern Quoll from scat records within the Rocky Hills habitat type immediately south of the Development Envelope and within Riverine and Breakaway habitats within the Development Envelope (Astron 2015 and Biota 2011). All previous records of this species in the Development Area were from sites consistent with the preferred habitat for this species.

The most important habitat types for the Northern Quoll likely includes the Gorge and Breakaway habitat (Figure 1-4), which contain rocky environments of high relief that are particularly important for Northern Quolls as they provide potential denning sites for breeding and shelter and diverse microhabitats for foraging (Astron 2017a). The Riverine and Rocky Hills habitats, especially adjacent to Gorge and Breakaway habits provide microhabitats for (e.g. crevices and cracks) for foraging (Astron 2017a).



LEGEND

- Development Envelope
- Ministerial Statement 208
- Railway
- Major Watercourse
- Ghost Bat Roost (Nocturnal Feeding)
- Ghost Bat Roost (Diurnal/ potential maternal)

Conceptual Mine Layout

- Mine Pit
- Waste Dump
- Topsoil / Subsoil Stockpile
- Haul Road

Fauna Habitat

- Breakaway
- Loamy/stony plain
- Gorge
- Rocky hills
- Riverine
- Low hills and slopes
- Drainage
- Disturbed

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Iron Ore (WA)

Figure 1-4: Ghost Bat and Northern Quoll habitat in the Development Envelope

Drawn: T.M.
Date: Mar, 2019

Plan No: PDE0161883v5
Proj: MGA94 Zone50

e) Subterranean fauna - Troglofauna

Troglofauna were first recorded at Mesa A in 2003 as by-catch of stygofauna sampling. Since 2003 numerous troglofauna surveys and assessments have been undertaken across the Robe Valley. The combined coverage of these surveys provides a considerable knowledge base of the troglofauna present in the Mesa H and J Development Envelope.

One of the key characteristics of geological units known to provide habitat for troglofauna relates to the physical features, particularly the presence of fractures and cavities sufficient in size to accommodate troglofauna. Throughout the Pilbara, a range of geological formations contain the necessary physical characteristics that have been shown to provide habitat for troglofauna. In the Development Envelope the Robe Pisolite is considered to be the geological unit that provides primary habitat for troglofauna as it contains the necessary cavities to accommodate troglofauna. The clay pockets and lenses within the Robe Pisolite may also contribute to the suitability of the habitat for troglofauna as the retention of water in, or on top of, certain clay types may assist in maintaining high humidity levels in the subterranean environment. Troglofauna habitat is shown in Figure 1-5.

Compilation of all troglofauna sampling to date has recorded 34 troglofauna species from the Development Envelope and all are considered potential SRE species.

Two Priority 1 PECs relevant to troglofauna are present in the Development Envelope:

- *Subterranean invertebrate communities of mesas in the Robe Valley region*; and
- *Subterranean invertebrate community of pisolitic hills in the Pilbara*

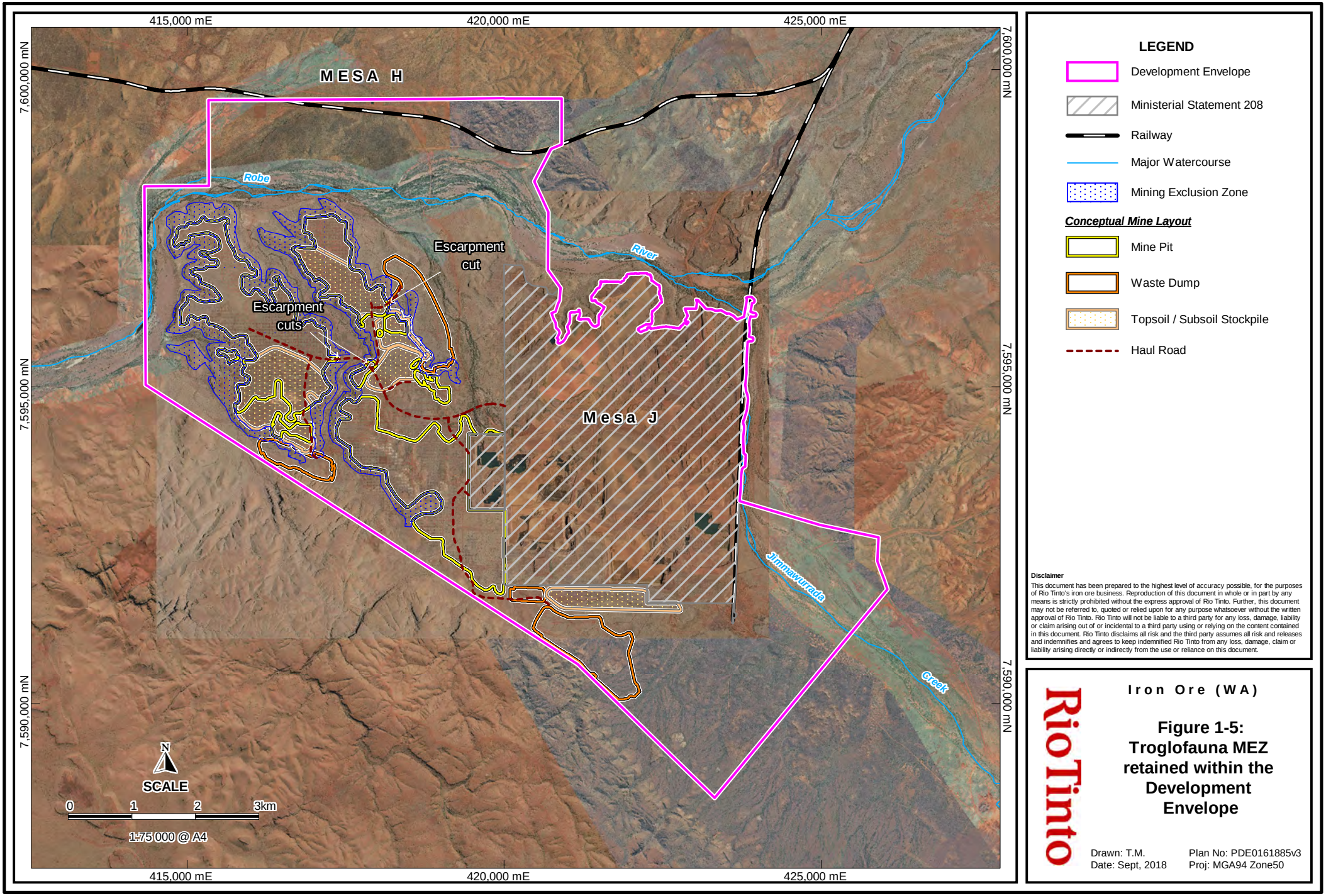
No troglofauna of conservation significance (i.e. those listed as Priority, Schedule or Vulnerable at State or Federal levels) were recorded in the Development Envelope.

f) Subterranean fauna - Stygofauna

Compilation of all stygofauna sampling to date has recorded:

- 46 stygofauna species have been recorded in and around the Development Envelope.
- 16 key species are recorded from within the Mesa J Hub potential drawdown impact area, including:
    - 9 widespread species;
    - 7 potential SRE species, including a number of listed threatened species:
        - *Nedsia hurlberti* – Schedule 3;
        - *Nedsia sculptilis* – Schedule 3; and
        - Blind Cave Eel, *Ophisternon candidum* – Vulnerable; Schedule 3;
- One Priority 1 PEC (*Stygofaunal Community of the Bungaroo Aquifer)* overlaps with the Development Envelope.

Stygofauna habitat and the modelled extent of groundwater drawdown is shown in Figure 1-6.



LEGEND

- Development Envelope
- Ministerial Statement 208
- Railway
- Major Watercourse
- Mining Exclusion Zone

Conceptual Mine Layout

- Mine Pit
- Waste Dump
- Topsoil / Subsoil Stockpile
- Haul Road

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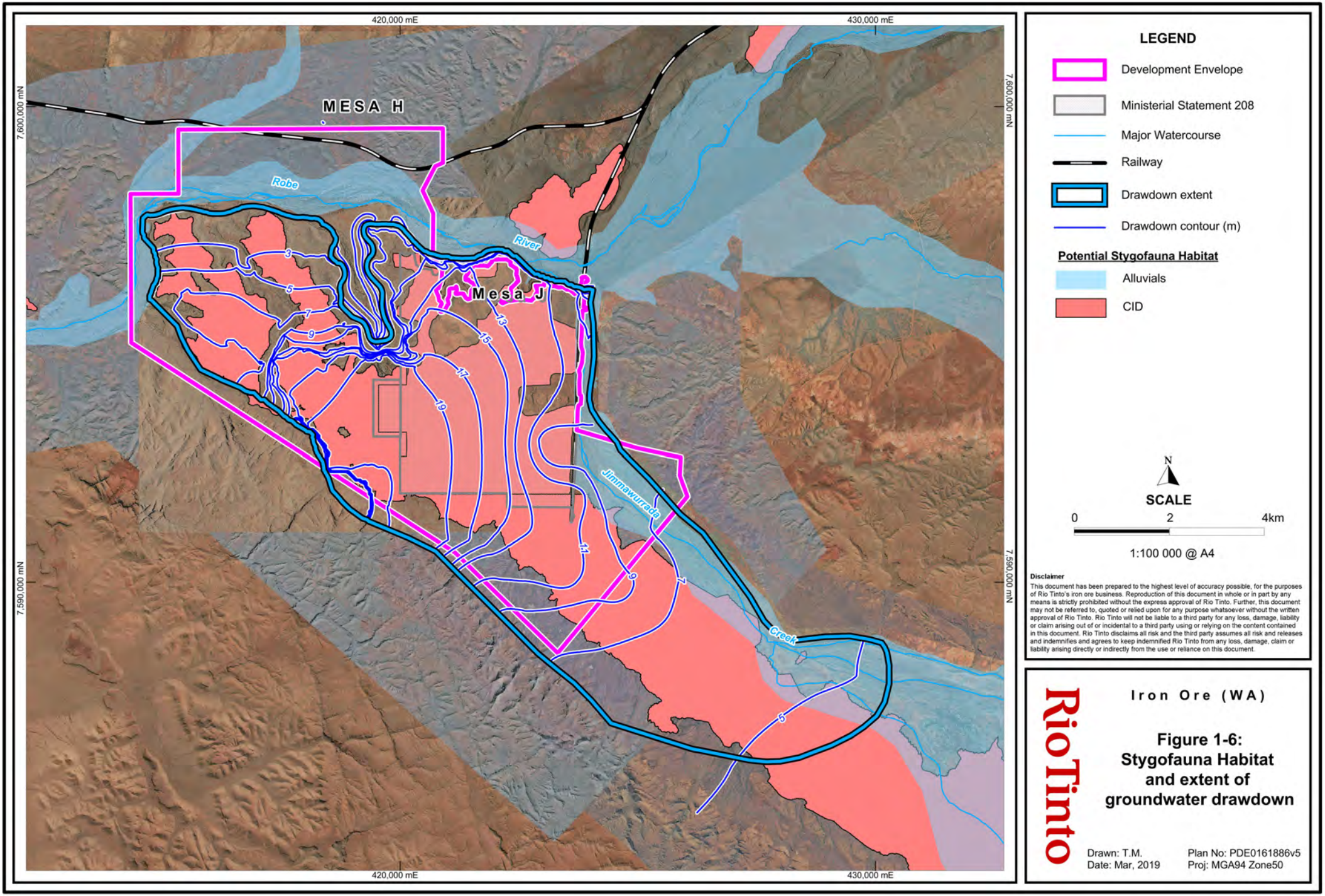
Iron Ore (WA)

Figure 1-5: Troglofauna MEZ retained within the Development Envelope

Drawn: T.M.
Date: Sept, 2018

Plan No: PDE0161885v3
Proj: MGA94 Zone50



LEGEND

- Development Envelope
- Ministerial Statement 208
- Major Watercourse
- Railway
- Drawdown extent
- Drawdown contour (m)

Potential Stygofauna Habitat

- Alluvials
- CID

N

SCALE

0 2 4km

1:100 000 @ A4

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Iron Ore (WA)

Figure 1-6: Stygofauna Habitat and extent of groundwater drawdown

Drawn: T.M.
Date: Mar, 2019

Plan No: PDE0161886v5
Proj: MGA94 Zone50

1.4.2 Key Assumptions and Uncertainties

The key limitations relating to the information used for this EMP include:

- Limited hydrogeological data on the Jimmawurrada Alluvial Aquifer and Robe River Alluvial Aquifer, to better inform the hydraulic connectivity between the CID and alluvial aquifers and hence possible impacts to pools and vegetation.
- Limited understanding of the response of riparian vegetation to cumulative stressors e.g. dewatering, water abstraction, climate variability.
- Inherent difficulty in interpolating local groundwater table elevation from limited groundwater data available in the Robe River and Jimmawurrada Creek to predict the groundwater dependence of riparian vegetation.
- Limited regional population studies for Ghost Bat and Northern Quoll, to provide an understanding of the long-term natural population variability and movements of these species.
- Limited data on the sensitivity of the Ghost Bat and Northern Quoll to noise and vibration.
- Inherent limitations in troglofauna and stygofauna sampling methodology that limit predictive ability of habitat modelling. Limitations include limited access to the subterranean environment (via drill holes only); modification of potential habitat through establishment of drill holes; trapping and scraping methodology may not be appropriate for some species depending on species preferences and mobility; sampling bias towards orebodies; difficulty in determining the specific geological strata that specimens originate from therefore limiting predictive ability of habitat modelling.
- Lack of taxonomic framework and specialist expertise to identify and determine conservation significance of many groups of subterranean fauna.
- Limited knowledge of troglofauna and stygofauna distribution patterns, ecological requirements and resilience.

The key assumptions relating to this EMP are:

- The hydrogeological modelling of groundwater abstraction from the CID aquifers provide accurate estimates of the extent and depth of groundwater drawdown, however may not capture the full range of climatic variables experienced in an arid environment (which may vary on a decadal-scale). The hydrogeological models will be updated as additional data become available hence revisions to the proposed management of pools, phreatophytic vegetation and stygofauna may be required.
- Facultative phreatophytic vegetation along Jimmawurrada Creek may be utilising groundwater to varying degrees despite the current depth to water table potentially being close to the limit of accessibility in some areas for facultative phreatophytic species, thus there is potential for impacts from abstraction of groundwater to the Jimmawurrada Creek Alluvial Aquifer.
- Baseline data collected for riparian vegetation, fish, the Ghost Bat, the Northern Quoll and subterranean fauna provide representative species inventories and reflect sampling over variable seasonal conditions, however may not necessarily capture the full range of climatic variables experienced in an arid environment (which may vary on a decadal-scale).
- Baseline surveys provide complete representative species inventories and reflect sampling over variable seasonal conditions.
- Tolerance of conservation significant fauna species to some level of noise, vibration and light emissions without any significant impact to their normal behaviours or survival.

- The effectiveness of blast management measures to prevent disturbance to the mesa façades. The Proponent has a strong record of maintaining landform stability, as demonstrated at Mesa A and J, with no record of mesa façade collapse or failure.

1.4.3 Management Approach

A risk-based approach has been taken through the Environmental Impact Assessment processes to identify the key environmental values that may be impacted by the Mesa J Hub and warrant additional management. Regional data, baseline survey data and, where available, ongoing monitoring data have been used to assess the potential impacts of the Mesa J Hub on environmental values.

The key environmental values that have been identified as warranting additional management are:

- riparian vegetation associated with the Robe River and Jimmawurrada Creek;
- semi-permanent and permanent pools and aquatic fauna;
- conservation significant fauna - Ghost Bat and Northern Quoll; and
- subterranean fauna - troglofauna and stygofauna.

This EMP adopts a combination of an outcome-based approach and a management-based approach.

- For parts of the environment that can be objectively measured and monitored an outcome-based approach is adopted with establishment of trigger and threshold criteria and associated contingency actions if the environmental criteria are not met. Trigger criteria are set at a conservative level to ensure management actions are implemented well in advance of the environmental outcome being compromised. Thus, trigger criteria are set at a level below the threshold criteria to signal the need to focus and investigate and where applicable, mitigate the impact.
- For parts of the environment that are not amenable to objective measurement, a management-based approach is adopted with a management objective that relates to the EPA's environmental objective for the relevant environmental factor, management actions to meet the environmental objective and management targets to assess the effectiveness of the management actions.

This EMP also describes the monitoring that will be undertaken to measure performance against the environmental outcomes and to assess the effectiveness of management actions in meeting management-based objectives. The monitoring to be undertaken as part of this EMP has been designed to build upon and improve on existing monitoring programs conducted as part of the Mesa J Project and build upon data from baseline surveys.

Key to the overall environmental management approach for the Mesa J Hub is avoidance of direct disturbance to key environmental values such as pools and riparian vegetation of the Robe River and Jimmawurrada Creek. Specific to the Mesa H Project is avoidance of direct disturbance to potential diurnal/maternal Ghost Bat roosts and denning habitat of the Northern Quoll. Where avoidance is not practicable, the management approach is to minimise disturbance to key environmental values, particularly habitats, such as troglofauna and stygofauna habitat and the mesa escarpments as detailed in this EMP.

1.4.4 Rationale for choice of provisions

Environmental criteria have been developed based on consideration of:

- Threatening processes and risks associated with each environmental factor;
- The current state of knowledge for each environmental value;
- The availability of suitable monitoring methods; and
- Relevance to the condition environmental outcomes sought for each environmental factor.

The specific trigger and threshold criteria and actions defined in Table 2-1 to Table 2-5 have been chosen as they provide a basis for detecting and avoiding or otherwise managing potential impacts, such that the condition environmental outcomes stated in conditions 6, 7, 8 and 9 of MS xxxx can be achieved.

Trigger criteria are set at a conservative level to ensure management actions are implemented well in advance of the environmental objective being compromised. Exceedance of a trigger criterion will, therefore, not be treated as a non-compliance. There is potential for the threshold criteria for vegetation to be exceeded due to natural variability; this must be accounted for in the management response. Exceedance of a threshold criterion will be treated as a potential non-compliance against the environmental objective if the exceedance is attributable to the Mesa J Hub.

The tables of EMP provisions (Table 2-6 to Table 2-10) contain environmental outcomes that include 'no irreversible impact'. For the purpose of this EMP, an irreversible impact is defined as, 'an impact resulting in a permanent loss of environmental value(s); or where intensive, and/or un-proven management intervention, potentially over a long timeframe, would be required to restore the environmental value(s)'.

The tables of EMP provisions (Table 2-6 to Table 2-10) include monitoring to measure performance against the environmental outcome and to determine whether trigger or threshold levels have been exceeded. Table 2-7, Table 2-8, Table 2-9 and Table 2-10 also include supporting monitoring that will be undertaken. Supporting monitoring is not directly required as a measure of performance but will be used to provide context, to assess the impact on the environmental value and to investigate possible causes should the trigger or threshold criteria be exceeded

The rationale for selection of provisions for each environmental value is discussed below.

a) Inland waters

Two environmental outcomes have been adopted for riparian vegetation, semi-permanent and permanent pools and aquatic fauna for different aspects of the Mesa J Hub:

- Ensure there is no irreversible impact to the semi-permanent and permanent Pools (water quality / integrity) and aquatic fauna of the Robe River pools and health of riparian vegetation communities of the Robe River and Jimmawurrada Creek as a result of groundwater abstraction and discharge for the Mesa J Hub.
- Ensure that groundwater abstraction and surplus dewater discharge, does not cause long term impacts to the Aboriginal heritage values linked to the physical and/or biological surroundings of the Robe River or Jimmawurrada Creek.

Riparian Vegetation

The outcomes for riparian vegetation were selected as it is acknowledged that the Mesa J Hub may have an impact on riparian vegetation communities, particularly in Jimmawurrada Creek 'Zone 3' (Table 1-3), however potential impacts are not expected to be permanent as they will be limited in spatial extent and/or will occur over a limited time period and changes are considered unlikely to be so great that they result in permanent changes in the composition of riparian vegetation.

The selected trigger and threshold criteria are based on standard deviations in foliage cover of phreatophytic overstorey riparian tree species from the baseline period mean as measured by mean vegetation index. Mean vegetation index is a readily measurable indicator of the health of riparian vegetation for which reference sites can be established and regular monitoring undertaken. Measurement of mean vegetation index is also consistent with other riparian vegetation monitoring programs. The approach taken is analogous to the 'control chart' method (Morrison 2008) that has been applied to a wide range of environmental impact studies and monitoring programs. In line with this, a trigger criterion of ≥ 2 standard deviations from baseline mean vegetation index has been selected for the following reasons:

- Decline from a baseline mean in number of standard deviations aligns with commonly accepted convention for establishing trigger criteria to detect potential environmental impacts.
- Quantifying decline in number of standard deviations from the baseline mean takes into account the natural variability observed in the system. This is preferable to using a set value or percentage decline which does not take natural variability into account.
- In a normally distributed dataset, 2 standard deviations from the mean encompasses 95% of the observed values, that is, there is a 5% chance of measuring a value either higher or lower than 2 standard deviations from the mean prior to any disturbance being imposed. This is aligned with the convention of using a statistical significance level of p=0.05.

A threshold criterion of ≥ 2 standard deviations from baseline mean vegetation index over a period of two consecutive monitoring events has been selected. Mean vegetation index is a readily measurable indicator of the health of riparian vegetation and comparison with standard deviation from baseline values is consistent with other riparian vegetation monitoring programs conducted by the Proponent in the Pilbara region. Rainfall and streamflow can fluctuate, both seasonally and across multiple years, influencing the condition of phreatophytic vegetation. As such two years has been selected as a suitable timeframe to assess whether the condition of upper canopy vegetation is under threat of long term impacts from the Mesa J Hub, and to differentiate natural variation of the canopy from the potential impacts of groundwater abstraction and surplus water discharge. Following the completion of collection and analysis of baseline data, the trigger and threshold criteria will be reviewed and adjusted if deemed appropriate.

Trigger and threshold criteria for detection of new introduced species in the riparian zone of the Robe River were selected as an indicator of potential impacts from discharge of surplus water. Introduced species can be monitored regularly, have a baseline, and measurement of these parameters is consistent with other flora and vegetation monitoring programs.

Semi-permanent and permanent pools and aquatic fauna

The outcome for semi-permanent and permanent pools was selected based on the high cultural and environmental value of Robe River Pools.

The selected triggers and threshold criteria for semi-permanent and permanent pools of the Robe River are groundwater levels adjacent to select pools, pool depth, water quality and aquatic fauna (fish).

Installation of paired alluvial aquifer bores in the Robe River near targeted pools is proposed to monitor groundwater levels and hence potential impact to water levels in pools. Bores will be placed (subject to approvals) on the north and south side of the river. The south edge of the river receives water from the Mesa H CID / basement aquifers that has a northern groundwater flow direction, whilst the northern edge receives groundwater from the aquifer to the north that has a southern flow direction. The drawdown from Mesa H operations are likely to be observed earlier in the south edge of the river channel rather than in the north, hence if the predicted maximum drawdown (~0.5m) is observed in the proximal monitoring bores and not in the distal bores would be a clear indication the drawdown is higher than expected.

Trigger and threshold criteria have also been developed for Yeera Bluff (Gnieroora) Pool. A depth trigger of 2m and threshold of 1m was selected on the basis that is appears that it is a permanent pool. It is likely that if this pool is dry, others will be too and key environmental values will be compromised Surface water is directly associated with maintaining the cultural and aesthetic values.

A trigger criterion was developed for water quality in pools exceeding the rolling quarterly median measured against the operational guideline site specific trigger value (SSTV) equivalent to the 95th percentile value of baseline or the ANZECC/ARMCANZ (2000) default trigger value for toxicants for protection of 95% of species, whichever is higher (except for pH).

An additional threshold criteria for semi-permanent and permanent pools of the Robe River is fish species richness. A threshold criterion of three or less species of fish recorded in Robe River Pools was selected on the basis of approximately 27 years of sampling of Robe River pools (Streamtec 2017, WRM 2017). The total number of species recorded is 11 species with a range in species richness of 4 to 11 in any sampling event. To date, species richness has been highly correlated with pool depth and volume and hence climate. A threshold has been developed of three (or less) species recorded across all sampling sites indicating that pool levels may have dropped beyond the range of natural variability.

b) Terrestrial Fauna

Ghost Bat

Outcome-based and management-based provisions have been adopted for the Ghost Bat on the basis that objective measurement and reporting is possible for some parts of the environment and some of the potential impacts but not for others.

The environmental outcome adopted for the Ghost Bat is:

- No irreversible impact as a result of the Project to retained escarpments of Mesa H which are high value habitat for the Ghost Bat.

No irreversible impact to the retained escarpments is defined as not resulting in 'significant damage'. Significant damage is considered to be damage that negatively impacts the structural integrity and microclimate of the cave such that future Ghost Bat use of the site is prevented.

This outcome has been selected as the escarpments of Mesa H represent potential roosting and foraging habitat. Habitat loss through disturbance to roost caves, specifically caves that play a role in breeding activities (maternal roosts) and nearby areas is seen as a key risk to this species conservation status. The Mesa H Project has been designed to retain the mesa escarpment, except where cuts are required to access the top of the mesa, and to avoid direct disturbance to diurnal/potential maternal roosts and known nocturnal roosts on Mesa H particularly those associated with or in close proximity to the diurnal / potential maternal roosts.

Vibration levels and direct disturbance near the potential diurnal/maternal roosts have been selected as triggers as both can be directly targeted to the highest value habitat, are readily measurable, can be monitored regularly and are consistent with other Ghost Bat monitoring programs. Ensuring the vibration levels at the potential diurnal/maternal roosts remain below a peak particle velocity determined for each cave reduces the risk that vibrations compromise the structural integrity of the roosts.

Temperature and humidity monitoring of the two diurnal/potential maternal caves on Mesa H (MH16-34 and AC4) have been selected on the basis of ensuring that the roost cave is viable for Ghost Bats not only from a physical perspective, but also from a cave microclimate perspective. The approach is readily measurable and will enable verification that blasting and mine pit development within adjacent pits does not inadvertently open up new cavities or openings at the back of the potential diurnal/maternal roost caves which may change the cave microclimate.

The management objective adopted for the Ghost Bat is:

- Improve knowledge of the Ghost Bat population and utilisation of high value habitat in the Robe Valley in order to assist in maintaining biological diversity and ecological integrity.

This management objective has been selected as it relates to the EPA objective for Terrestrial Fauna and is specific to the Project. One of the limitations noted during the Environmental Impact Assessment is the lack of long-term data that would provide an estimate of natural Ghost Bat population variability and an indication of how the Ghost Bat utilises caves within the central part of the Robe Valley. The proposed management action to undertake a five-year study of Ghost Bat

utilisation of high value habitat in the Robe Valley has been selected to start to address this limitation.

Northern Quoll

Northern Quoll population numbers fluctuate on both annual and inter-annual cycles. This variability is driven by both the reproductive biology of individuals (males usually die-off after one year) and longer-term cycles in response to regional stochastic processes such as rainfall, fire and related changes of prey populations (How et al. 2009). This natural variability makes threshold criteria based on population dynamics inappropriate for compliance at this stage. Protection of high value habitat for the Northern Quoll is, therefore, the most appropriate strategy to protect this conservation significant fauna within the Development Envelope.

The environmental outcome adopted for the Northern Quoll is:

- No irreversible impact as a result of the Project to Breakaways and Gullies habitat retained in the escarpment of Mesa H.

This outcome has been selected as the escarpment of Mesa H contains high value denning and foraging habit. The Mesa H Project has been designed to retain the mesa escarpment, except where cuts are required to access the top of the mesa, and to avoid the highest value sections of mesa escarpment (Astron 2017a).

A trigger and threshold have been developed for direct disturbance to the breakaway and gullies habitat of the retained escarpment. Direct disturbance to these breakaway and gorge habitats in the retained escarpment is readily measurable and can be monitored regularly. Ensuring direct disturbance to the breakaway and gullies habitat of the mesa escarpment is minimised reduces the risk that Northern Quoll denning habitat is disturbed or degraded.

Note that the proposed triggers and thresholds relate to the Northern Quoll habitat within the *retained* sections of the escarpments (MEZs) which already account for the approved disturbance (escarpment cuts and waste dump). i.e. the triggers and thresholds are impacts over and above the proposed / approved impacts to the MEZ.

c) Subterranean Fauna

Outcome-based and management-based provisions have been adopted for subterranean fauna on the basis that objective measurement and reporting is possible for some parts of the environment but not for others.

Subterranean fauna surveys in general have low capture rates per survey effort meaning the abundance and diversity of specimens recorded during surveys are highly variable (Halse and Pearson 2014). These sampling artefacts mean that threshold criteria based on abundance or diversity would be inappropriate at this stage. Protection of high value habitat for subterranean fauna is, therefore, considered the most appropriate strategy to protect subterranean fauna so that biological diversity and ecological integrity are maintained. The following environmental outcomes have been adopted:

- Troglofauna: The Proponent shall ensure there is no irreversible impact as a result of the Project to the troglofauna habitat retained within the Mesa H MEZ.
- Stygofauna: The Proponent shall ensure there is no irreversible impact, as a result of the Proponents water management activities, to stygofauna habitat within the CID aquifer and stygofauna and Blind Cave Eel habitat within the alluvial aquifer habitat of Jimmawurrada Creek and the Robe River shown in Figure 1-6.

Mesa H comprises iron-rich Robe Pisolite which is considered to be the geological unit that provides primary habitat for troglofauna. As the Robe Pisolite is also the target ore body, a key part of the Mesa H Project design is to ensure retention of a significant volume of Robe Pisolite habitat in the

form of a MEZ. The environmental outcome has been selected to reflect this key part of the Mesa H Project design.

Trigger and threshold criteria have been developed to limit the direct removal, through operational error, of troglofauna habitat to be retained in the MEZ. Blasting and excavation carried out as part of the mining process have a degree of operational error associated with them. The trigger and threshold criteria, while recognising the practical limits to operational precision, have been structured to ensure that significant volumes of troglofauna habitat are not lost from the MEZ over the life of the mine. Volume excavated is readily measurable and is part of the causal relationship between mining and impacts on troglofauna.

The amount, quality and distribution of stygofauna habitat within the Development Envelope may be influenced by dewatering as well as pit excavation. The below water table extent of the Robe Pisolite, alluvium and Wittenoom aquifer are considered to be the geological units that provide primary habitat for stygofauna. Trigger and threshold criteria have been developed around the amount and quality of water drawdown at key locations in the CID and alluvial aquifer habitat of Jimmawurrada Creek and the Robe River. The ongoing persistence of connected stygofauna habitat in the Development Envelope was a key consideration when defining these criteria and thus doubles as trigger and threshold criteria for stygofauna and Blind Cave Eel habitat. Trigger and threshold values criteria also been developed around the ongoing persistence of a diverse stygofauna community, including the Blind Cave Eel, within the available stygofauna habitat.

The management objectives adopted for subterranean fauna are:

- Troglofauna: The Proponent shall protect the biological diversity and ecological integrity of the troglofauna assemblage at Mesa H by minimising impacts as far as practicable.
- Stygofauna: The Proponent shall protect the biological diversity and ecological integrity of the stygofauna assemblages within the CID and Alluvial aquifer habitats shown in Figure 1-6 by minimising impacts as far as practicable.

These management objectives have been selected as they relate to the EPA objective for Subterranean Fauna and are specific to a key part of the Mesa H Project. Six management targets (three for troglofauna and three for stygofauna) have been selected to assess whether the management actions are effective in meeting the environmental objective. Management targets relate to:

- clearing of native vegetation in the MEZs to limit the potential for degradation of retained troglofauna habitat as a result of diminished organic nutrient inputs;
- troglofauna specimen capture rate to assess whether the Mesa H Project has an impact on troglofauna utilization of retained habitat in the MEZs; and
- further research to understand the distribution of key stygofauna species and allow refinement of the proposed outcome and management based provisions.

Management actions and targets have been selected to address potential impacts of the Mesa H Project as well as to build upon existing data.

2. EMP PROVISIONS

This section of the EMP identifies the legal provisions that the Proponent will implement to ensure that the environmental outcomes of conditions 6, 7, 8 and 9 are met during implementation of the Mesa J Hub.

Outcome and management based provisions are provided in Section 2.1. Monitoring and reporting are detailed in Section 2.4 and Section 2.5 respectively.

Table 2-6 to Table 2-10 detail for all provisions within this EMP.

2.1 Outcome and Management Based Provisions

The following outcome based provisions are included in this EMP:

Mesa H and J: Inland waters, Vegetation and Aquatic Fauna

- No irreversible impact, as a result of the proponent's water abstraction, to groundwater dependent vegetation within the Robe River.
- No irreversible impact, as a result of the proponent's water abstraction, to riparian vegetation communities within Jimmawurrada Creek.
- No irreversible impact, as a result of the Proponent's discharge of surplus water, to the health of riparian vegetation of Jimmawurrada Creek and the Robe River.
- No irreversible impact, as a result of the Proponent's drawdown and discharge, to the pool ecosystems of the Robe River.

Mesa H: Terrestrial Fauna – Ghost Bat and Northern Quoll

- No irreversible impact, as a result of the proponent's activities, to Breakaways and Gullies habitat (and associated Ghost bat Roosts) retained in the escarpments of Mesa H.

Mesa H: Subterranean Fauna – Troglofauna and Stygofauna

- No irreversible impact, as a result of the proponent's activities, to the troglofauna habitat retained within the Mesa H MEZ.
- No irreversible impact, as a result of the proponent's water management activities, to stygofauna habitat within the CID aquifer and stygofauna and Blind Cave Eel habitat within the alluvial aquifer habitat of Jimmawurrada Creek and the Robe River.

The following management based provisions are included in this EMP:

Mesa H: Terrestrial Fauna – Ghost Bat

- The Proponent shall improve knowledge of the Ghost Bat population and utilisation of high value habitat in the Robe Valley in order to assist in maintaining biological diversity and ecological integrity.

Mesa H: Subterranean Fauna – Troglofauna and Stygofauna

- The Proponent shall protect the biological diversity and ecological integrity of the troglofauna assemblages of Mesa H by minimising impacts as far as practicable.
- The Proponent shall protect the biological diversity and ecological integrity of the stygofauna assemblages within the CID and Alluvial aquifer habitat by minimising impacts as far as practicable.

2.2 Performance Indicators (environmental criteria)

2.2.1 Trigger level criteria

Trigger criteria measures are set at a conservative level to ensure management actions are implemented well in advance of the environmental objective being compromised. Thus, trigger criteria are set at a level below the threshold criteria to signal the need to focus and investigate and where applicable, mitigate the impact further or increase the level of protection or rehabilitation.

Mesa H and J: Inland waters, Vegetation and Aquatic Fauna

1. The mean vegetation index for riparian overstorey taxa (E. victrix, E. camaldulensis and M. argentea) of Zones 1 & 2 of Jimmawurrada Creek and the Robe River changes by ≥ 2 standard deviations.
2. A statistically significant decline from baseline ($p<0.05$) in the number and/or cover of native perennial species of Zones 1 & 2 of Jimmawurrada Creek and the Robe River.
3. Detection of new introduced species at a potential impact site, previously not detected within the Development Envelope.
4. Decline of >0.5m between paired Alluvial Aquifer bores in the Robe River near targeted pools.
5. Yeera Bluff (Gnieroora) Pool drops below 2m depth.
6. Water quality in pools exceeds rolling quarterly median measured against the operational guideline SSTV equivalent of 95%ile value of baseline or the ANZECC/ARMCANZ (2000) default TV for toxicants for protection of 95% of species, whichever is higher (except for pH).

Mesa H: Terrestrial Fauna – Ghost Bat

1. Vibration levels exceed 50mm/s peak particle velocity at the potential diurnal/maternal Ghost Bat roost caves.
2. Disturbance, other than approved clearing, within 50m of the recorded back of the potential diurnal/maternal Ghost Bat roost caves.

Mesa H: Terrestrial Fauna – Northern Quoll

1. Disturbance of >5% of potential Northern Quoll denning habitat on the retained escarpment of Mesa H.

Mesa H: Subterranean Fauna – Troglofauna

1. Operational error during mining resulting in removal of greater than 0.01% by volume annually of the MEZ at Mesa H.

Mesa H: Subterranean Fauna – Stygofauna

1. Groundwater levels drop three (3) m below predicted water table heights in the Jimmawurrada Creek alluvial aquifer.
2. Diversity of stygofauna Orders collected during annual survey events reduced to three (3) or less.

2.2.2 Threshold level criteria

Mesa H and J: Inland waters, Vegetation and Aquatic Fauna

3. The mean vegetation index for the riparian upper canopy (*E. victrix, E. camaldulensis* and *M. argentea*) of Zones 1 & 2 of Jimmawurrada Creek and the Robe River declines by ≥ 2 standard deviations from baseline over two consecutive monitoring events.

4. A statistically significant decline from baseline ($p<0.05$) in the number and/or cover of native perennial species over two consecutive monitoring events.
5. Detection of new introduced species rated high or very high management priority (by the Department of Biodiversity, Conservation and Attractions) at a potential impact site, previously not detected within the Development Envelope and a significant increase in cover or abundance over successive monitoring events.
6. Decline of ≥1 m between paired Alluvial Aquifer bores in the Robe River near targeted pools.
7. Yeera Bluff (Gnieroora) Pool drops below 1m depth.
8. Three (3) or less species of fish recorded during a sampling event.

Mesa H: Terrestrial Fauna – Ghost Bat

1. Significant damage to diurnal/maternal Ghost Bat roost caves.
2. Disturbance, other than approved than approved clearing, within 40m of the recorded back of the potential diurnal/maternal Ghost Bat roost caves.

Mesa H: Terrestrial Fauna – Northern Quoll

1. Disturbance of >10% of potential Northern Quoll denning habitat on the retained escarpment of Mesa H.

Mesa H: Subterranean Fauna – Troglofauna

1. Net loss of the MEZ at Mesa H, at the completion of mining.

Mesa H: Subterranean Fauna – Stygofauna

1. Alluvial aquifer in Jimmawurrada is dry for two (2) consecutive years.
2. Absence of Blind Cave Eel recorded for two (2) consecutive annual sampling events.
3. Absence of stygofauna specimens for two (2) consecutive annual sampling events.

2.2.3 Management Targets

Mesa H: Terrestrial Fauna – Ghost Bat

1. Estimate the local population of Ghost Bats in the central part of the Robe Valley.
2. Indicate how Ghost Bats use caves within the central part of the Robe Valley (e.g. diurnal versus maternal), including the degree of utilisation of caves by pregnant females.

Mesa H: Subterranean Fauna – Troglofauna

1. Total clearing of native vegetation across the surface of the MEZ is less than 30% of the MEZ surface area.
2. Troglofauna specimen capture rate is not below the baseline minimum for three (3) consecutive sampling events at Mesa H.

Mesa H: Subterranean Fauna – Stygofauna

1. Understand the distribution and ecology of key stygofauna taxa within the Robe Valley area.

2.3 Response Actions

The Proponent has developed a number of trigger level actions that would be implemented if the associated trigger criterion signals the need to increase mitigation or protection (Table 2-6 to Table 2-10). These trigger level actions will be implemented by the Proponent to mitigate and manage impacts so they once again will meet trigger and safeguard the threshold criteria.

The Proponent has developed a number of threshold contingency actions that would be implemented if the associated threshold criterion signals that the environmental outcome is exceeded (Table 2-6 to Table 2-10). The threshold contingency actions will be implemented to manage aspects of the proposal and achieve the condition environmental outcome and manage the impact to below threshold and trigger criteria again and hence bring the Proponent back into compliance.

2.4 Monitoring

Monitoring will be undertaken to measure performance against the environmental outcomes and to assess the effectiveness of management actions in meeting management-based objectives. Monitoring will inform, through the environmental criteria, when trigger or threshold contingency actions will be implemented.

2.4.1 Inland Waters

The Proponent will monitor the health of riparian vegetation of the Robe River and Jimmawurrada Creek both within the potential groundwater drawdown and surplus water discharge impact zones and at reference sites.

The effects of groundwater drawdown on facultative and obligate phreatophytes are dependent upon both the baseline groundwater level and the rate of groundwater drawdown. For example, trees accessing shallow groundwater may be more sensitive to groundwater drawdown than trees growing above a groundwater table at greater depth. While it is inherently difficult to interpolate local groundwater table elevation from limited data and hence predict groundwater dependence of local phreatophytes, monitoring the cover of the upper canopy provides an indicator of stress either due to groundwater drawdown or due to surplus water discharge. The health of phreatophytic species along the Robe River and Jimmawurrada Creek will, therefore, be monitored utilizing remote sensing with supporting field-based surveys. Due to the difficulty of distinguishing phreatophytic riparian trees using remote sensing, the phreatophytic assemblages of the Robe River and Jimmawurrada Creek will be treated as a functional group 'riparian overstorey' for trigger and threshold criteria.

The Proponent will monitor the health of obligate and facultative vegetation of the Robe River and Jimmawurrada Creek using remote sensing to ensure there are no significant changes to health beyond natural variation. Annual remote sensing will provide an indication of vegetation condition over the riparian zones. The foliage cover of the upper canopy will be assessed as a time series, to compare against both baseline conditions and also alongside correlative parameters including rainfall, water levels and fire. The large coverage of canopy captured in remote sensing will accommodate assessment of potential relationships between dewatering and vegetation condition across the entire riparian zone, overcoming some of the limitations of field-based assessment. The monitoring to be undertaken is summarised in Table 2-1.

Baseline data from potential impact and reference sites will be collected prior to operations commencing to quantify natural variation in foliage cover (and health). The mean of all measurements made during the baseline period will be calculated for each reach (or system). Changes over time at these reaches (or zones) will be compared back to the baseline and to reference sites to assess any potential impacts from the Project.

A decline in vegetation index of ≥ 2 standard deviations from the baseline for upper canopy vegetation has been selected as the trigger (trigger criterion 1) to prompt causal investigation and if necessary, remedial actions. Applying criteria to the results of one image with no temporal replication does not adequately accommodate investigation into causation, and comparison with vegetation health at reference sites, and hence is not appropriate as a pass/fail compliance measure. However, a shift of ≥ 2 standard deviations from a sample of adequate size (through spatial coverage) does warrant investigation, including time series assessment of vegetation condition in conjunction with correlative environmental parameters and monitoring results from reference sites. The outcomes of investigation will inform the proponent whether dewatering

operations pose a risk of irreversible impact to the riparian vegetation of the Robe River and Jimmawurrada Creek.

A decline in vegetation index of ≥ 2 standard deviations from the baseline for upper canopy vegetation over a period of two consecutive sampling events has been selected as the threshold criterion (threshold criterion 1) for the Robe River and Zones 1 and 2 in Jimmawurrada Creek. In the absence of data to support that obligate and facultative phreatophytic species can recover or re-establish following periods of stress, a decline of ≥ 2 standard deviations from baseline has been selected as a pass/fail criterion. In the event this criterion is exceeded, the Proponent will conduct additional assessments of the impacted riparian vegetation, and liaise with the EPA Services on both the appropriateness of a decline of ≥ 2 standard deviations as a compliance threshold, and also the remedial actions required to prevent the impacts becoming irreversible.

The species richness and cover of both native and introduced species will be recorded during field-based, post-wet season, annual monitoring surveys in selected transects established during baseline surveys. Monitoring of the understorey vegetation will provide data about the structure, cover and health of both native and introduced species to assist in investigation of any trends that may occur as a result of changed hydrological regime and measured against management criteria. Trends in the presence of native species will be analysed in parallel with the presence of introduced species, to detect any threats which introduced species may pose to native vegetation. The presence of introduced species will be monitored in isolation as an early warning indicator, though the threshold criterion take into account the balance of all species, to ensure that the potential increased productivity as a result discharge is not misinterpreted as a negative impact to the health of riparian vegetation.

Due to the difficulty in establishing reference pool levels due to differences in pool morphology, depth and overstorey cover (which impacts evaporations rates), paired bores (on the north/south sides of the Robe River) once installed will be monitored continuously via data loggers and downloaded quarterly. The paired bores on either side of the Robe River will enable early detection of changes to water table levels in the Robe River proximal to the Mesa J Project when mine pit dewatering commences, relative to its paired alluvial bore on the other side of the Robe River. This is considered the most accurate way to determine a mine dewatering related change to water table levels in the pools as compared to natural seasonal pool water table fluctuations.

Pool depth at Yeera Bluff will be determined by bathymetry measurements, field morphology measurements or remotely via drone. Water quality will be sampled quarterly in five (5) key pools in the Robe River to determine adherence to the SSTV or ANZECC/ARMCANZ values.

Fish species richness will be recorded during biannual surveys of selected Robe River pools through direct observation. Water levels and quality will be assessed through the use of paired bores, bathymetry and direct sampling (of fish and water).

Table 2-1: Monitoring required to evaluate performance against the environmental outcomes for hydrological processes and riparian vegetation

Monitoring action	Location	Frequency and timing	Data collection method and analysis	Responsible
Capture and analysis of remote sensing images (criterion 1)	Selected potential impact sites and reference sites established during baseline monitoring	Annual during operational mine life[1]	Remote sensing images Calculation of vegetation index and analysis of changes to vegetation index	Operations Environment team
Annual field survey (criterion 2)	Selected transects established during baseline monitoring	Annual during operational mine life Post wet season	Understorey riparian taxa: condition, cover and health Introduced species: number and locations	Operations Environment team
Paired Alluvial Aquifer bores[2] in the Robe River near targeted pools (criterion 3).	3 sets of paired bores, on the Mesa H side of the Robe River, paired with a bore on the opposite side of the River	Quarterly downloads (of daily data)	Bore data loggers Automated triggers in database	Mesa H and J Hydrogeology team
Yeera Bluff (Gnieroora) Pool depth (criterion 4)	Yeera Bluff (Gnieroora) Pool	Biannual	Bathymetry measurements Field morphology monitoring of impact and reference pools or remote assessment via drone	Mesa H and J Hydrogeology team Operations Environment Team
Water quality (criterion 5)	5 Key pools on the Robe River; Japanese, Yeera Bluff (Gnieroora), Medawandy, Yarramudda, Martangkuna	Quarterly	Monitoring of impact and reference pools	Operations Environment team
Monitoring of aquatic fauna (fish) (criterion 6)	13 pools on the Robe River; Mussel Pool – Yeera Bluff (Gnieroora) Pool (established in 1991)	Bi-annual	Fish – direct observation at selected pools	Operations Environment team

[1] Locations may not always be available due to accessibility, weather conditions, safety considerations etc.

[2] Alluvial Bore locations subject to approval from the Kuruma Marthadunera People.

2.4.2 Terrestrial fauna (Ghost Bat)

Protection of high value habitat for the Ghost Bat is the most appropriate strategy to protect this conservation significant fauna within the Development Envelope. High value habitat for the Ghost Bat includes the escarpment and cave structures associated with mesa formations in the Robe Valley. Trigger and threshold criteria have been applied to potential diurnal/maternal roosts, as diurnal/maternal roosts are recognised as geographically restricted and ecologically critical. These trigger and threshold criteria have been designed to ensure no 'significant damage' to critical Ghost Bat roosts, where 'significant damage' is defined as 'damage that negatively impacts the structural integrity and microclimate of the cave such that future Ghost Bat use of the site is prevented'.

Baseline monitoring of the two potential diurnal/maternal caves on Mesa H (MH16-34 and AC4), MH16-34 will continue to be undertaken prior to commencement of mining. Additional data from longer term monitoring of these caves may indicate that a different status, and potentially a different level of management, may be appropriate for these caves; this may require revision of the EMP.

Vibration levels will be measured at the potential diurnal/maternal Ghost Bat roost caves at Mesa H for all blasts within 300 m of the potential diurnal/maternal roosts. Ensuring the vibration levels at the potential diurnal/maternal roosts remain below a peak particle velocity determined for each cave reduces the risk that vibrations compromise the structural integrity of the roosts. Annual land clearing reconciliation using GIS disturbance layers will also be undertaken to monitor disturbance close to the potential diurnal/maternal roost caves. Annual assessment of Ghost Bat roost utilisation across the broader Robe Valley will also be completed as supporting monitoring to provide context to any potential impacts from blasting or ground disturbance in the vicinity of the potential diurnal/maternal roosts.

Temperature and humidity of the two potential diurnal/maternal caves on Mesa H (MH16-34 and AC4) will be monitored on a continuous basis, and calibrated with ambient temperature and humidity. The approach is to support the above described monitoring actions to verify that blasting and mine pit development within adjacent pits does not inadvertently open up new cavities or openings at the back of the potential diurnal/maternal roost caves which may change the cave microclimate.

The Proponent has identified that there is a lack of regional population studies for the Ghost Bat to assist in understanding the long-term natural population variability and movements of this species. The EMP includes a management objective to improve knowledge of the Ghost Bat population and utilisation of high value habitat in the Robe Valley. The associated monitoring includes bi-annual collection of scats from Ghost Bat roost caves across the broader Robe Valley where safety and heritage considerations allow. Analysis of scat samples will include genetic and hormone analysis to provide information on utilisation of caves by individuals including pregnant females.

Table 2-2 summarises the monitoring required to measure performance against the environmental outcome and to assess the effectiveness of management actions in meeting the management-based objective.

Table 2-2: Monitoring required to evaluate performance against the environmental outcome and to assess the effectiveness of management actions for the Ghost Bat

Monitoring action	Location	Frequency and timing	Data collection method and analysis	Responsible
Vibration levels (criterion 1)	Caves MH16-34 and AC4 (Figure 1-4)	For all blasts within 300m of caves MH16-34 and AC4	Modelling of peak particle velocity prior to blast. Vibration monitoring of actual peak particle velocity. Analysis of modelled versus actual peak particle velocity.	Drill and Blast team

Land clearing reconciliation (criterion 2)	Caves MH16-34 and associated cave complexes, and AC4 (Figure 1-4)	Annual during operational mine life	GIS avoidance and disturbance layers. Internal approvals request process.	Operations Environment team
Temperature and Humidity	Caves MH16-34 and AC4 (Figure 1-4)	Ongoing (continuous) during operational mine life	Temperature and humidity logging and data analysis correlated against ambient temperature; and timing of mine pit development / blasting data in adjacent pits.	Operations Environment team
Scat collection and analysis (management target)	Caves across the broader Robe Valley*	Bi-annual for 5 years	Scat collection from Ghost Bat roost caves. Genetic and hormone analysis.	Operations Environment team

* Access subject to safety and heritage assessments of caves

2.4.3 Terrestrial fauna (Northern Quoll)

Protection of high value habitat for the Northern Quoll is the most appropriate strategy to protect this conservation significant fauna within the Mine Development Envelope. High value habitat for the Northern Quoll in the Robe Valley includes the Breakaways and Gullies habitat contained within the mesa escarpments which provides denning habitat. Trigger and threshold criteria for disturbance to Northern Quoll denning habitat on the retained escarpments of Mesa H will be applied.

An annual field survey of Northern Quoll will be undertaken as supporting monitoring.

Offset actions, including Northern Quoll monitoring, are currently being undertaken on parts of Yarraloola Station as part of the approved Yandicoogina Threatened Species Offset Plan (TSOP). Yarraloola Pastoral Station underlies and surrounds the Development Envelope. Camera monitoring and trap monitoring protocols for the annual field survey will be based on the protocols established as part of the TSOP so that data from the two programs are comparable. Forty cameras will be utilised at eight mesas across the Robe Valley (nominally Mesa A, Mesa B, Mesa C, Mesa F, Mesa G, Mesa H, Mesa 2402D and Mesa 2403E).

Four trap sites will be established within the Robe Valley and designed in two categories ‘impact’ or ‘reference’ sites. Impact sites will be located at Mesa B (TSOP Site Q) and Mesa H (TSOP Site L) and reference sites will be located at Mesa G (TSOP Site K) and Mesa F (TSOP Site B). Each site will consist of 20 cage traps spaced at 50 m intervals and will be set up, where possible, in preferred habitat for this species in the Robe Valley. The preferred habitat is seen as the rocky escarpments abutting a major drainage system (i.e. Robe River), however additional habitats including the Plains habitat will be included in the monitoring design to enable a full picture of extent of habitat utilisation to be understood.

Table 2-3 summarises the monitoring required to measure performance against the environmental outcome and the supporting field monitoring that will be undertaken.

Table 2-3: Monitoring required to evaluate performance against the environmental outcome for the Northern Quoll

Monitoring action	Location	Frequency and timing	Data collection method and analysis	Responsible
Land clearing reconciliation (criterion 1)	Escarpment of Mesa H	Annual during the operational mine life	GIS avoidance and disturbance layers. Internal approvals request process.	Operations Environment team
Annual field survey (supporting monitoring)	Escarpments of mesas across the broader Robe Valley and other targeted habitats (e.g. Plains) 40 camera monitoring sites spread over Mesa A, Mesa B, Mesa C, Mesa F, Mesa G, Mesa H, Mesa 2402D and Mesa 2403E 4 trap monitoring sites located at Mesa B, Mesa H, Mesa G and Mesa F	Annual (May–September) during operational mine life	Camera monitoring Trapping	Operations Environment team

2.4.4 Subterranean fauna (troglofauna)

Protection of high value habitat for troglofauna is the most appropriate strategy to protect troglofauna so that biological diversity and ecological integrity are maintained. High value habitat in the Development Envelope includes the CID comprising Mesa H. The Proponent will ensure that at least 50% by volume of pre-mining troglofauna habitat will be retained through delineation of a MEZ.

Monitoring of the retained volume of troglofauna habitat in the MEZ will require regular on-ground surveying of the actual pit shell for comparison with the planned pit shell.

A biennial field survey for troglofauna specimens will also be conducted (Table 2-4). This will be the primary source of monitoring data with which to evaluate progress against management targets. As a minimum, the survey will include trapping and scraping from 25 drill holes in the Mesa H MEZ. Previously sampled sites will be used wherever possible to ensure results from each survey are readily comparable. All specimens will be identified to species level and aligned with existing taxa/specimens where possible. Molecular identification will be used where morphological identification is not possible or is less efficient. All specimens with troglomorphic characteristics will be included in the analysis and reporting as 'potentially troglobitic' until shown otherwise.

Following biennial sampling, troglofauna capture rate will be calculated as the number of troglobitic specimens collected per 100 trapping sites, per survey. Appendix 1 shows baseline values for capture rates at Mesa H. Capture rate has naturally high variability with survey timing, location and rainfall potentially influencing the capture rate. Specimens collected via scraping will be excluded from capture rate calculations to ensure pre-mining data are comparable with data collected during mining.

Table 2-4: Monitoring required to evaluate performance against the environmental outcome and to assess the effectiveness of management actions for troglofauna

Monitoring action	Location	Frequency and timing	Data collection method and analysis	Responsible
Pit shell reconciliation (criterion 1)	Mine pits at Mesa H	Annual during operational mine life	High accuracy differential GPS. 3-dimensional coordinates of the mine pit shell in the area of active mining. Reconcile actual and planned 3-dimensional pit shell.	Mine Planning team
Land clearing reconciliation (management target)	MEZ at Mesas H	Annual during operation mine life	GIS avoidance and disturbance layers. Internal approvals request process.	Operations Environment team
Troglofauna field survey (management target)	Minimum 25 sites	Biennial during operational mine life Post- wet season	Trapping and scraping. Morphological and molecular species level identifications. Analysis to evaluate capture rate trends	Operations Environment team

2.4.5 Subterranean fauna (stygofauna)

Protection of high value habitat for stygofauna is the most appropriate strategy to protect stygofauna so that biological diversity and ecological integrity are maintained. High value habitat in the Mine Development Envelope includes the alluvial aquifer, and the CID aquifer (BWT Robe Pisolite).

Monitoring of the retained stygofauna habitat will be completed by monthly monitoring of groundwater levels in groundwater bores (Table 2-5). These bores will intercept the alluvial aquifer of the Robe River and Jimmawurrada Creek and be strategically located to assess cumulative impacts from mine dewatering. Trigger and threshold criteria have been chosen on the modelled extent of drawdown in relation to the thickness of the alluvial aquifer.

An annual field survey for stygofauna specimens will also be conducted. Previously sampled sites will be used wherever possible to ensure results from each survey are readily comparable. Reference sites will also be sampled to provide context to the results. All specimens will be identified to species level and aligned with existing taxa/specimens where possible. Molecular identification will be used where morphological identification is not possible or is less efficient. All specimens with stygobitic characteristics will be included in the analysis and reporting as 'potentially stygobitic' until shown otherwise. Results will also be compared with those from monitoring conducted for the Bungaroo CWP to improve understanding of the regional context of the stygofauna community at Mesa H.

Following annual sampling, the number of stygobitic Orders collected will be calculated as a measure of diversity. Order level comparison has been chosen as species level identifications are not always possible. Surveys where three or less Orders are collected will be considered a breach of trigger criteria and stimulate management intervention.

Environmental DNA (eDNA) survey will be conducted annually in the dewatering impact footprint to detect the persistence of the Blind Cave Eel. Representative reference sites from the wider Robe Valley will be included to provide regional context and further understanding of the distribution and ecology of the species. An inability to detect the Blind Cave Eel in the dewatering impact footprint for two consecutive years - via either eDNA or direct collection - is regarded as a breach of threshold

criteria. Monitoring for eels using eDNA has been piloted by industry leading researchers during the environmental approvals process and shows great potential for efficient and effective detection (Biota 2018).

Further research focussing on understanding the distribution and ecology of stygofauna will be supported. Key subjects are the Blind Cave Eel, *Nedsia sculptilis* and *Nedsia hurlberti*, as well as the PEC entitled '*Stygofaunal Community of the Bungaroo Aquifer*'. Currently, Rio Tinto is proposing to support an Australian Research Council Linkage project entitled 'Transforming assessment of subterranean ecosystems using environmental DNA'. This project aims to develop eDNA methods for more effective and efficient monitoring of stygobitic communities and, if successful, could be incorporated into this EMP through adaptive management.

Table 2-5: Monitoring required to evaluate performance against the environmental outcome and to assess the effectiveness of management actions for stygofauna

Monitoring action	Location	Frequency and timing	Data collection method and analysis	Responsible
Groundwater levels (criterion 1)	Strategically located bores intercepting the alluvial aquifer.	Monthly	Groundwater monitoring Bore network (as per the Groundwater Operating Strategy (GWOS)).	Hydrogeologists
Stygofauna field survey (criterion 2)	• Minimum 25 sites within the dewatering extent. • Minimum 10 reference sites within the wider Robe Valley.	Annually	Haul net sampling Morphological and molecular species identifications Comparison with Bungaroo CWP results. Calculate number of stygobitic Orders present.	Operations Environment team
Blind Cave Eel eDNA field survey (criterion 3)	• Minimum five sites within the dewatering extent. • Minimum 10 reference sites within the wider Robe Valley.	Annually	eDNA water sample methods and analysis as per Biota (2018).	Operations Environment team

Table 2-6: EMP Provisions – Inland Waters and Flora and Vegetation

Outcome based provisions – Inland Waters and Flora and Vegetation			
EPA objectives: - To maintain the hydrological regimes of groundwater and surface water so that environmental values are protected. - To protect flora and vegetation so that biological diversity and ecological integrity are maintained. **Outcomes relating to Condition xx:** - No irreversible[3] impacts to the semi-permanent and permanent Pools (water quality / integrity) and aquatic fauna of the Robe River and health of riparian[4] vegetation of the Robe River and Jimmawurrada Creek as a result of groundwater abstraction and discharge for the Project. **Key environmental values:** Groundwater Dependant Ecosystems: Semi-permanent and Permanent Pools (water quality / integrity) and aquatic fauna of the Robe River and riparian[5] vegetation of the Robe River and Jimmawurrada Creek. **Key impacts and risks:** Potential adverse impacts to the semi-permanent and permanent Pools (water quality / integrity) and aquatic fauna of the Robe River and health of riparian[6] vegetation of the Robe River and Jimmawurrada Creek as a result of groundwater abstraction and discharge for the Mesa J Hub.			
Environmental criteria	**Response actions**	**Monitoring**	**Reporting**
Trigger criterion: 1. The mean vegetation index for riparian overstorey[7] taxa (*E. victrix, E. camaldulensis and M. argentea*) of Zones 1 & 2[8] of Jimmawurrada Creek and the Robe River declines by ≥ 2 standard deviations from baseline.	• Review discharge regime, frequency, extent and timing in relation to predicted impacts on riparian vegetation. • Review supporting water quality data for surplus discharge (conducted under the Groundwater Operating Strategy) and supporting field-based overstorey and understorey vegetation monitoring data at selected sites • Review local/regional reference data. • Increase frequency and/or extent of on-ground assessments as appropriate.	• Capture and analysis of remote sensing images within selected[9], established monitoring areas, as appropriate[10]. • Annual condition, cover and health of riparian vegetation (understorey) within selected established monitoring areas.	The environmental outcome will be reported against the trigger criteria for each calendar year by 30 April in the ACAR for MS xxxx. If the trigger criterion was exceeded during the reporting period, the ACAR will discuss potential reasons for exceedance of the trigger criterion and include a description of the effectiveness of trigger level actions.

[3] Where 'irreversible impact' is defined as, 'an impact resulting in a permanent loss of environmental value(s); or where intensive, and/or un-proven management intervention, potentially over a long timeframe, would be required to restore the environmental value(s)'.

[4] See Section b) for more information regarding composition of riparian vegetation within the Robe River and Jimmawurrada Creek systems.

[5] See Section b) for more information regarding composition of riparian vegetation within the Robe River and Jimmawurrada Creek systems.

[6] See Section b) for more information regarding composition of riparian vegetation within the Robe River and Jimmawurrada Creek systems.

[7] Due to the difficulty in distinguishing *E. victrix* and *E. camaldulensis* (reliance on seed capsules that are not always present), the overstorey riparian vegetation will be represented as a functional group for the trigger and threshold criteria. Should any exceedance occur around these species specific on-ground investigations may be appropriate.

[8] Impacts are predicted in Zone 3 of Jimmawurrada creek which may exceed this trigger periodically during initial dewatering and later in the mine life (estimated to be 2030)

[9] The Proponent will determine "selected" transects from the established transects based on factors such as trigger and threshold outcome from H2 survey, discharge and/or dewatering extent and volume.

[10] Locations may not always be available due to accessibility, weather conditions, safety considerations etc.

2. A statistically significant decline from baseline ($p<0.05$) in the number and/or cover of native perennial species	• Review contingency actions/strategy, including potential modification to surplus water management and discharge regime. • Implement remedial or management actions as appropriate. • Consult with DWER if investigation indicates threshold criterion is likely to be exceeded.		
3. Detection of a new introduced species at a potential impact site, previously not detected within the Development Envelope			
4. Decline of >0.5m between paired Alluvial Aquifer bores[11] in the Robe River near targeted pools.	• Review dewatering regime, in relation to predicted drawdown. • Review local/regional reference data. • Increase frequency and/or extent of on-ground assessments as appropriate. • Review contingency actions/strategy, including potential modification to drawdown management and discharge regime. • Implement remedial or management actions as appropriate. • Consult with DWER if investigation indicates threshold criterion is likely to be exceeded.	• Monitoring bores (subject to installation approval). • Quarterly download of daily data.	
5. Yeera Bluff (Gnieroora) Pool drops below 2 m depth[12].	• Review dewatering regime, in relation to predicted drawdown. • Review local/regional reference data. • Increase frequency and/or extent of on-ground assessments as appropriate. • Review contingency actions/strategy, including potential modification to surplus water management and discharge regime.	• Pool morphology and bathymetry via Biannual (post wet and dry) monitoring. • Direct visualization or remote assessment via drone.	The environmental outcome will be reported against the trigger criteria for each calendar year by 30 April in the ACAR for MS xxxx. If the trigger criterion was exceeded during the reporting period, the ACAR will discuss potential reasons for exceedance of the trigger criterion and include a description of the effectiveness of trigger level actions

[11] Alluvial Bore locations subject to approval from the Kurama Marthadunera People.

[12] Except where a cyclonic event changes pool morphology

	• Implement remedial or management actions as appropriate. • Consult with DWER if investigation indicates threshold criterion is likely to be exceeded. • Compare to alluvial bore water depths to ascertain if mining and / or climatic related.		
6. Exceedance of rolling quarterly median measured against the operational guideline SSTV equivalent of 95%ile value of baseline or the ANZECC/ARMCANZ (2000) default TV for toxicants for protection of 95% of species, whichever is higher (except for pH).	• Review discharge regime, frequency, extent and timing in relation to predicted impacts on water quality. • Review local/regional reference data. • Increase frequency and/or extent of on-ground assessments as appropriate. • Review contingency actions/strategy, including potential modification to surplus water management and discharge regime. • Implement remedial or management actions as appropriate.	Quarterly pool water sampling	The environmental outcome will be reported against the trigger criteria for each calendar year by 30 April in the ACAR for MS xxxx. If the trigger criterion was exceeded during the reporting period, the ACAR will discuss potential reasons for exceedance of the trigger criterion and include a description of the effectiveness of trigger level actions
Threshold criterion: 1. The mean vegetation index for riparian vegetation overstorey[13] taxa (*E. victrix, E. camaldulensis and M. argentea*) of Zones 1 & 2[14] of Jimmawurrada Creek and the Robe River changes by ≥ 2 standard deviations from baseline values over two (2) consecutive sampling events.	As for trigger level actions with the addition of: • If exceedance of threshold criterion is considered likely to be attributable to the Project, submit a report including proposed contingency actions to the DWER. • Implement contingency action/s as agreed with the DWER. • Monitor to ensure contingency actions are successful and review procedures, if appropriate.	As for trigger level monitoring with the addition of monitoring of the effectiveness of contingency actions	• Notify the DWER within 7 days of the non-compliance being known and provide a report within 21 days of the non-compliance being known. • The environmental outcome will be reported against the threshold criterion for each calendar year in the ACAR. • If the threshold criterion was exceeded during the reporting period, the ACAR will include a description of the effectiveness of threshold contingency action/s that have been implemented to manage the potential impact. • Submit a report within 12 months after notification to the DWER of the non-compliance detailing the:

[13] Due to the difficulty in distinguishing *E. victrix* and *E. camaldulensis* (reliance on seed capsules that are not always present), the overstorey riparian vegetation will be represented as a functional group for the trigger and threshold criteria. Should any exceedance occur around these species specific on-ground investigations may be appropriate.

[14] Impacts are predicted in Zone 3 of Jimmawurrada creek which may exceed this trigger periodically during initial dewatering and later in the mine life (estimated to be 2030)

2. A statistically significant decline from baseline (P<0.05) in the number and/or cover of native perennial species over two successive monitoring events			o effectiveness of contingency actions o analysis of trends of riparian tree health o schedule for ongoing reporting.
3. Detection of new introduced species rated high or very high management priority (by DBCA) at a potential impact site, previously not detected within the Development Envelope and a significant cover or abundance over successive monitoring events.			
4. Yeera Bluff (Gnieroora) Pool drops below 1m depth[15]	As for trigger level actions with the addition of: • If exceedance of threshold criterion is considered likely to be attributable to the Project, submit a report including proposed contingency actions to the DWER. • Implement contingency action/s including either: o Cease dewatering below the 120 mRL in Pit 7 of Mesa H. o Option for supplementary water direct to Yeera Bluff Pool o Or actions as agreed with the DWER. • Monitor to ensure contingency actions are successful and review procedures, if appropriate.	As for trigger level monitoring with the addition of monitoring of the effectiveness of contingency actions.	• Notify the DWER within 7 days of the non-compliance being known and provide a report within 21 days of the non-compliance being known. • The environmental outcome will be reported against the threshold criterion for each calendar year in the ACAR. • If the threshold criterion was exceeded during the reporting period, the ACAR will include a description of the effectiveness of threshold contingency action/s that have been implemented to manage the potential impact.

[15] Except where a cyclonic event changes pool morphology

5. Three (3) or less species of fish recorded in Robe River Pools.	• If exceedance of threshold criterion is considered likely to be attributable to the Project, submit a report including proposed contingency actions to the DWER. • Implement contingency action/s as agreed with the DWER. • Monitor to ensure contingency actions are successful and review procedures, if appropriate.	Bi-annual (pre and post wet) survey of semi-permanent and permanent pools	• Submit a report within 12 months after notification to the DWER of the non-compliance detailing the: o effectiveness of contingency actions. o schedule for ongoing reporting.

Environmental criteria	Response actions	Monitoring	Reporting
Supporting[16] riparian and aquatic fauna monitoring parameters for the trigger and threshold criteria			
Riparian overstorey taxa (*E. victrix, E. camaldulensis*)	N/A	• Annual post-wet season survey in selected[17], established transects, as appropriate[18]	N/A
Riparian understorey taxa (native and introduced)	N/A		
Aquatic ecosystems	N/A	• Continue biophysical/ecological survey established in 1991: aquatic fauna (macroinvertebrates and fish), channel/pool morphology, riparian/bank condition, weeds, water flows and water quality.	

[16] Parameters collected during annual surveys will assist in the interpretation of trigger and threshold criteria should an exceedance or trend be noted.

[17] The Proponent will determine "selected" transects from the established transects based on factors such as trigger and threshold outcome from H2 survey, discharge and/ or dewatering extent and volume.

[18] Locations may not always be available due to accessibility, weather conditions, safety concerns etc.

Table 2-7: EMP Provisions – Terrestrial Fauna (Ghost Bat)

Terrestrial fauna – Ghost Bat			
EPA objectives: To protect terrestrial fauna so that biological diversity and ecological integrity are maintained **Key environmental values:** Conservation significant fauna species – Ghost Bat **Key impacts and risks:** Potential loss or degradation of high value (roosting) habitat as a result of implementation of the Project			
Outcome-based provisions			
Outcome: No irreversible[19] impact, as a result of the Project, to Breakaways and Gullies habitat retained in the escarpments of Mesas H			
Environmental criteria	**Response Actions**	**Monitoring**	**Reporting**
Trigger criterion: 1. Vibration levels exceed 50 mm/s peak particle velocity at the potential diurnal/maternal Ghost Bat roost caves as shown in Figure 1-4.	• Complete in-field inspection of the area. • Review blast vibration predictions and blast vibration monitoring data. • Update vibration model if appropriate. • Review supporting Ghost Bat monitoring data.	Blast vibration monitoring for all blasts within 300 m of the potential diurnal/maternal Ghost Bat roosts. Temperature and humidity monitoring in Diurnal Roost caves.	• The environmental outcome will be reported against the trigger criteria for each calendar year by 30 April in the ACAR for MS xxxx. • If the trigger criterion was exceeded during the reporting period, the ACAR will discuss potential reasons for exceedance of the trigger criterion and include a description of the effectiveness of trigger level actions in controlling vibration levels at the potential diurnal/maternal Ghost Bat roost caves.
Threshold criterion: 1. Significant damage[20] to diurnal/maternal Ghost Bat roost caves.	As for trigger level actions with the addition of: • Conduct geotechnical assessment of the site to assess structural stability of the roost. • Review temperature and humidity monitoring data to determine if the roost cave microclimate has been compromised. Remediate any noticeable new cave openings exposed pit-side. • If structural stability of the roost is considered to be compromised as a result of the Project, submit a report including proposed contingency actions to the DWER. • Implement contingency action/s as agreed with the DWER.	As for trigger level monitoring with the addition of monitoring of the effectiveness of contingency actions	• Notify the DWER within 7 days of the non-compliance being known and provide a report within 21 days of the non-compliance being known. • The environmental outcome will be reported against the threshold criterion for each calendar year in the ACAR. • If the threshold criterion was exceeded during the reporting period, the ACAR will include a description of the effectiveness of threshold contingency action/s that have been implemented to manage the potential impact. • Submit a report within 12 months after notification to the DWER of the non-compliance detailing the: o effectiveness of contingency actions o schedule for ongoing reporting.

[19] Where 'irreversible impact' is defined as, 'an impact resulting in a permanent loss of environmental value(s); or where intensive, and/or un-proven management intervention, potentially over a long timeframe, would be required to restore the environmental value(s)'.

[20] Where 'significant damage' is defined as, 'damage that negatively impacts the structural integrity and microclimate of the cave such that future Ghost Bat use of the site is prevented'.

	• Monitor to ensure contingency actions are successful and review procedures, if appropriate.		
Environmental criteria	**Response Actions**	**Monitoring**	**Reporting**
Trigger criterion: 2. Disturbance, other than approved clearing, within 50 m of the recorded back of the potential diurnal/maternal Ghost Bat roost caves	• Complete in-field inspection of the area. • Review site specific observations; clearing extent; blast vibration predictions / blast vibration monitoring levels; and other natural factors (i.e. seasonal rainfall data etc.) to determine if disturbance is attributable to implementation of the Project. • Review supporting Ghost Bat monitoring data • Investigate potential remediation strategies (such as review of land clearing procedure or modified blast management strategy).	Annual land clearing reconciliation against potential diurnal/maternal Ghost Bat roost caves.	• The environmental outcome will be reported against the trigger criteria for each calendar year by 30 April in the ACAR for MS xxxx. • If the trigger criterion was exceeded during the reporting period, the ACAR will discuss potential reasons for exceedance of the trigger criterion and include a description of the effectiveness of trigger level actions in managing disturbance near the potential diurnal/maternal Ghost Bat roost caves.
Threshold criterion: 2. Disturbance, other than approved clearing, within 40 m of the recorded back of the potential diurnal/maternal Ghost Bat roost caves	As for trigger level actions with the addition of: • Conduct geotechnical assessment of the site to assess structural stability of the roost. • If exceedance of threshold criterion is considered likely to be attributable to the Project, submit a report including proposed contingency actions to the DWER. • Implement contingency action/s as agreed with the DWER. • Monitor to ensure contingency actions are successful and review procedures, if appropriate.	As for trigger level monitoring with the addition of monitoring of the effectiveness of contingency actions.	• Notify the DWER within 7 days of the non-compliance being known and provide a report within 21 days of the non-compliance being known. • The environmental outcome will be reported against the threshold criterion for each calendar year in the ACAR. • If the threshold criterion was exceeded during the reporting period, the ACAR will include a description of the effectiveness of threshold contingency action/s that have been implemented to manage the potential impact. • Submit a report within 12 months after notification to the DWER of the non-compliance detailing the: o effectiveness of contingency actions

			o schedule for ongoing reporting.
Supporting[21] Ghost Bat monitoring parameters for the trigger and threshold criteria			
Ghost Bat monitoring	N/A	• Annual assessment of evidence of Ghost Bat use in potential diurnal/ maternal roost caves in the broader Robe Valley	N/A

[21] Parameters collected during annual surveys will assist in the interpretation of trigger and threshold criteria should an exceedance or trend be noted.

Management-based provisions			
Management objective: Improve knowledge of the Ghost Bat population and utilisation of high value habitat in the Robe Valley in order to assist in maintaining biological diversity and ecological integrity			
Management Actions	**Management Targets**	**Monitoring**	**Reporting**
Undertake a five year study of Ghost Bat utilisation of high value habitat.	• Estimate[22] the local population of Ghost Bats in the central part of the Robe Valley. • Indicate how Ghost Bats use caves within the central part of the Robe Valley (e.g. diurnal versus maternal), including the degree of utilisation of caves by pregnant females[23].	Bi-annual collection and analysis (genetic and hormone) of scat samples from across the broader Robe Valley[24].	• The environmental outcome will be reported against the management target for each calendar year by 30 April in the ACAR for MS xxxx. • If a management target was not met during the reporting period, the annual report will include discussion of the effectiveness of the management actions and whether revision of the management actions is required.

[22] Preliminary estimate of the local population based on the data collected during the five year study period

[23] Preliminary indication of utilisation based on the data collected during the five year study period

[24] Access subject to safety and heritage assessments of caves

Table 2-8: EMP Provisions – Terrestrial Fauna (Northern Quoll)

Terrestrial fauna – Northern Quoll			
EPA objectives: To protect terrestrial fauna so that biological diversity and ecological integrity are maintained **Key environmental values:** Conservation significant fauna species – Northern Quoll **Key impacts and risks:** Potential loss or degradation of high value (denning) habitat as a result of implementation of the Project			
Outcome-based provisions			
Outcome: No irreversible[25] impact, as a result of the Project, to Breakaways and Gullies habitat retained in the escarpments of Mesas H			
Environmental criteria	**Response Actions**	**Monitoring**	**Reporting**
Trigger criterion: 1. Disturbance of ≥ 5% of potential Northern Quoll denning habitat on the retained escarpments[26] (MEZs) of Mesa H	• Complete in-field inspection of the area. • Review site specific observations such as clearing extent and natural factors (e.g. seasonal rainfall data) to determine if disturbance is attributable to implementation of the Project. • Review supporting Northern Quoll monitoring data. • Review local/regional reference data. • Increase frequency and/or extent of on-ground assessments as appropriate. • Investigate potential remediation strategies, including rehabilitation.	Annual land clearing reconciliation against escarpments of Mesas H.	The environmental outcome will be reported against the trigger criteria for each calendar year by 30 April in the ACAR for MS xxxx If the trigger criterion was exceeded during the reporting period, the ACAR will discuss potential reasons for exceedance of the trigger criterion and include a description of the effectiveness of trigger level actions in managing disturbance of the mesa escarpments.

[25] Where 'irreversible impact' is defined as, 'an impact resulting in a permanent loss of environmental value(s); or where intensive, and/or un-proven management intervention, potentially over a long timeframe, would be required to restore the environmental value(s)'.

[26] Where disturbance of 'retained escarpments" is disturbance over and above existing or approved disturbance

Environmental criteria	Response Actions	Monitoring	Reporting
Threshold criterion: 1. Disturbance of >10% of potential denning Northern Quoll habitat on the retained escarpments (MEZs) of Mesa H.	As for trigger level actions with the addition of: • If exceedance of threshold criterion is considered likely to be attributable to the Project, submit a report including proposed contingency actions to the DWER. • Implement contingency action/s as agreed with the DWER. • Monitor to ensure contingency actions are successful and review procedures, if appropriate.	As for trigger level monitoring with the addition of monitoring of the effectiveness of contingency actions.	• Notify the DWER within 7 days of the non-compliance being known and provide a report within 21 days of the non-compliance being known. • The environmental outcome will be reported against the threshold criterion for each calendar year in the ACAR. • If the threshold criterion was exceeded during the reporting period, the ACAR will include a description of the effectiveness of threshold contingency action/s that have been implemented to manage the potential impact. • Submit a report within 12 months after notification to the DWER of the non-compliance detailing the: o effectiveness of contingency actions o schedule for ongoing reporting.
Supporting[27] Northern Quoll monitoring parameters for the trigger and threshold criteria			
Northern Quoll monitoring	N/A	Annual field survey of Northern Quoll	N/A

[27] Parameters collected during annual surveys will assist in the interpretation of trigger and threshold criteria should an exceedance or trend be noted.

Table 2-9: EMP Provisions – Subterranean Fauna (Troglofauna)

Subterranean fauna – troglofauna			
EPA objectives: To protect subterranean fauna so that biological diversity and ecological integrity are maintained **Key environmental values:** Subterranean fauna - troglofauna **Key impacts and risks:** Loss of habitat from mining as a result of implementation of the Project			
Outcome-based provisions			
Outcome: No irreversible impact, as a result of the Project, to the troglofauna habitat retained within the Mesa H MEZ			
Environmental criteria	**Response Actions**	**Monitoring actions**	**Reporting**
Trigger criterion: 1. Operational error during mining resulting in removal of greater than 0.01% by volume annually per mesa of the MEZ at Mesas H.	• Review 3-dimensional pit shell and adjust to ensure no predicted net loss of the MEZ per individual mesa (i.e. amend mine plan to ensure retention of the same volume of habitat as approved under MS xxxx; or backfill; or attempt habitat recreation). • Assess the adequacy of work practices and propose changes if necessary to prevent future deviations from the planned 3-dimensional pit shell.	Annual pit shell reconciliation for mine pits at Mesa H	• The environmental outcome will be reported against the trigger criteria for each calendar year by 30 April in the ACAR for MS xxxx • If the trigger criterion was exceeded during the reporting period, the environmental outcome will be reported against the trigger criteria for each calendar year by 30 April in the ACAR for MS xxxx. • If trigger criterion was exceeded during the reporting period, the ACAR will discuss potential reasons for exceedance of the trigger criterion and include a description of the effectiveness of trigger level actions to prevent removal of the MEZ.
Threshold criterion: 1. Net loss of the MEZ at Mesa H at the completion of mining.	As for trigger level actions with the addition of: • If exceedance of threshold criterion is considered likely to be attributable to the Project, submit a report including proposed contingency actions (e.g. backfill; attempt habitat recreation) to the DWER. • Implement contingency action/s as agreed with the DWER. • Monitor to ensure contingency actions are successful and review procedures, if appropriate.	Monitor the effectiveness of contingency actions	• Notify the DWER within 7 days of the non-compliance being known and provide a report within 21 days of the non-compliance being known. • The environmental outcome will be reported against the threshold criterion for each calendar year in the ACAR. • If the threshold criterion was exceeded during the reporting period, the ACAR will include a description of the adequacy of threshold contingency action/s that have been implemented to manage the potential impact. • Submit a report within 12 months after notification to the DWER of the non-compliance detailing the: o adequacy of contingency actions to re-instate the appropriate amount of lost habitat o schedule for ongoing monitoring and reporting.

Management-based provisions			
Management objective: To minimize impacts as far as practicable to protect the biological diversity and ecological integrity of the troglofauna assemblages of Mesa H			
Management actions	**Management targets**	**Monitoring**	**Reporting**
• Maintain MEZ (significant troglofauna habitat). • Minimise ground disturbance and potential for degradation in the retained MEZ habitat.	• Maintain MEZ (significant troglofauna habitat). • Total clearing of native vegetation across the surface of the MEZ is less than 30% of the MEZ surface area. • Troglofauna specimen capture rate is not below the baseline minimum for three consecutive sampling events for Mesa H.	• Annual land clearing reconciliation against escarpments of Mesa H. • Biennial troglofauna field survey.	• The environmental outcome will be reported against the management target for each calendar year by 30 April in the ACAR for MS xxxx. • If a management target was not met during the reporting period, the annual report will include discussion of the effectiveness of the management actions and whether revision of the management actions is required.
Supporting[28] Troglofauna monitoring parameters for the trigger and threshold criteria			
Troglofauna monitoring	N/A	Daily weather and climatic data	N/A

[28] Parameters collected during annual surveys will assist in the interpretation of trigger and threshold criteria should an exceedance or trend be noted.

Table 2-10: EMP Provisions – Subterranean Fauna (Stygofauna)

Subterranean fauna – stygofauna			
EPA objectives: To protect subterranean fauna so that biological diversity and ecological integrity are maintained **Key environmental values:** Subterranean fauna – stygofauna community and Blind Cave Eel **Key impacts and risks:** Loss of habitat from mining (groundwater management) as a result of implementation of the Project			
Outcome-based provisions			
Outcome: No irreversible impact, as a result of the Proponents water management activities, to the stygofauna habitat within the CID aquifer and stygofauna and Blind Cave Eel habitat within the alluvial aquifer habitat of Jimmawurrada Creek and the Robe River shown in Figure 1-6.			
Environmental criteria	**Response Actions**	**Monitoring actions**	**Reporting**
Trigger criterion: 1. Groundwater levels drop three (3) m below predicted water table heights in the Jimmawurrada Creek alluvial aquifer. 2. Diversity of stygofauna Orders collected during annual survey events reduced to 3 or less.	• Review site specific observations such as clearing extent and natural factors (e.g. seasonal rainfall data) to determine if exceedance is attributable to implementation of the Project. • Review trends in alluvial groundwater levels • Review stygofauna monitoring data. • Review local/regional reference data. • Increase frequency and/or extent of monitoring as appropriate. • Investigate potential remediation strategies.	• Monthly monitoring of groundwater levels in alluvial aquifer bores. • Annual stygofauna field survey.	• The environmental outcome will be reported against the trigger criteria for each calendar year by 30 April in the ACAR for MS xxxx • If the trigger criterion was exceeded during the reporting period, the environmental outcome will be reported against the trigger criteria for each calendar year by 30 April in the ACAR for MS xxxx. • If trigger criterion was exceeded during the reporting period, the ACAR will discuss potential reasons for exceedance of the trigger criterion and include a description of the effectiveness of trigger level actions to prevent loss of habitat.
Threshold criterion: 1. Alluvial aquifer is dry for 2 consecutive years. 2. Absence of Blind Cave Eel recorded for two consecutive annual sampling events. 3. Absence of stygofauna specimens for two consecutive sampling events.	As for trigger level actions with the addition of: • If exceedance of threshold criterion is considered likely to be attributable to the Project, submit a report including proposed contingency actions (e.g. backfill; attempt habitat recreation) to the DWER. • Implement contingency action/s as agreed with the DWER. • Monitor to ensure contingency actions are successful and review procedures, if appropriate.	• Monthly monitoring of groundwater in alluvial aquifer bores. • Annual eDNA field survey targeting the Blind Cave Eel. • Annual stygofauna field survey.	• Notify the DWER within 7 days of the non-compliance being known and provide a report within 21 days of the non-compliance being known. • The environmental outcome will be reported against the threshold criterion for each calendar year in the ACAR. • If the threshold criterion was exceeded during the reporting period, the ACAR will include a description of the adequacy of threshold contingency action/s that have been implemented to manage the potential impact. • Submit a report within 12 months after notification to the DWER of the non-compliance detailing the: o adequacy of contingency actions to re-instate the appropriate amount of lost habitat o schedule for ongoing monitoring and reporting.

Management-based provisions			
Management objective: The Proponent shall protect the biological diversity and ecological integrity of the stygofauna assemblages within the CID and Alluvial aquifer habitat shown in Figure 1-6 by minimizing impacts as far as practicable.			
Management actions	**Management targets**	**Monitoring**	**Reporting**
• Continue to improve understanding of stygofauna distribution and ecology by supporting research. (e.g. ARC Linkage Project currently entitled 'Transforming assessment of subterranean ecosystems using environmental DNA'). • Retain significant connected stygofauna habitat.	Understand the distribution and ecology of key stygofauna taxa within the Robe Valley area.	• Annual stygofauna field survey results. • Annual eDNA field survey targeting the Blind Cave Eel.	• The environmental outcome will be reported against the management target for each calendar year by 30 April in the ACAR for MS xxxx. • If a management target was not met during the reporting period, the annual report will include discussion of the effectiveness of the management actions and whether revision of the management actions is required.

Supporting[29] Stygofauna monitoring parameters for the trigger and threshold criteria			
Meteorological monitoring	N/A	Daily weather and climatic data.	N/A
Water quality	N/A	Water quality parameters in alluvial aquifer bores.	

[29] Parameters collected during annual surveys will assist in the interpretation of trigger and threshold criteria should an exceedance or trend be noted.

2.5 Reporting

The management outcomes will be reported against the management target (Table 2-11) for each calendar year in the Annual Compliance Assessment Report (ACAR) for the Mesa J Hub against MS xxxx.

The annual report will also include a summary of the analysis of monitoring data to facilitate adaptive management.

In the event that trigger and threshold criteria are exceeded during the reporting period or management targets are not met, the annual report will include a description of the effectiveness of any management contingency actions that have been implemented to manage the impact. A stand-alone report will also be produced for the DWER within 21 days of any exceedance of the threshold criteria. A follow up report detailing the adequacy of the response actions will also be submitted to the DWER within 12 months of the initial notification.

Table 2-11: Mesa J Hub Environmental Management Plan Reporting Table

Key environmental factors: Inland waters, vegetation and aquatic fauna; terrestrial fauna (Ghost Bat and Northern Quoll); subterranean fauna (troglofauna and stygofauna).	
Condition environmental outcome, trigger and threshold criteria as per MS xxxx	**Reporting period** **1 January - 31 December**
Trigger criteria:	**Status report:** Environmental outcome achieved Environmental outcome not achieved
Inland waters, vegetation and aquatic fauna 1) The mean vegetation index for riparian overstorey[30] taxa (*E. victrix, E. camaldulensis and M. argentea*) of Zones 1 & 2[31] of Jimmawurrada Creek and the Robe River changes by ≥ 2 standard deviations. 2) A statistically significant decline from baseline ($p<0.05$) in the number and/or cover of native perennial species of Zones 1 & 2 of Jimmawurrada Creek 3) Detection of new introduced species at a potential impact site, not previously detected within the Development Envelope. [surplus water discharge] 4) Decline of >0.5m between paired Alluvial Aquifer bores[32] in the Robe River near targeted pools. 5) Yeera Bluff (Gnieroora) Pool drops below 2m depth. 6) Water quality in pools exceeds rolling quarterly median measured against the operational guideline SSTV equivalent of 95%ile value of baseline or the ANZECC/ARMCANZ (2000) default TV for toxicants for protection of 95% of species, whichever is higher (except for pH).	
Ghost bat 1) Vibration levels exceed 50mm/s peak particle velocity at the potential diurnal/maternal Ghost Bat roost caves. 2) Disturbance, other than approved clearing, within 50m of the recorded back of the potential diurnal/maternal Ghost Bat roost caves.	
Northern Quoll 1) Disturbance of >5% of potential Northern Quoll denning habitat on the retained escarpment of Mesa H.	

[30] Due to the difficulty in distinguishing E. *victrix* and *E. camaldulensis* (reliance on seed capsules that are not always present), the overstorey riparian vegetation will be represented as a functional group for the trigger and threshold criteria. Should any exceedance occur around these species specific on-ground investigations may be appropriate.

[31] Impacts are predicted in Zone 3 of Jimmawurrada creek which may exceed this trigger periodically during initial dewatering and later in the mine life (estimated to be 2030)

[32] Alluvial Bore locations subject to approval from the Kurama Marthadunera People.

Key environmental factors: Inland waters, vegetation and aquatic fauna; terrestrial fauna (Ghost Bat and Northern Quoll); subterranean fauna (troglofauna and stygofauna).	
Condition environmental outcome, trigger and threshold criteria as per MS xxxx	**Reporting period** **1 January - 31 December**
Troglofauna 1) Operational error during mining resulting in removal of greater than 0.01% by volume annually of the MEZ at Mesa H.	
Stygofauna 1) Groundwater levels drop three (3) m below predicted water table heights in the Jimmawurrada Creek alluvial aquifer. 2) Diversity of stygofauna Orders collected during annual survey events reduced to three (3) or less	
Threshold criteria:	**Status report:** Environmental outcome achieved Environmental outcome not achieved
Inland waters, vegetation and aquatic fauna 1) The mean vegetation index for riparian vegetation overstorey (upper canopy) taxa (E. victrix, E. camaldulensis and M. argentea) of Zones 1 & 2 of Jimmawurrada Creek and the Robe River declines by ≥ 2 standard deviations from baseline values over two consecutive sampling events. 2) Statistically significant decline from baseline ($p<0.05$) in the number and/ or cover of native perennial species of Zones 1 & 2 of Jimmawurrada Creek and the Robe River. 3) Statistically significant decline from baseline ($p<0.05$) in the number and/or cover of native perennial species over two successive monitoring events. 4) Decline of ≥1 m between paired Alluvial Aquifer bores in the Robe River near targeted pools. 5) Yeera Bluff (Gnieroora) Pool drops below 1m depth[33]. 6) Three (3) or less species of fish recorded across all sampled Robe River Pools.	
Ghost bat 1) Significant damage to diurnal/maternal Ghost Bat roost caves. 2) Disturbance, other than approved clearing, within 40m of the recorded back of the potential diurnal/maternal Ghost Bat roost caves.	
Northern Quoll 1) Disturbance of >10% of potential denning Northern Quoll habitat on the retained escarpment of Mesa H.	

[33] Except where a cyclonic event changes pool morphology

Key environmental factors: Inland waters, vegetation and aquatic fauna; terrestrial fauna (Ghost Bat and Northern Quoll); subterranean fauna (troglofauna and stygofauna).	
Condition environmental outcome, trigger and threshold criteria as per MS xxxx	**Reporting period** **1 January - 31 December**
Troglofauna 1) Net loss of the MEZ at Mesa H, at the completion of mining.	
Stygofauna 1) Alluvial aquifer in Jimmawurrada is dry for two (2) consecutive years. 2) Absence of Blind Cave Eel recorded for two (2) consecutive annual sampling events. 3) Absence of stygofauna specimens for two (2) consecutive annual sampling events.	
Management-based targets:	**Status report:** Environmental target achieved Environmental target not achieved
Ghost bat 1) Estimate the local population of Ghost Bats in the central part of the Robe Valley. 2) Indicate how Ghost Bats use caves within the central part of the Robe Valley (e.g. diurnal versus maternal), including the degree of utilisation of caves by pregnant females.	
Troglofauna 1) Total clearing of native vegetation across the surface of the MEZ is less than 30% of the MEZ surface area. 2) Troglofauna specimen capture rate is not below the baseline minimum for three (3) consecutive sampling events at Mesa H.	
Stygofauna 1) Understand the distribution and ecology of key stygofauna taxa within the Robe Valley area.	

3. ADAPTIVE MANAGEMENT AND REVIEW OF THIS EMP

The Proponent will implement adaptive management to learn from the implementation of mitigation measures, monitoring and evaluation against trigger and threshold criteria, to more effectively meet the conditioned environmental outcome.

The following approach will apply:

- Monitoring data will be systematically evaluated and compared to baseline and reference site data on a regular basis in a process of adaptive management to verify whether riparian vegetation responses to the impact are the same or similar to predictions.
- The effectiveness and relevance of trigger level and threshold contingency actions will be evaluated on an annual basis to determine if any changes to management actions are required.
- The effectiveness and relevance of management actions will be evaluated on an annual basis to determine is any changes are required.

4. STAKEHOLDER CONSULTATION

Consultation specific to this EMP will be undertaken during the Environmental Impact Assessment process for the Mesa H Proposal. Consultation will be documented and any concerns will be addressed prior to finalisation of the EMP. Stakeholder consultation will include the Department of Biodiversity, Conservation and Attractions - Park and Wildlife Service and the Department of Water and Environmental Regulation – EPA Services and Compliance and Reporting (Water).

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6. APPENDIX

Appendix 1: Baseline Troglofauna 'hit rate' for Mesa H

Change in specimen capture rate over time for troglofauna recorded from the Mesa H landform.

Collection rate has been converted to a rate per 100 trapped holes. Data tracks changes over eight sampling events spanning 12 years including pre mining initiation. The variation in collection rate is naturally large (17 to 228.6). Larger collection rates are more likely influenced by rainfall prior to sampling rather than mining, however the required timing and size of the rainfall event is still uncertain from the current data. All troglobitic but indeterminate specimens are included in these calculations for completeness. Specimens collected via scraping have been omitted; this collection method was only employed in recent sampling events and is thus will not be comparable pre and post mining. Weather information was taken from Pannawonica BOM Station.

Mesa H	**Pre-mining**							
Sample collection date	**2005/2006 (21st Nov - 20th Jan)**	**2010 (21st Sep - 10th Nov)**	**2015 EIA P1 (29th Oct - 12th Dec)**	**2016 EIA P2 (12th Dec - 21st Jan)**	**2016 EIA P3 (7th May - 28th Jun)**	**2016 EIA P4 (14th Sep - 27th Oct)**	**2016 EIA P5 (27th Oct - 14th Dec)**	**2017 EIA P6 (14th Dec - 31st Jan)**
Rainfall during survey	5.8	0.0	40.4	3.8	13.6	0.4	37.8	151.0
Rainfall 3 months prior to collection date	13.0	23.8	40.4	9.0	171.8	2.4	38.2	187.8
Rainfall 12 months prior to collection date	530.4	219.2	422.0	354.2	312.8	348.6	360.0	448.4
Number of trapped holes	6	23	46	46	30	43	47	14
Number of specimens collected	0	24	23	20	8	34	8	32
Number of specimens per 100 trapped holes	n/a	104.3	50.0	43.5	26.7	79.1	17.0	228.6

Robe River Mining Co. Pty. Limited

ABN: 71 008 694 246

Mesa J Hub Closure Plan

July 2018

Mineral Field: 08 – Ashburton

FDMS No: RTIO-HSE-0168839

Version 1.1

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EXECUTIVE SUMMARY

Overview

The Mesa J Hub deposits include Mesa J, Mesa K and Mesa H, and are located in the Pilbara region of Western Australia, approximately 16km from Pannawonica in the Shire of Ashburton. The deposits are located within the traditional lands of the Kuruma Marthudunera people and the area is managed by Robe River Mining Co Pty Limited, which is a member of the Rio Tinto Group.

The Mesa K mine commenced operations in 1988 and Mesa J in 1992, and comprise open cut operations utilising conventional drill-and-blast and load and haul mining methods. Ore is crushed on-site before being transported via rail to Cape Lambert for shipping. This closure plan incorporates the current Mesa J and K operation and has been extended to include the adjacent Mesa H deposit.

The currently approved Mesa J and Mesa K mines have an operational life of 13 years with completion of mining scheduled for 2029. The proposed development of Mesa H will incorporate mining until 2037. Mineral waste generated by mining will be placed in a small number of external dumps as well as progressively backfilled into pit voids as they become available. The site is expected to encounter some highly erodible materials which will be used for pit backfill or placed in external waste dumps with appropriate final parameters and/or capping with competent waste. The site has been assessed as having a low geochemical risk and is not expected to encounter acid or metalliferous drainage during mining or post closure.

Scope

This document, titled ‘Mesa J Hub Closure Plan July 2018’, represents the updated closure plan for the Mesa J and K operations and proposed Mesa H operations and supersedes previous closure plans. It is applicable to mine developments and all associated infrastructure at Mesa J Hub iron ore deposits within the following leases:

- ML248SA Section 103 (Part)
- ML248SA Section 104

The scope of the plan has been aligned to existing tenure boundaries, which may differ from the footprint approved or referred under Part IV of the *Environmental Protection Act 1986.*

Post-mining land use

Post-mining land use options in the Pilbara are generally limited due to the remote location. The proposed final land use assumes that the site will be rehabilitated to create a safe, stable and non-polluting landscape revegetated with native species, to maximise environmental and cultural heritage outcomes and ensure the site does not adversely impact on the current surrounding land use.

Due to the nature of the mining activity undertaken, the final landform will include large voids and waste dumps, and will therefore be unlikely to support pastoral activities in the immediate disturbed areas. However, it is recognized that surrounding areas are likely to remain subject to pastoral activity. For the purpose of this closure plan, it is assumed that the post closure landform will be shaped and rehabilitated to support ongoing pastoral activity and to ensure that the visual amenity and associated heritage and ecological values will be retained in the post closure landform. The final land use will be determined prior to closure during final planning phases and in consultation with relevant stakeholders.

Closure objectives

The following objectives have been developed in relation to the closure strategy contained within this closure plan:

- Public safety hazards have been managed.
- Contaminated sites are appropriately managed in accordance with the Contaminated Sites Act 2003 (WA).
- Final landform is stable and considers ecological and hydrological issues.
- Vegetation on rehabilitated land is self-sustaining and compatible with the final land use.
- Infrastructure has been appropriately managed.
- Robe River permanent pools function similar to the pre-mining state.

Indicative completion criteria have been proposed for each of these objectives; however these have not been the subject of consultation with stakeholders at this point, which is considered acceptable given the long timeframe for mining operations for this site.

Anticipated closure outcome

At closure all below water table pits (with the exception of pit 15 at Mesa J) will be backfilled to suppress the formation of pit lakes. Above water table pits will be backfilled opportunistically with waste. Several pits in the Mesa J mining area will be backfilled with waste fines and capped with inert waste rock. Mining exclusion zones will remain undisturbed as agreed. External waste dumps will be reprofiled to meet final design parameters. Disturbed surfaces will be rehabilitated including pit floors (excluding pit faces). Abandonment bunding or other appropriate means of access restriction will be placed around pits as described within the plan. Disturbed landform features will be rehabilitated with appropriate native species.

CLOSURE PLAN CHECKLIST

The following table provides cross reference to the requirements of the Department of Mines and Petroleum / Environmental Protection Authority *Guidelines for preparing mine closure plans* (2015).

	Mine Closure Plan (MCP) Checklist	Y/N/NA	Page No.	Comments	Change from previous version (Y/N)	Page No.	Comments
1	Has the Checklist been endorsed by a senior representative within the operating company?						
Public Availability							
2	Are you aware that from 2015 all MCPs will be made publically available?	Y	NA				
3	Is there any information in this MCP that should not be publicly available?	Y	Appendix C				
4	If "Yes" to Q3, has confidential information been submitted in a separate document / section?	Y	Appendix C				
Cover page, table of contents							
5	Does the MCP cover page include: Project Title, Company Name, Contact Details (including telephone numbers and email address) Document ID and version number, Date of submission (needs to match the date of this checklist)	Y					
Scope and purpose							
6	State why the MCP is submitted (e.g. as part of a Mining Proposal, a reviewed MCP or to fulfil other legal requirement)	Y	1				
Project overview							
7	Does the project summary include land ownership details, location of the project, comprehensive site plans and background information on the history and status of the project?	Y	3-47				

	Mine Closure Plan (MCP) Checklist	Y/N/NA	Page No.	Comments	Change from previous version (Y/N)	Page No.	Comments
Legal obligations and commitments							
8	Does the MCP include a consolidated summary or register of closure obligations and commitments been included?	Y	Appendix A				
Stakeholder engagement							
9	Have all stakeholders involved in closure been identified?	Y	12				
10	Does the MCP included a summary or register of historic stakeholder engagement been provided, with details on who has been consulted and the outcomes?	Y	Appendix B				
11	Does the MCP include a stakeholder consultation strategy to be implemented in the future?	Y	12				
Post mining land use(s) and closure objectives							
12	Does the MCP include agreed post-mining land use, closure objectives and conceptual landform design diagram?	Y	13, 13 and Appendix F	Preliminary final land use options, closure objectives and final landform design is presented in the plan. These will continue to be refined during operations and agreed with relevant parties prior to closure.			
13	Does the MCP identify all potential (or pre-existing) environmental legacies which may restrict the post mining land use (including contaminated sites)?	NA		There are no contaminated sites associated with the operation.			
14	Has any soil or groundwater contamination that occurred, or is suspected to have occurred, during the operation of the mine, been reported to DER as required under the Contaminated Sites Act 2003?	NA		There are no known or suspected contaminated sites associated with the operation.			

	Mine Closure Plan (MCP) Checklist	Y/N/NA	Page No.	Comments	Change from previous version (Y/N)	Page No.	Comments
Development of completion criteria							
15	Does the MCP include an appropriate set of specific completion criteria and closure performance indicators?	Y		14			
Collection and analysis of closure data							
16	Does the MCP include baseline data (including pre-mining studies and environmental data)	Y	18 and Appendix C				
17	Has materials characterisation been carried out consistent with applicable standards and guidelines (e.g. GARD Guide)?	Y	24				
18	Does the MCP identify applicable closure learnings from benchmarking against other comparable mine sites?	Y	Appendix C				
19	Does the MCP identify all key issues impacting mine closure objectives and outcomes (including potential contamination impacts)?	Y	49				
20	Does the MCP include information relevant to mine closure for each domain or feature?	Y	59				
Identification and management of closure issues							
21	Does the MCP include a gap analysis / risk assessment to determine if further information is required in relation to closure of each domain or feature?	Y	48 and Appendix D				
22	Does the MCP include the process, methodology and has the rationale been provided to justify identification and management of the issues?	Y	48 and Appendix D				

	Mine Closure Plan (MCP) Checklist	Y/N/NA	Page No.	Comments	Change from previous version (Y/N)	Page No.	Comments
Closure Implementation							
23	Does the MCP include a summary of closure implementation strategies and activities for the proposed operations or for the whole site?	Y	59				
24	Does the MCP include a closure work program for each domain or feature?	Y	59	To be developed prior to closure			
25	Does the MCP contain site layout plans to clearly show each type of disturbance as defined in Schedule 1 of the MRF Regulations?	Y	62	Mine layout is included in the plan and discussed in detail; however it is not categorised according to MRF regulations.			
26	Does the MCP contain a schedule of research and trial activities?	Y	Appendix E				
27	Does the MCP contain a schedule of progressive rehabilitation activities?	N		Indicative closure schedule provided. Opportunities for rehabilitation assessed annually			
28	Does the MCP include details of how unexpected closure and care and maintenance will be handled?	Y	66				
29	Does the MCP contain a schedule of decommissioning activities?	N		To be developed prior to closure			
30	Does the MCP contain a schedule of closure performance monitoring and maintenance activities?	Y	67				
Closure monitoring and maintenance							
31	Does the MCP contain a framework, including methodology, quality control and remedial strategy for closure performance monitoring including post-closure monitoring and maintenance?	N		To be developed prior to closure			

	Mine Closure Plan (MCP) Checklist	Y/N/NA	Page No.	Comments	Change from previous version (Y/N)	Page No.	Comments
Financial provisioning for closure							
32	Does the MCP include costing methodology, assumptions and financial provision to resource closure implementation and monitoring?	Y	68				
33	Does the MCP include a process for regular review of the financial provision?	Y	68				
Management of information and data							
34	Does the MCP contain a description of management strategies including systems and processes for the retention of mine records?	Y	69				

Corporate endorsement:

I hereby certify that to the best of my knowledge, the information within this Mine Closure Plan is true and correct and addresses the relevant requirements of the *Guidelines for Preparing Mine Closure Plans* approved by the Director General of Mines and Petroleum.

Graeme Weeks

General Manager Technical Services, Rio Tinto Iron Ore

Date: 05 July 2018

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ABBREVIATIONS

AEP	Annual Exceedance Probability
AMD	Acid or Metalliferous Mine Drainage
AWT	Above Water Table
BWT	Below Water Table
DER	Department of Environmental Regulation
DMP	Department of Mines and Petroleum
ENSO	El Niño Southern Oscillation
EPA	Environmental Protection Authority
ESP	Exchangeable Sodium Percentage
IBRA	Interim Biogeographic Regionalisation for Australia
ILUA	Indigenous Land Use Agreements
IOD	Indian Ocean Dipole
IODMS	Iron Ore Document Management System
K&M	Kuruma Marthudunera
MNES	Matters of National Environmental Significance
mRL	Metres above Relevant Level (Sea Level)
MS208	Ministerial Statement 208
MS776	Ministerial Statement 776
NVCP	Native Vegetation Clearing Permits
PAF	Potentially Acid Forming
PCO	Present Closure Obligation
SCARD	Spontaneous Combustion and Acid Rock Drainage
TPC	Total Projected Closure
ZOI	Zone of Instability

SCOPE AND PURPOSE

1. Purpose

Planning for closure of a site is a critical business process that demonstrates Rio Tinto's commitment to sustainable development. This closure plan follows the format and content requirements for mine closure plans as recommended in the Department of Mines and Petroleum (DMP) / Environmental Protection Authority (EPA) *Guidelines for preparing mine closure plans* (2015).

This closure plan has been developed to achieve the following goals:

- to reflect the current knowledge and requirements for closure of Mesa H, Mesa J and Mesa K mines (collective known from here as the Mesa J Hub) and identify the future requirements to continue to progress towards a planned and managed closure of the site;
- to inform the development of closure provisions;
- to meet the internal requirements of the Rio Tinto Closure Standard (2015) mandated for all Rio Tinto businesses;
- for submission to the Department of State Development, to satisfy a request from that Department; and
- to support the environmental approval of the Mesa H Deposit.

2. Scope

This plan covers the current mining operations at Mesa J and K deposits, and the proposed development of the Mesa H deposit. The plan is applicable to areas and mine development features within the following leases[1],

- ML248SA Section 103 (Part);
- ML248SA Section 104.

The plan excludes the following:

- The Pannawonica town and associated access roads
- The mainline rail and associated infrastructure
- Previously developed deposits at Eastern Deepdale and Middle Robe
- The Coastal Water Project (a water supply borefield feeding into the public water system)
- Other undeveloped deposits in the Robe Valley.

The plan will refer to the areas described above as the 'Mesa J Hub' throughout this document.

This closure plan supersedes all previous closure, decommissioning and rehabilitation plans for the Mesa J Hub.

The Robe JV hold mineral leases pursuant to the RR Agreement Act over multiple undeveloped deposits in the Robe Valley. Development of several of these deposits will potentially require continued utilisation of the Mesa J Hub infrastructure after completion of mining at the Mesa J, K and H deposits. These future developments are excluded from the scope of this current Mesa J Hub closure plan, but will be included in future closure plan updates with improved certainty of the specifics of these developments.

[1] Note that the scope of the closure plan has been aligned to tenure boundaries, which may differ from the footprint approved or referred under Part IV of the *Environmental Protection Act 1986*.

2.1 Closure Planning Process

Closure planning is an iterative process that commences during the planning phase of the mine development and is regularly updated and refined during the operational phase (Figure 1). Closure plans are updated to account for changes resulting from:

- amendments to the mine plan;
- improvements of the site closure knowledge base (e.g. through daily activities, technical studies and research actions, progressive rehabilitation);
- new or amended regulation;
- changes to surrounding land uses; and
- evolving stakeholder expectations.

Reviews brings specialists together to discuss current performance, proposed mine changes and opportunities to improve closure outcomes. At the end of the review, improvement actions are assigned and the closure plan is updated.

A key output of closure planning is the development of a closure cost estimate. Closure provisions are subsequently integrated into our business planning processes to ensure funds will be available to close the site effectively.

The detail of each closure plan increases as the knowledge base develops. When the site approaches scheduled closure, studies will be completed to define how infrastructure, decontamination, rehabilitation, the workforce and communications will be managed throughout the mine closure period (and beyond). Stakeholder engagement continues and endorsement of completion criteria is conducted at this time.

In the final closure plan, location specific management plans are provided for each closure domain. These detailed plans cover the physical closure, dismantling and subsequent rehabilitation implementation requirements. The supporting technical reports that have been used to predict the post-closure outcomes are appended to the final closure plan.

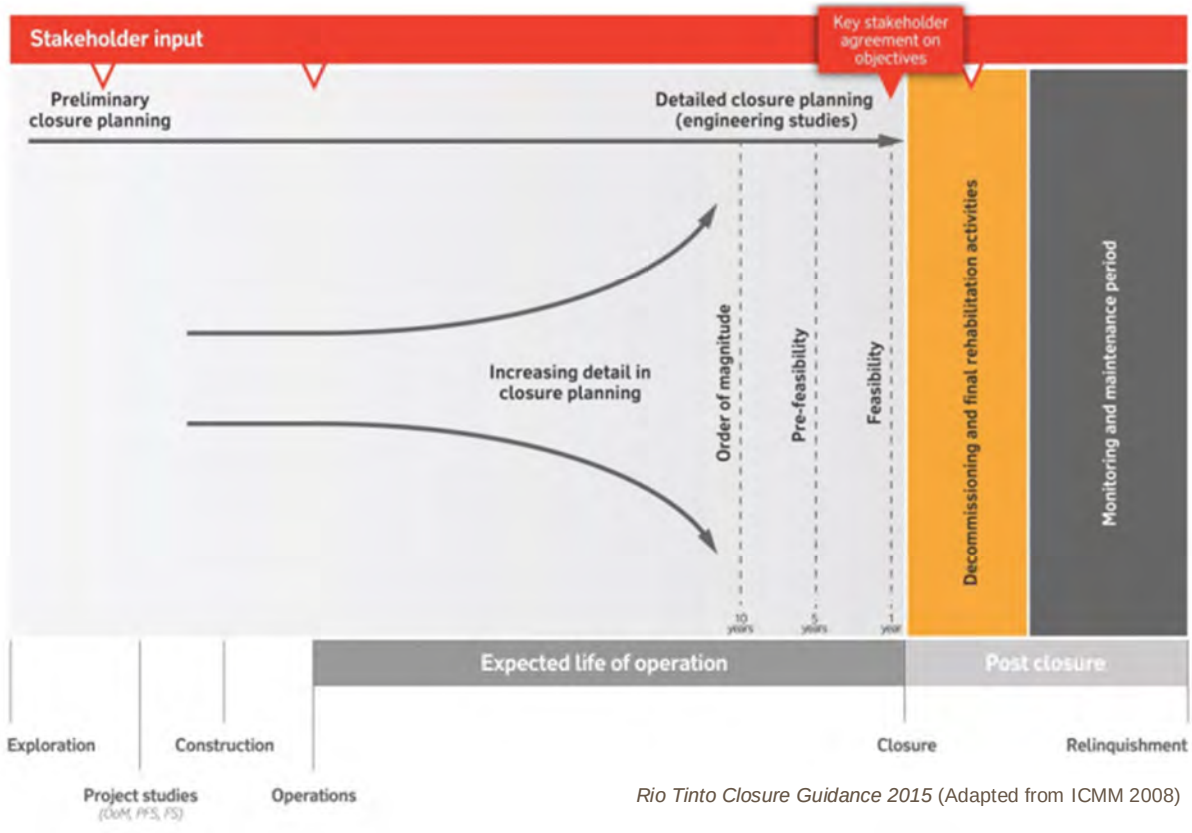


Figure 1: Progression of closure planning

PROJECT OVERVIEW

3. Description of the operation

3.1 Location

The Mesa J Hub includes Mesa H, Mesa J and Mesa K deposits, and is located in the Pilbara region of Western Australia, approximately 100km east of Onslow and 14km southwest of the township of Pannawonica (Figure 2, Figure 3).The area falls within the local authority of the Shire of Ashburton. Tenure associated with current and proposed mining activities is shown in Figure 4, and listed above in Section 2. The mine is located within the traditional lands of the Kuruma Marthudunera (K&M) people (Figure 5). The nearest Aboriginal community is a small settlement known as "The Block" located three kilometres north of Mesa H, which is not permanently occupied.

The Mesa J Hub is overlain by pastoral leases as shown in Figure 4. The eastern operations of Mesa J and K fall within the Yalleen Station (N049492) lease and the western side of Mesa J and H fall within the Yarraloola Station (N049500) lease. Both Yalleen and Yarraloola Stations are owned by Robe River Iron Associates, which is majority owned by Rio Tinto. Both stations are currently sub-leased, with Yalleen managed by Williambury Station Pty Ltd and Yarraloola managed by Cardoo Holdings.

The site is located in proximity to various sensitive environmental and cultural heritage receptors. The ephemeral Robe River is located immediately north of Mesa J and H and south of Mesa K, with permanent and semi-permanent pools occurring in proximity to the deposits. The Robe River and associated pools, together with the mesa landform, have significant cultural value for the local indigenous people. The Robe River and pools, and the breakaway landform on the mesa perimeter, also have value for local biodiversity. There are two Priority Ecological Communities (PEC's) associated with troglofauna communities in mesa landforms of the Robe Valley, comprising 'Subterranean invertebrate communities of mesas in the Robe Valley region' and 'Subterranean invertebrate community of pisolitic hills in the Pilbara'.

The Mesa J Hub is operated under a Joint Venture (JV) agreement of which Rio Tinto owns the majority share. The allocations are as follows;

- Rio Tinto (53%)
- Mitsui Iron Ore Development Pty Ltd (33%)
- Pannawonica Iron Associates (10.5%); and,
- Cape Lambert Iron Associates (3.5%).

3.2 Mine Operations

The Mining operations currently managed by the Robe JV have been active in the Robe Valley for over 40 years at multiple locations, facilitated by the *RR Agreement Act 1964* (Agreement Act). Robe JV deposits within the scope of this closure plan comprise the following:

- Mesa J deposit, which commenced mining in 1992.
- Mesa K deposit 1.5 km north-east of Mesa J, that commenced mining in 1988,
- Mesa H deposit, immediately west of Mesa J, which is proposed for development from 2019.

At Mesa J and K, iron ore is mined using conventional open cut mining methods of drilling and blasting, and load and haul. Waste rock is hauled to designated waste dumps or to back fill unused pits, with a priority to store in unused pits. Only a limited number of external dumps are proposed. Ore is hauled to the processing plants at Mesa J, with product transported to Cape Lambert via rail. Mining of the Mesa H deposit will follow a similar method with ore hauled to the Mesa J plants for processing. Minor expansion of the Mesa J plant facilities will occur.

The Mesa J, K and H deposits have a current combined operational life of 20 years with completion of mining scheduled for 2037. The current mine development schedule is outlined in Table 1 below. The mine schedules and plans are subject to regular review to ensure optimised performance of the operations and are therefore subject to change over time. The key landforms associated with the mine are shown in Table 2 below, and the proposed construction and rehabilitation design criteria for these landforms are included in Appendix F. The proposed mine layout is shown in Figure 6.

Table 1: Indicative mining schedule

Deposit	Pit	Commencement	Completion	Description	Regulatory Status
Mesa H	Pit 1	2023	2027	BWT	Proposed
Mesa H	Pit 2	2028	2031	BWT	Proposed
Mesa H	Pit 3	2030	2032	BWT	Proposed
Mesa H	Pit 4	2030	2035	BWT	Proposed
Mesa H	Pit 5	2034	2036	BWT	Proposed
Mesa H	Pit 6	2020	2027	BWT	Proposed
Mesa H	Pit 7	2026	2034	BWT	Proposed
Mesa H	Pit 8	2026	2032	BWT	Proposed
Mesa H	Pit 9	2021	2026	AWT	Proposed
Mesa J	Pit 1	1992	1999	AWT	Complete
Mesa J	Pit 2	1992	2016	AWT	Complete
Mesa J	Pit 3	1993	2021	AWT	Complete
Mesa J	Pit 4	1993	TBC	AWT	Approved
Mesa J	Pit 5	1994	2021	AWT	Approved
Mesa J	Pit 6	2000	2025	BWT	Approved
Mesa J	Pit 7	1998	2019	BWT	Approved
Mesa J	Pit 8	2000	2021	BWT	Approved
Mesa J	Pit 9	2002	2019	BWT	Approved
Mesa J	Pit 10	TBC	TBC	BWT	Approved
Mesa J	Pit 11	2006	2021	BWT	Approved
Mesa J	Pit 12	2007	2020	BWT	Approved
Mesa J	Pit 14	2024	2028	BWT	Approved
Mesa J	Pit 15	1998	2020	BWT	Approved
Mesa K[2]	Pit 1	2021	2021	AWT	Approved
Mesa K	Pit 2	2021	2022	AWT	Approved
Mesa K	Pit 3	2022	2023	AWT	Approved
Mesa K	Pit 4	2023	2024	AWT	Approved
Mesa K	Pit 5	2023	2025	AWT	Approved
Mesa K	Pit 6	2024	2028	AWT	Approved

[2] Mesa K Pits were previously known as Gully, Central and Gravel Pits, and mined from 1988

Table 2: Waste landform inventory

Landform	Type	Description	Status	Completion Date
Mesa H NE Dump	Waste Dump	Non-hazardous waste	Proposed	2025
Mesa H SW Dump	Waste Dump	Non-hazardous waste	Proposed	2025
Mesa H SE Dump	Waste Dump	Non-hazardous waste	Proposed	2029
Mesa H Pit1 backfill	In pit Waste Dump	Non-hazardous waste	Proposed	2024
Mesa H Pit2 backfill	In pit Waste Dump	Non-hazardous waste	Proposed	TBC
Mesa H Pit3 backfill	In pit Waste Dump	Non-hazardous waste	Proposed	2034
Mesa H Pit4 backfill	In pit Waste Dump	Non-hazardous waste	Proposed	End mine life
Mesa H Pit6/8 backfill	In pit Waste Dump	Non-hazardous waste	Proposed	Post-closure
Mesa H Pit9 backfill	In pit Waste Dump	Non-hazardous waste	Proposed	2030
Mesa J Boondock WD	Waste Dump	Non-hazardous waste	Complete	Complete[3]
Mesa J Pit 11 inpit WD	In pit Waste Dump	Non-hazardous waste	Proposed	2025
Mesa J P12 WD	In pit Waste Dump	Non-hazardous waste	Active	2020
Mesa J P6 WD	In pit Waste Dump	Non-hazardous waste	Active	2020
Mesa J P7/15 WD	In pit Waste Dump	Non-hazardous waste	Proposed	End mine life
Mesa J TSF1	TSF	In-pit TSF	Rehabilitated	Rehabilitated
Mesa J TSF3	TSF	In-pit TSF	Active	2020
Mesa J TSF4	TSF	In-pit TSF	Active	2020
Mesa J TSF5	TSF	In-pit TSF	Active	2019
Mesa J Pit 7/14 TSF	TSF	In-pit TSF	Proposed	End mine life
Mesa J Pit 8 TSF	TSF	In-pit TSF	Proposed	2028
Mesa J Pit 9 TSF	TSF	In-pit TSF	Proposed	2029
Mesa K North WD	Waste Dump	Non-hazardous waste	Active	Complete
Mesa K WD	Waste Dump	Non-hazardous waste	Proposed	2023
Mesa K Pit 1 backfill	In-pit Waste Dump	Non-hazardous waste	Proposed	2026
Mesa K Pit 2 backfill	In-pit Waste Dump	Non-hazardous waste	Proposed	2029
Mesa K Pit 3 backfill	In-pit Waste Dump	Non-hazardous waste	Proposed	2033
Mesa K Gravel Pit WD	In pit Waste Dump	Non-hazardous waste	Rehabilitated	Rehabilitated

[3] Although Boondocksis complete, an extension has been proposed. This extension is subject to sterilisation drilling.

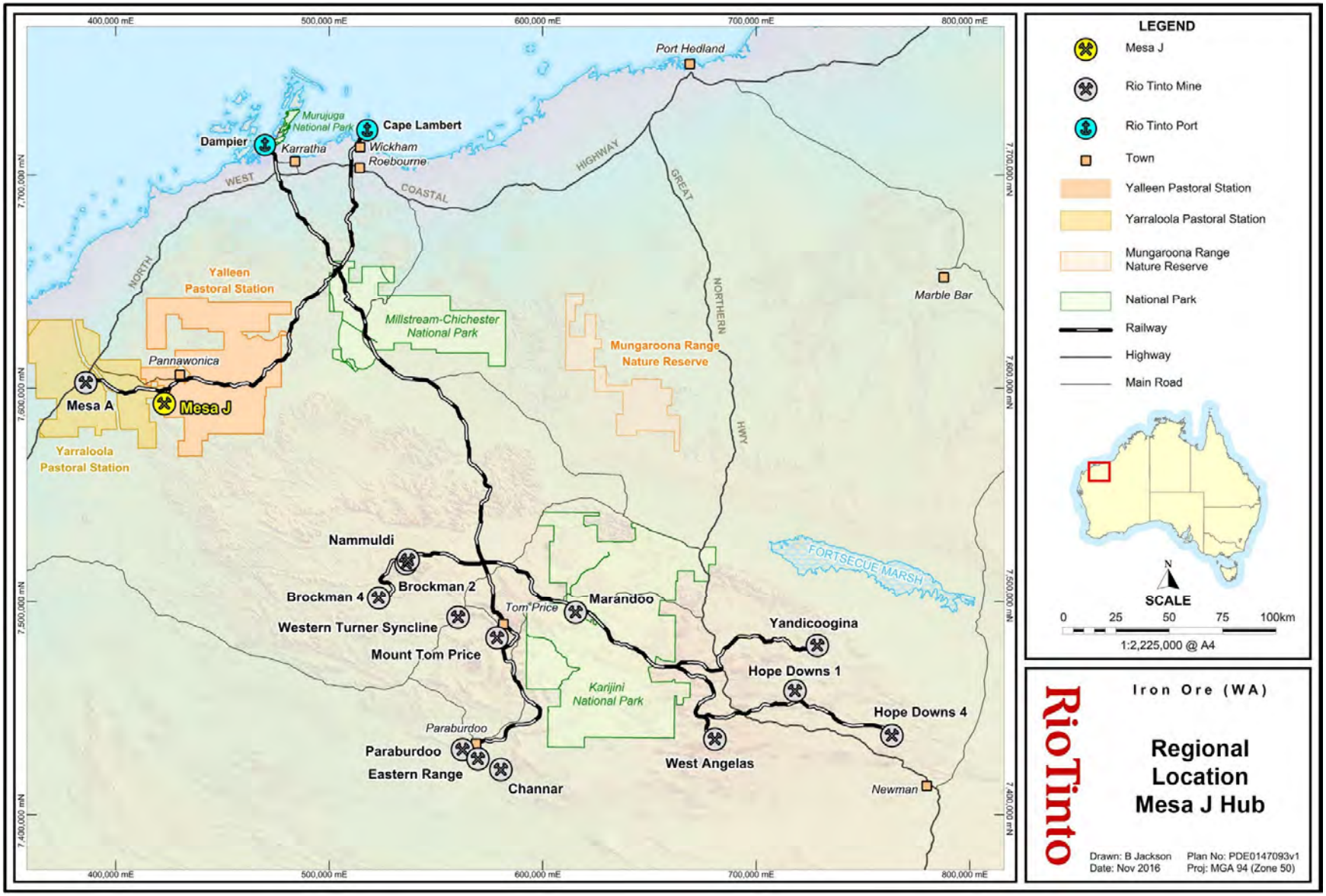


Figure 2: Regional location of Mesa J Hub

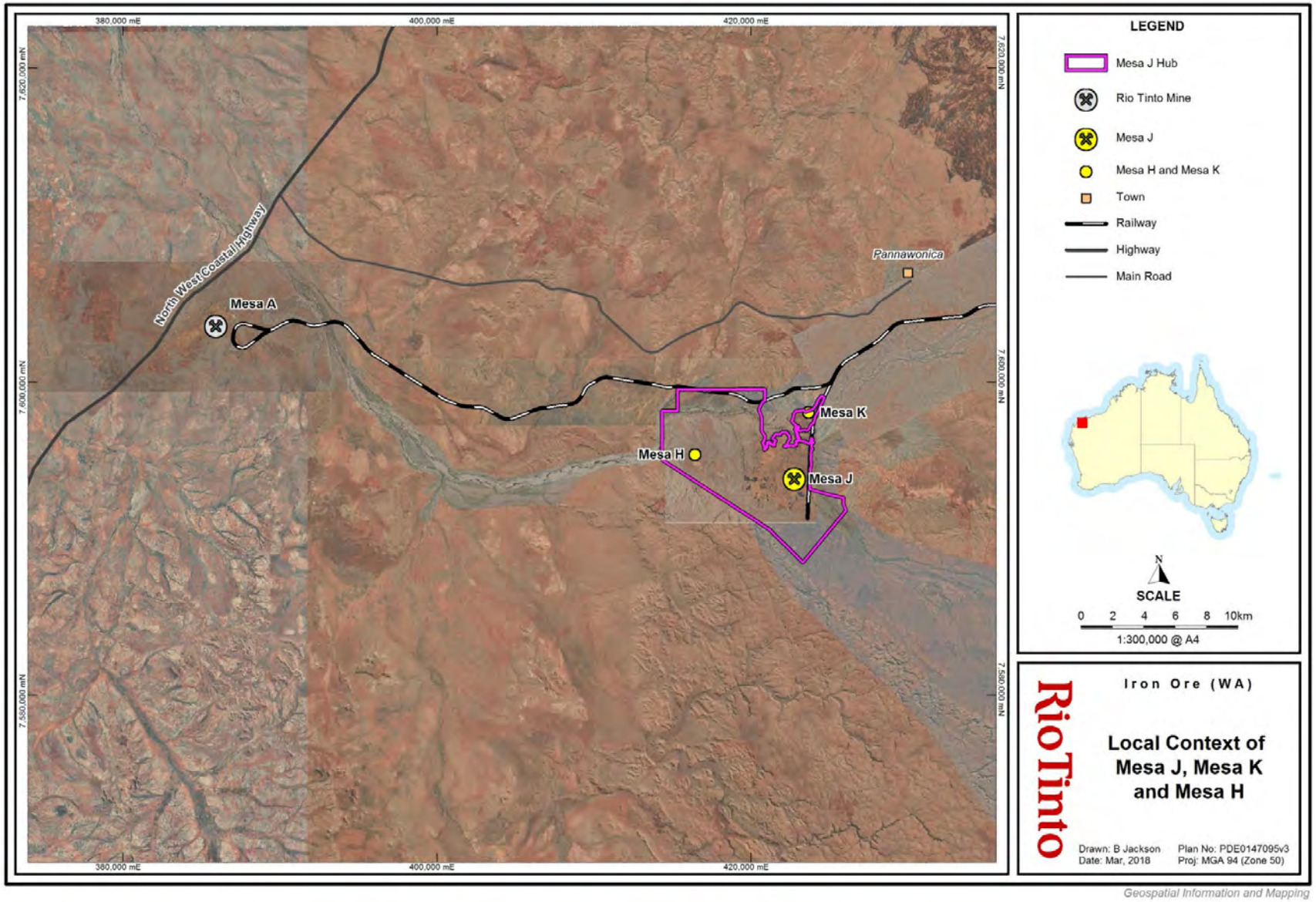


Figure 3: Local context of the Mesa J Hub in the Robe Valley

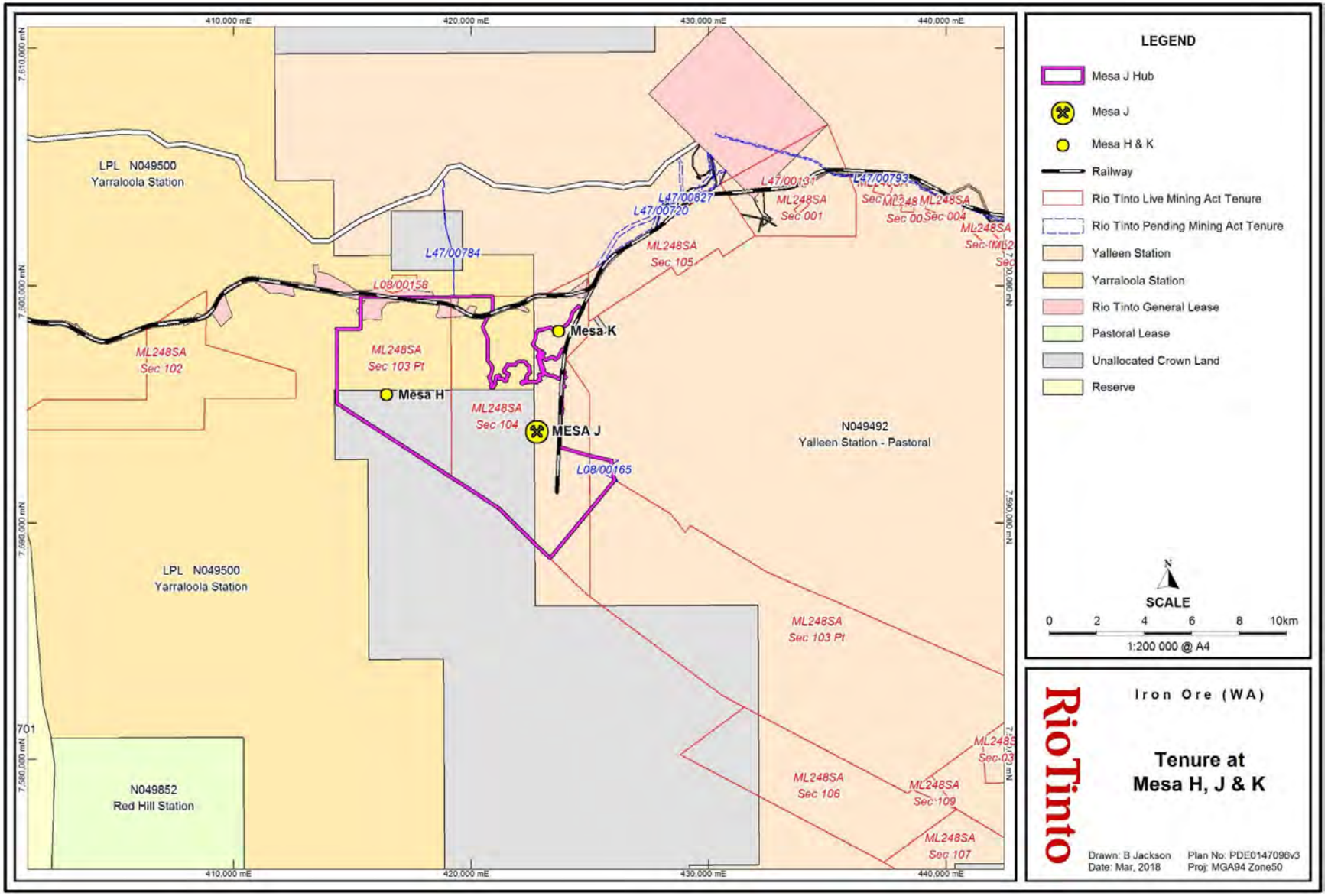


Figure 4: Tenure associated with Mesa J Hub mining activities

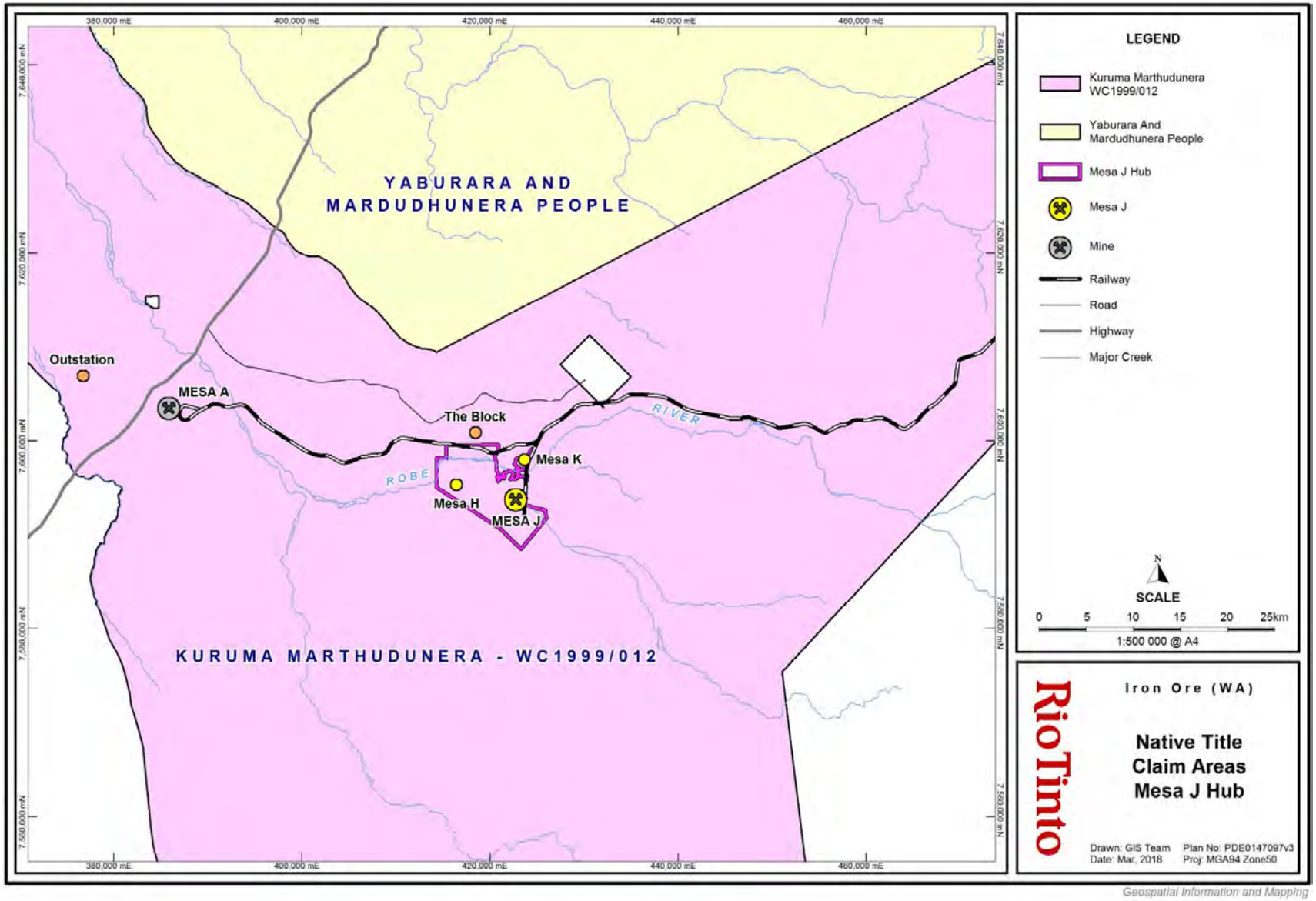


Figure 5: Traditional Owner locations

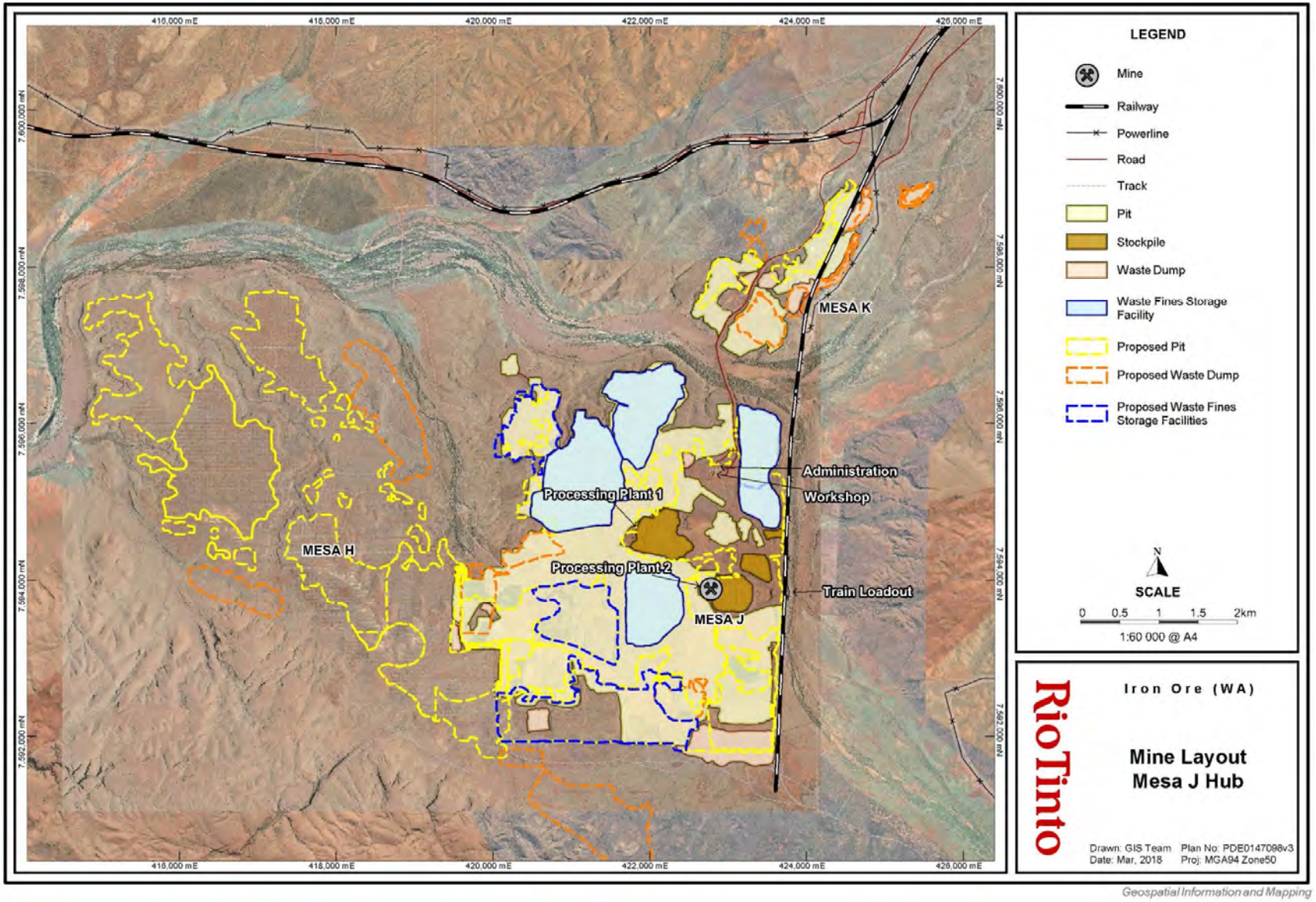


Figure 6: Mesa J Hub Mine Layout

IDENTIFICATION OF CLOSURE OBLIGATIONS AND COMMITMENTS

4. Legal obligations

A closure obligations register is presented as Appendix A. It contains details of legal obligations from the following instruments:

- *Iron Ore (Robe River) Agreement Act 1964*;
- Ministerial Statement 208 (Mesa J Iron Ore Development);
- Ministerial Statement 776 (Mesa K Remnant Mining Project);
- relevant Native Vegetation Clearing Permits (NCVP); and
- mineral leases issued under the *Mining Act 1978* pursuant to approval under the *Iron Ore (Robe River) Agreement Act 1964*.

The register also identifies legislation, standards and guidelines that may not apply to Mesa J Hub specifically, but that may be relevant to closure of mine sites generally.

STAKEHOLDER ENGAGEMENT

5. Stakeholder engagement

5.1 Engagement process

Stakeholder engagement is a key part of mine closure planning as it ensures that the expectations of stakeholders are understood by the mine operator and these can be considered and managed during the planning and implementation phase of closure. Rio Tinto has established processes for consultation with stakeholders, these are imbedded in both the Rio Tinto *Mine closure standard* (2015) and *Community and social performance standard* (2015). These standards are aligned with principles from the Australian and New Zealand Minerals and Energy Council and the Minerals Council of Australia (ANZMEC/MCA, 2000). Consultation commences at appropriate times during the early stages of exploration planning and will continue until the final relinquishment of the site.

As part of this process all likely impacted stakeholders are identified and recorded in a register. This register is used to ensure relevant and timely communications are held with stakeholders across a broad range of topics relevant to the mining operations, including closure, and is regularly reviewed and updated to maintain currency. Regular consultation is conducted with a wide range of stakeholders via a variety of forums, for example various State and Local Government agency briefing meetings and Traditional Owner consultation forums established under Indigenous Land Use Agreements. Discussions regarding closure and related activities are included in these meetings as appropriate. The level of closure specific content and detail will increase as closure approaches (see Figure 1).

A communications register specifically for closure of Mesa J Hub is maintained and a copy as at the time of writing is included in Appendix B. This register is used to ensure stakeholder feedback is tracked and monitored to ensure that appropriate actions are taken to address these issues in a timely manner.

POST-MINING LAND USE AND CLOSURE OBJECTIVES

6. Post-mining land use

6.1 Historical land use

The Pilbara is classified as an Extensive Land Use Zone. The lands surrounding the mine are the traditional lands recognised as belonging to the Kuruma and Marthudunera (K&M) people. Since European settlement land uses in the region have included cattle grazing, exploration and mining and conservation reserves. Prior to the commencement of this mine the immediate area was primarily used for pastoral purposes.

6.2 Proposed post-mining land use

Options for post-mining land use in this region are considered limited. However it is recognised that there is an increasing focus on seeking options for diversification of land use and options which are currently unidentified or not considered viable may eventually be implemented.

The proposed final land use assumes that the site will be rehabilitated to create a safe, stable and non-polluting landscape revegetated with native species, to maximise environmental and cultural heritage outcomes and ensure the site does not adversely impact on the current surrounding land use.

Due to the nature of the mining activity undertaken, the final landform will include large voids and waste dumps, and will therefore be unlikely to adequately support pastoral activities in the immediate disturbed areas. However, it is recognized that surrounding areas are likely to remain subject to pastoral activity, and the Mesa J Hub closure needs to be undertaken in such a manner that minimizes land use impacts.

Visual representation of the site at completion of mining, and after completion of proposed rehabilitation activities are included in Figure 28 to Figure 32.

7. Closure objectives

7.1 Rio Tinto vision for closure in the Pilbara

Closure objectives have been developed with consideration of Rio Tinto's general vision for closure, which is to:

- Relinquish its mining leases to the Western Australian State Government.
- Preserve, protect and manage the cultural heritage values of the area in cooperation with the Traditional Owners and other stakeholders.
- Develop and implement strategies for closure which consider the implications on local communities.
- Achieve completion criteria which have been developed with stakeholders and agreed with WA Government.
- Develop landforms that are safe and stable and compatible with the surrounding environment and post-mining land use.
- Achieve environmental outcomes that are compatible with the surrounding environment.
- Implement a workforce strategy which addresses the impacts of closure on employees and contractors.
- Achieve successful closure in a cost effective manner.

7.2 Mesa J Hub closure objectives

The site specific closure objectives that are proposed for the Mesa J Hub are shown in Table 3, along with the proposed criteria for how these objectives will be assessed and measured (completion criteria).

Due to the early stage of closure these objectives require further consultation with key stakeholders and are likely to evolve in future versions of this plan as knowledge of closure issues progresses and detailed closure discussions commence.

8. Completion criteria

Completion criteria are defined as the indicators used to determine whether closure objectives have been met. They are used to measure the success of closure implementation against objectives, and to facilitate relinquishment of mining tenure.

The completion criteria, as detailed in Table 3, have been developed in consideration of the predicted closure outcomes. Measurement processes and the associated supporting data (evidence and / or metrics), that could be used to evaluate the success of closure at Mesa J Hub are also described in Table 3.

The completion criteria are subject to ongoing review and update, informed by the outcome from studies, monitoring and ongoing stakeholder consultation. Given the number of years until scheduled closure the completion criteria contained in this plan should be considered indicative only. As the site approaches scheduled closure the completion criteria will continue to be refined.

Table 3: Indicative completion criteria

Objective	Indicative completion criteria	Verification process/method	Evidence
Public safety hazards have been managed.	1) Safety and health risks have been identified. 2) Measures to mitigate the identified public safety (and fauna where appropriate) and human health hazards have been agreed with key stakeholders and have been implemented. 3) Transfer of any residual liabilities is agreed with stakeholders.	1) Risk assessment conducted and mitigation actions implemented. 2) Relevant stakeholders have been engaged on risk mitigation measures to be employed. 3) Independent audit(s)/review to confirm that hazard mitigation measures have been implemented. 4) Process for transfer of residual liabilities is documented.	1) Risk assessment report. 2) Audit report to confirm effectiveness of controls. 3) Records of stakeholder engagement. 4) Liability transfer agreement/s.
Contamination risks have been appropriately managed.	1) Requirements under the Contaminated Sites Act 2003 (WA) have been met for the identification, recording, management, remediation and transfer of any contaminated sites as appropriate.	1) The site has been appropriately assessed for the presence of suspected or known contaminated sites. 2) Suspected or known contaminated sites have been appropriately reported under the Contaminated Sites Act 2003. 3) Appropriate management measures to address contamination have been implemented. 4) Process for transfer of residual liabilities is documented.	1) Contaminated sites investigation report/s. 2) Reports submitted to the Department of Environment Regulation (if required). 3) Liability transfer agreement/s. (if required).

Objective	Indicative completion criteria	Verification process/method	Evidence
Final landform[4] is stable and considers ecological and hydrological factors.	1) There are no erosion features present that compromise landform integrity, and if present, erosion features are stable. 2) The final landform was designed and constructed with consideration given to its stability during intense rainfall and large flood events. 3) Final landforms are outside predicted zones of instability of pits. 4) Mining exclusion zones remains as per approval. 5) Ground water levels and quality are trending towards acceptable ranges to support stygofauna and ground water dependant ecosystems (outside mining areas). 6) Backfill of the final landform (with the exception of Pit 15) has been undertaken to prevent formation of pit lakes and facilitate ground water recovery. 7) Operational drainage structures have been constructed or modified to consider local surface water regimes post closure.	1) Rehabilitation monitoring program including quantitative evaluation of behaviour of rills and gullies (if required) over time. 2) Analysis of aerial imagery to provide qualitative analysis of landform stability. 3) Post-closure landform review to confirm that risks have been appropriately managed. 4) Survey of exclusion zones.	1) Rehabilitation monitoring results. 2) Post closure landform evaluation report. 3) Façade assessment. 4) Survey data assessment. 5) Ground water monitoring report 6) Drainage design report
Vegetation on rehabilitated land is self-sustaining and compatible with the final land use.	1) Seed used in rehabilitation works is of local provenance[5]. 2) Native plants within rehabilitated areas are observed to flower and/or fruit. 3) Recruitment of native perennial plants is observed. 4) Species richness[6] of native perennial plants within rehabilitated areas is not less than reference sites. 5) Any weed species recorded within rehabilitation areas are present within the local area. 6) Erosion from landforms does not threaten surrounding significant natural ecosystems (Robe River Pools).	1) Rehabilitation monitoring/site inspections. 2) Analysis of historical monitoring data.	1) Rehabilitation monitoring reports. 2) Ecological monitoring reports.

[4] 'Landform' includes all post mining constructed features: waste dumps, waste fines storage facilities, abandonment bunds and pits.

[5] Note: Some seed used in rehabilitation predates accurate recording of collection area. Note 2: Local is defined as Pilbara IBRA

[6] Richness is defined as the number of different species in the defined area.

Objective	Indicative completion criteria	Verification process/method	Evidence
Infrastructure appropriately managed.	1) Legal agreement to transfer residual liability completed (if required). 2) Where transfer of liability is not established, infrastructure has been decommissioned and removed.	1) Appropriate agreements and transfer processes in place and communicated for any infrastructure remaining post closure.	1) Agreements in place with party assuming liability for infrastructure. 2) Close out report 3) Visual inspection
Robe river pools (in proximity to Mesa J Hub) function similar to the pre-mining state.	1) Water quality in Robe River pools is comparable to natural local ecosystems. 2) Ecological function of the pools is comparable to natural local ecosystems incorporating climate changes.	1) Surface and groundwater quality monitoring. 2) Environmental and Ecological monitoring.	1) Water quality reports. 2) Ecological monitoring reports.

COLLECTION AND ANALYSIS OF CLOSURE DATA

The closure knowledge base (Appendix C) is a collection of baseline studies, models and interpretations, which are used to inform the closure planning process presented in this closure plan. The knowledge may be specific to the site or generally applicable to the Pilbara region; and includes information on the performance of closure-related trials completed at other Pilbara mining operations (when appropriate). At this stage of the closure plan development, only summaries of these reports are provided and the relevant information is summarised in this section. The relevant knowledge base reports will be included in the final closure plan.

9. Climate

The closest official Bureau of Meteorology weather recording station is at Pannawonica (station 005069), which is approximately 15km to the northeast of the Mesa J Hub. Climatic information has been captured from this site since 1971. In addition, Rio Tinto maintains an automatic weather station at Mesa J itself. Information in this closure plan is sourced from both stations.

9.1 Climate and significant weather events

The climate in the area can be characterised as arid tropical with two distinct seasons, hot wet summers and cooler dry winters. Mean daily maxima temperatures range from 41°C in summer to 27°C in winter (Figure 7).

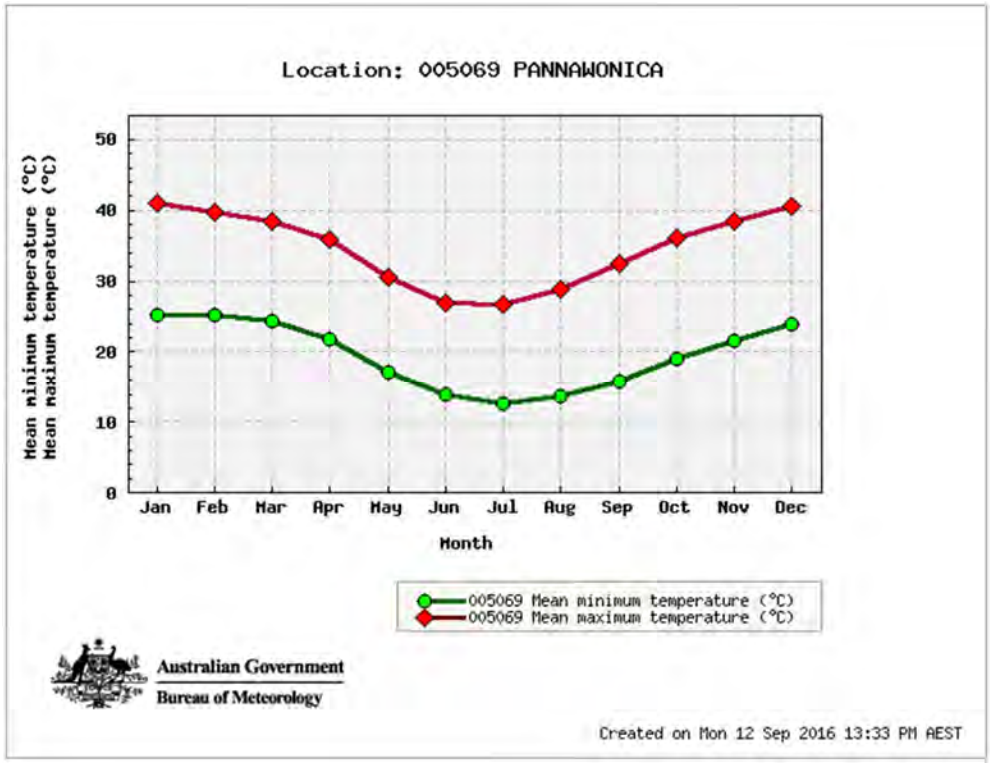


Figure 7: Mean monthly temperatures, Pannawonica 1971-2015.

The north/north-western coastline of Australia has experienced more tropical cyclones than anywhere else on mainland Australia. Most tropical cyclones are observed during the late summer, occurring between November and April. Tropical cyclones can produce damaging wind gusts in excess of 150 km per hour, with heavy rains resulting in regional flooding. Seven tropical cyclones are expected off the coast of the Pilbara each year, with three expected to make landfall.

Precipitation is driven by summer cyclonic activity, with the months of August, September and October have the lowest average rainfall, and January February and March the highest average rainfall (Figure 8). Annual rainfall is also highly variable, (Figure 9). Evaporation rates in the region greatly exceed rainfall, which is typical for similar climate conditions around Australia. Annual average pan evaporation rate is 3200-3600 mm/year (Figure 10).

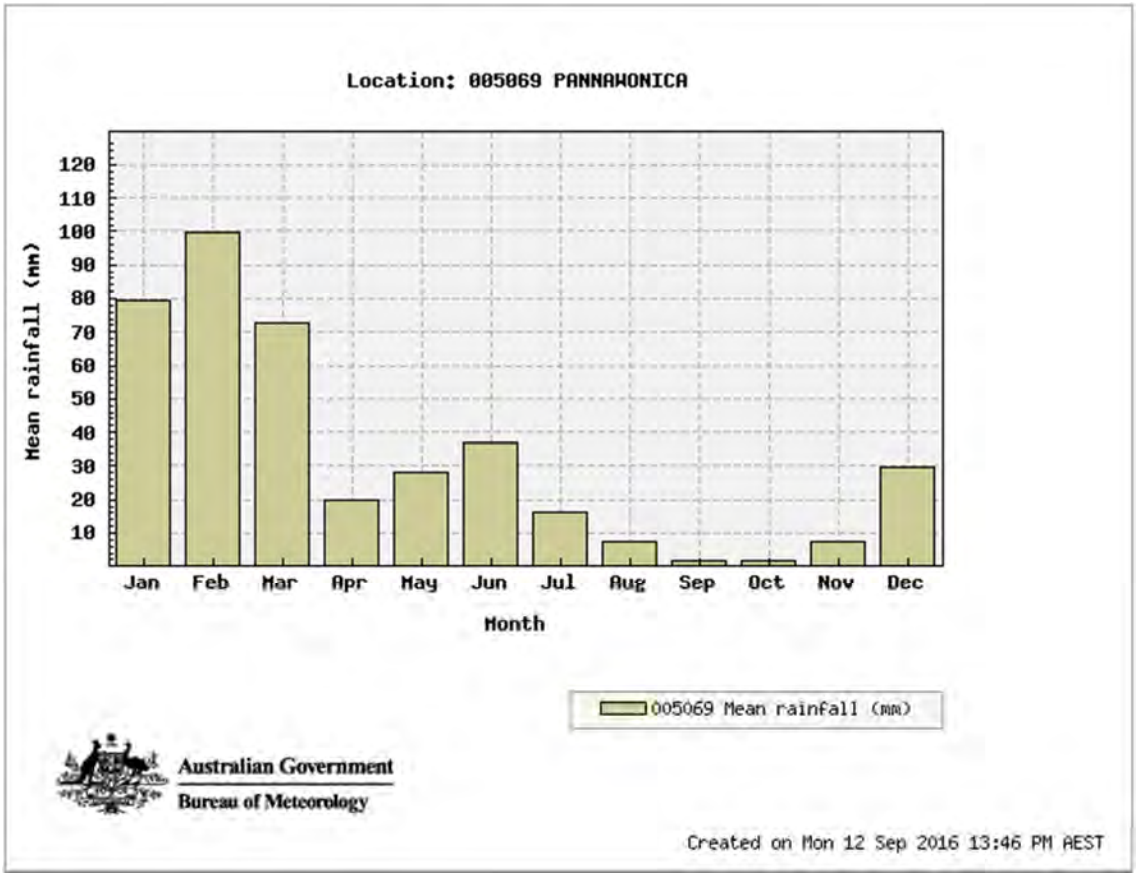


Figure 8: Mean monthly rainfall (1971 to 2015) at Pannawonica

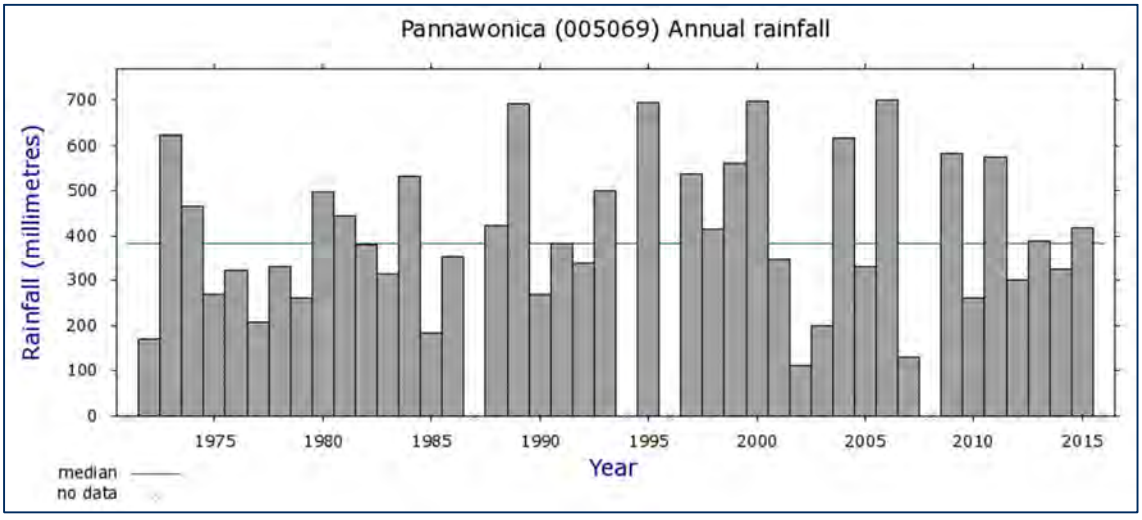


Figure 9: Historical annual rainfall (1971 to 2015) at Pannawonica

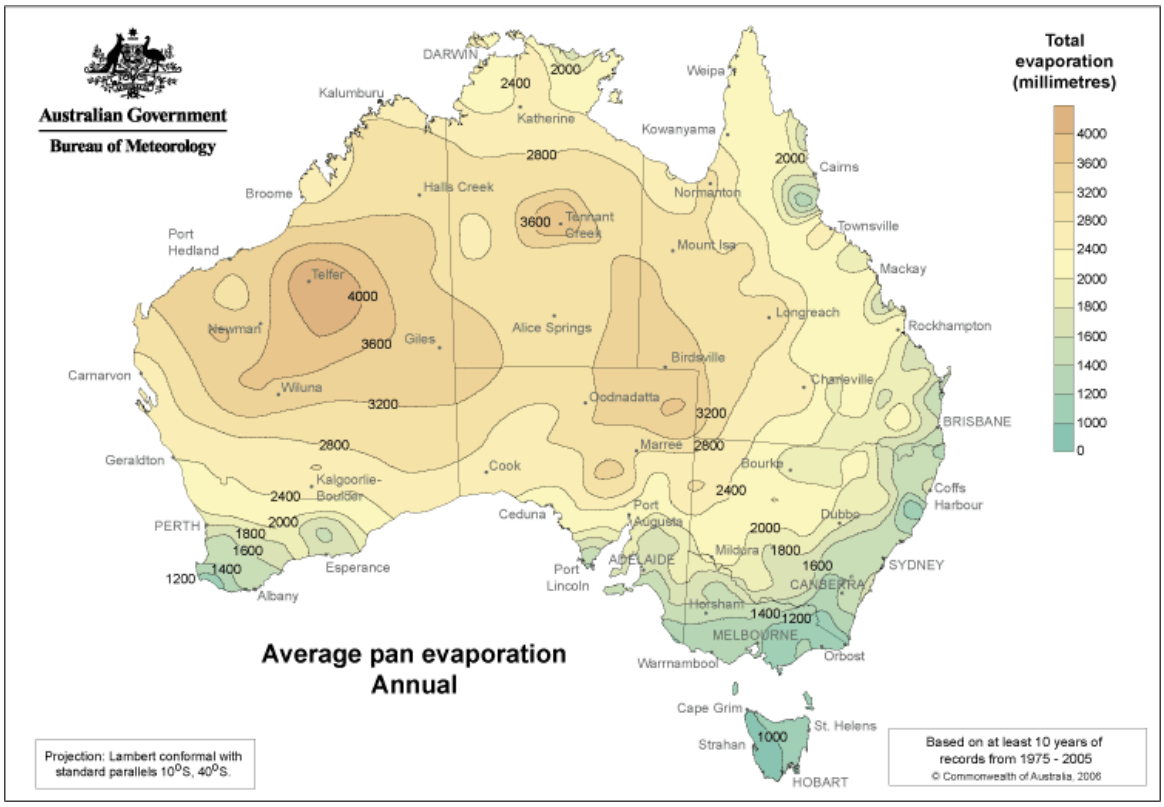


Figure 10: Average annual pan evaporation rates across Australia

9.2 Climate and landform stability

The heavy, intense rainfall experienced in the Pilbara makes rainfall the key climatic factor that influences surface stability in built landforms. Rainfall erosivity (measured in mega joule millimetre per hectare per hour per year - MJ.mm/ha/hr/yr) is the term used to describe the erosive force of rain. For Pilbara sites, long-term annual erosivity values range from ~1,000-1,600 MJ.mm/ha/hr/yr. Rainfall in the Pilbara is typically more erosive than Perth's rainfall, even though it only receives on average half the rainfall that Perth receives on an annual basis. For comparison, average annual erosivity values for Perth are ~1000 MJ.mm/ha/hr/yr from an average of 780 mm of rain a year.

Rainfall erosivity is highly variable for each rainfall event. Studies of Pilbara rainfall concluded that at Tom Price, for example, erosivity for the period 1998 to 2009 ranged from 212 – 6,349 MJ.mm/ha/hr/yr. A review of data in the Paraburdoo area indicates that the most erosive year recorded was 2007, where 421mm fell during February, with only a further 283mm during the rest of that year. This singular rain period embodied 11,994 MJ.mm/ha/hr/yr of erosive force, or 89% of the entire erosivity of rain for that year. Given the pattern of intense and infrequent rainfall events in the Pilbara, it can be expected that only a few events every year (~1-3 events) will generate the majority of runoff and erosion of that occurs each year.

The studies showed a rapid decline in erosion or sediment yield occurs when annual rain decreases below about 300mm per year due to a corresponding decline in rainfall volumes and rainfall erosivity. However, when annual rainfall increases above ~300mm, vegetation growth increases and becomes increasingly effective in controlling soil erosion. Hence, there is a point of maximum erosion potential at an annual rainfall value of ~200-400 mm such that surface (vegetation) cover is low due to lack of rain and ineffective for controlling erosion, yet rainfall erosivity is sufficiently high to cause erosion, as observed in the Pilbara. Outcomes from these studies have informed development of the *Rio Tinto Iron Ore (WA) Landform Design Guidelines* for achieving stable waste dumps.

9.3 Climate and vegetation growth

Water is generally the limiting factor for plant growth in the Pilbara's arid environment. As a consequence of the hot temperatures, high evaporative demand and infrequent and irregular rainfall, much of the vegetation displays xeromorphic adaptations (plant structural adaptations for survival in dry conditions). These adaptations include the ability to regulate water loss from leaves, extract water from very dry soils and match reproductive strategies with wetter periods. Many species are ephemeral and persist in soil seed banks in between wetter periods.

The adaptive capacity of Pilbara species implies a degree of resilience to changes to hydrological regimes. However, the impacts to Pilbara vegetation as a consequence of climate change are not clear. Changes in vegetation density and water use will alter the amount of runoff that occurs after a rainfall event, which in turn will alter creek flows and groundwater recharge.

Some initial studies within the wider Pilbara are underway to understand how the presence and absence of water affects vegetation growth within riparian corridors. The outcomes from these studies and other evolving research on climate change will be monitored and integrated into future closure studies to inform assumptions on climate influences and impacts.

9.4 Climate change

The understanding of how climate will change in the future in the Pilbara is guided by the outcomes of climate modelling, commissioned privately by Rio Tinto and other Australian government agencies. The main climate drivers for the Pilbara are the El Niño Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD) ocean currents. However, these ocean currents are not well represented in most global climate models, and as a result climate predictions for the northwest of Western Australia vary significantly. Consequently the impact of climate change, the change in water availability and influence on ecosystems, in the Pilbara is still unclear.

The ENSO and IOD ocean currents are currently being researched by CSIRO. At the same time, modelling is being progressively improved by various Australian Government agencies to expand our understanding of the climate drivers in the southern hemisphere, to understand the associated impacts on water availability and to predict changes to existing ecosystems.

From the modelling completed to date, our understanding of Pilbara climate change suggests the region will experience the following climate trends:

- A shift in the historical tropical cyclone season, with an earlier start and potentially later finish.
  - For the period 2051 to 2099, compared to present day, tropical cyclone frequency could decrease by half, and the duration of a given tropical cyclone by 0.6 days on average. Projections also suggest that tropical cyclones could increase in size and intensity
- Continuation of the highly variable multi-decadal scale rainfall trends.
  - Projected rainfall reductions range from 1 to 24 percent for mid-century, and 9 to 24 percent for the end of the century
- A significant warming trend, influencing maximum temperatures, with the largest changes during the January to March period.
  - On average, maximum temperatures are expected to increase by 2.1 to 3.2 ˚C by mid-century and by a total range of 3.8 to 4.6 ˚C by the end of the century. For minimum temperatures the corresponding averaged increases are 1.9 to 2.4 ˚C (mid-century) and 4.1 to 4.6 ˚C (end of the century).

These changes, if realised as modelled, are likely to make successful rehabilitation in the Pilbara more challenging. Current landform designs are conservative, providing contingency for increased erosion factors, however lower average rainfall will impact ability to establish vegetative cover.

10. Land

10.1 Biogeographic overview

The Mesa J Hub lies within the Pilbara Craton, a bioregion defined by the Interim Biogeographic Regionalisation for Australia (IBRA). The Pilbara bioregion is divided into four subregions: Chichester, Fortescue Plains, Hamersley and Roebourne Plains. The study area is located in the Hamersley subregion which is described as a “Mountainous area of Proterozoic sedimentary ranges and plateaux with Mulga low woodland over bunch grasses on fine textured soils and Snappy Gum over *Triodia brizoides* on skeletal sandy soils of the ranges”.

10.2 Geological setting

Mesa H, Mesa J and Mesa K are three of a group of pisolitic goethite-hematite iron deposits of Tertiary age which have formed in ancestral drainage channels (palaeochannels) of the Robe River (commonly known as a Channel Iron Deposits (CID), in the western Pilbara region of WA. This group is known as the Lower Robe (or Deepdale) group and comprises a series of mesas formed by the erosion of the surrounding landscape which has exposed the more competent CID paleochannel, thus creating and inverted topography. Subsequent erosion has dissected the outcropping CID paleochannel creating isolated mesa formations.

The Mesa J deposit consists of up to 50 metres thickness of CID (the Robe Pisolite), overlying basement rocks of Proterozoic age. The CID outcrops along the Robe River, and underlies Quaternary sediments elsewhere in the region. The CID at Mesa J occupies an area of approximately 3 x 3.5 km on the south-western side of the Robe River - Jimmawurrada Creek confluence.

The geology of Mesa K is homogenous on a large scale. The dominant geological formation is of dehydrated CID. On a smaller scale the geology varies with the amount of clay pods, rock fractures, alluvium sediment and hardcap.

The Mesa H deposit covers approximately 6.5 x 3 km of CID, at up to 80 m in thickness. It is dissected through the middle and bound to the east by incised drainage channels. The mineralised sequence outcrops as a low mesa-form hill in the north, rising up to 20 m above plain level (176 mRL) and bounded in the north west by the current Robe River. To the south the pisolite sequence is concealed by recent, unconsolidated fluvial gravel, clay, and localised calcrete. The Buckland Hills form the southern boundary along a north-westerly strike and rises up to 266 mRL.

Stratigraphy is shown in Figure 11, Figure 12 and Figure 13. The key formations comprise:

- Alluvial Cover.
- Surficial Unit: Surficial deposits comprise nodules of massive, dark brown goethite surrounded by yellow clay. Where goethite nodules occur at topographic highs they are commonly silicified and contain minor crystalline carbonate. These calcite-dolomite-bearing deposits are essentially calcrete. Alluvial deposits associated with Jimmawurrada Creek mainly comprise coarse ‘shingle’ with red clay. Elsewhere, bedded red to grey clay dominates. Sandy alluvium appears to be rare.
- Hardcap Tertiary Pisolite (HTP): Which is the weathered and lateritised zone predominantly at the top of the Robe Pisolite. This zone ranges from 5m to 10m in thickness, and contains secondary soils, silica and alumina. The transition between the HTP and the underlying TP/TPH is gradational and visually difficult to identify. Hardcap Tertiary Pisolite often contains clay horizons.
- The upper ore zone: Tertiary Pisolite (TP) forms the main ore zone in the Mesa J and Mesa K deposits, but is less prominent at Mesa H, where it has undergone more weathering and is transitional to HTP. It has a pisolitic texture and is cemented together by a goethitic matrix. Internal zones of poorer quality material exist in the form of clay (TPC) or as hydrated/denatured pisolite (TPH/TPD), but these are infrequent.
    - Limonite zone: A limonite-rich zone is present at Mesa J in the vicinity of the water table and limonite persists below the water table. It appears to be coarser grained and the rocks show evidence of abundant secondary processes. Clay bodies are also far more irregularly distributed.
    - Clay Zone: A thick clay rich Tertiary Pisolite unit (TPC) is present extensively throughout Mesa H and extending in to the very southernmost portion of Mesa J. This unit marks the base of the upper ore zone and can be up to 20m in thickness.
- The lower Tertiary Pisolite zone: The Mixed/Massive Sub-Grade Pisolite (TPM), Found in the southern half of Mesa J, underlying the TP, and at Mesa H in a deep north westerly trending channel below the TPC zone. It is characterised by a limonitic, denatured/massive appearance and clay is common throughout. This zone has been subjected to a palaeo-water table, which has resulted in a significant hydration effect in comparison to the upper TP/TPH.
- The deepest parts of the CID are characterised by an enriched/denatured pisolite zone (TPD). It occurs at Mesa J in the south of the deposit and at Mesa H in the deep north westerly trending channel. It is a discreet, semi continuous unit of enriched pisolite that ranges in thickness from 2 m to 10 m. Geologically the unit consists of predominantly goethitic minerals with a minor hematitic component. Goethite, ochreous goethite and clay are most common.
- Basal Pisolite: The Basal Unit (TPB) is dominated by clay and reworked channel deposits, which may include conglomerate coarse pisolites. The Basal Unit also contains laterite, both as reworked remnants of a laterite profile developed on basement rocks, and as the products of extensive in situ lateritisation.
- Basement rock: Basement rocks comprises a number of rock types: Marra Mamba Iron Formation, Jeerinah Formation, duricrust and reworked pisolite and clay. The Marra Mamba Iron Formation and Jeerinah Formation are to be considered the basement and the duricrust, reworked pisolites and clay should be considered a basal unit of the Robe Pisolite sequence.

The Mesa deposits comprise a combination of low, medium and high erodibility wastes. Further discussion on the management of waste materials is contained in section 18.2. Table 4, Table 5 and Table 6 below illustrates the anticipated waste volumes for each deposit.

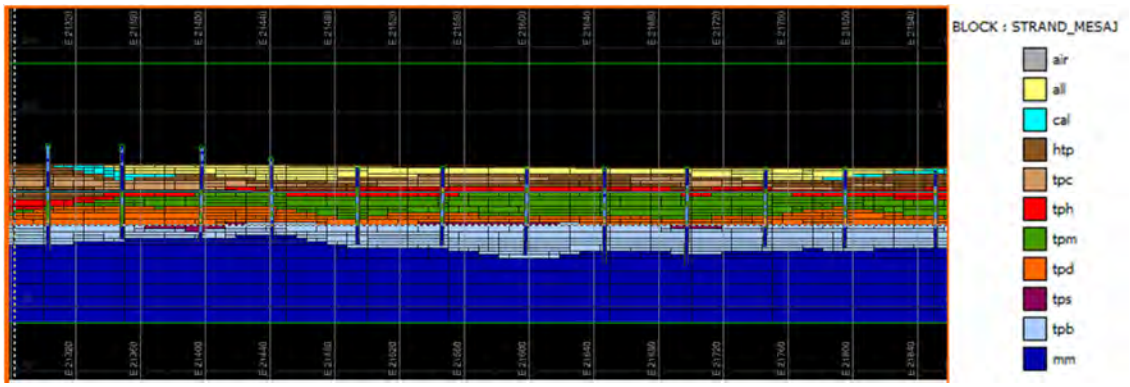


Figure 11: Mesa J stratigraphy

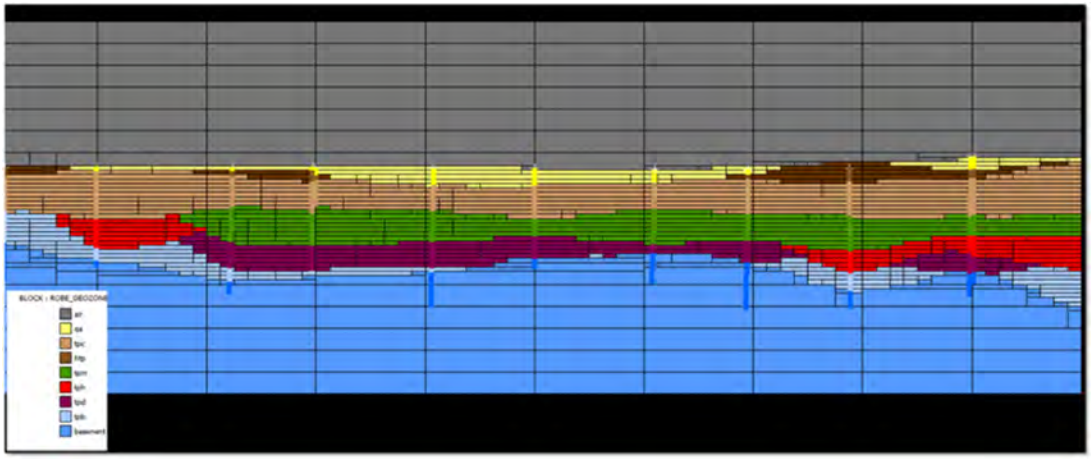


Figure 12: Mesa H stratigraphy (key as above, Figure 11)

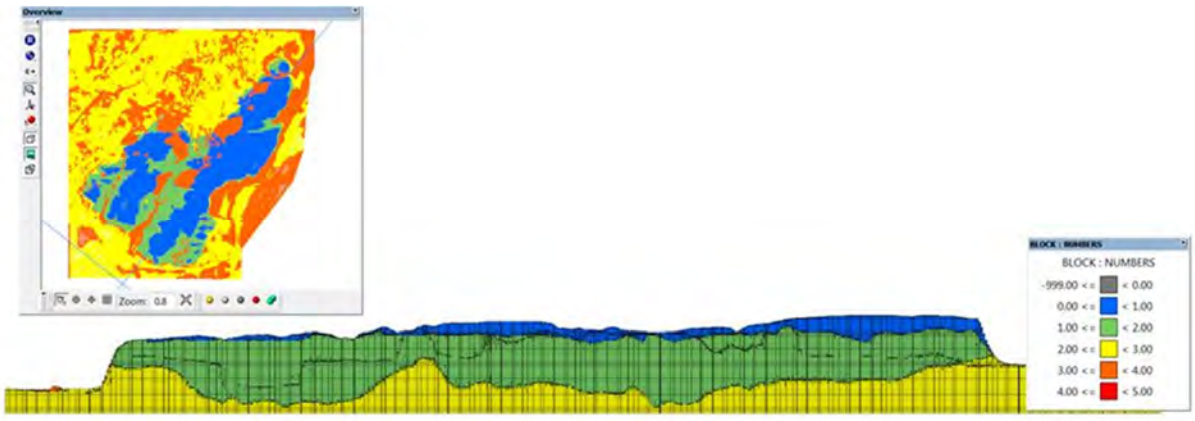


Figure 13: Mesa K stratigraphy, where blue represents weathered zone (HTP), green represents the main ore zone (TP) and yellow represents undifferentiated basement.

10.3 Mineral waste characteristics and inventory

Developing a comprehensive understanding of the types and volumes of materials that will remain at the completion of mining at Mesa J Hub is critical for the effective design, construction and rehabilitation of the mining landforms. Rio Tinto has well-developed processes for the collection and analysis of this data that are implemented from early exploration works and continues through the life of the mine. Long term material behaviour can also be predicted through characterisation of representative waste types and correlation to similar waste materials present at other sites.

Table 4 to Table 6 below provides a summary of the volumes of key material types at the Mesa J Hub. This information is used to inform the landform design and management strategies during operations and closure. Volumes are based on current mining models and will be subject to change. Further detail on these materials are provided in subsequent sections.

Table 4: Materials summary – Mesa H

Material	Volume (m^3)	Comments
Total waste material expected	123,330,000	
Material with potential AMD risk (PAF)	0	
Material with significant fibre risks	0	
Inert mineral waste - low erodibility		
Hydrated (HTP)	9,467,500	
Inert mineral waste- medium erodibility	0	
Inert mineral waste - high erodibility		
Alluvium	6,588,750	
TPB	1,754,922	
TPC	60,388,203	
TPD	2,075,000	Materials under review, may move to medium category
TPH	2,268,672	
TPM	27,752,734	
Rock	3,385,469	
Others	9,648,750	

Table 5: Materials summary – Mesa J

Material	Volume (m^3)	Comments
Total waste material expected	69,936,668	
Material with potential AMD risk (PAF)	0	
Material with significant fibre risks	0	
Inert mineral waste - low erodibility		
Hydrated (HTP)	41,639,543	
Inert mineral waste- medium erodibility	0	
Inert mineral waste - high erodibility		
Alluvium	3,328,296	
TPB	3,702,788	
TPC	14,441,944	Materials under review, may move to medium category
TPM	5,653,264	
TPH	1,170,833	

Table 6: Materials summary – Mesa K

Material	Volume (m^3)	Comments
Total waste material expected	5,386,250	
Material with potential AMD risk (PAF)	0	
Material with significant fibre risks	0	
Inert mineral waste - low erodibility		
Hydrated (HTP)	1,362,031	
Inert mineral waste- medium erodibility	0	
Inert mineral waste - high erodibility	0	
TPB	167,500	
TPC	560,000	
TPH	1,130,469	
TPM	2,121,250	
Rock	42,500	
Others	2,500.00	

10.3.1 Physical characteristics

The key physical property of the waste material that is applicable to the closure design is how susceptible the material is to erosion. Materials are assessed and classified in one of three levels of erodibility; low, medium or high. Materials which are classified as low erodibility, for example, are competent hard rock that is suitable for placement on the outer surface of waste landforms to provide long term protection against erosion. Potential waste types across the Mesa J Hub have been assessed using a combination of site-specific geophysical test work and extrapolation from equivalent material similar sites. Table 4 to Table 6 above lists the material types and volumes for the various erosion classifications. The erosion classification of individual landforms is included in Appendix F.

10.3.2 Geochemical characteristic

Rio Tinto has undertaken an extensive program of geochemical testing over several years to understand the potential for acidification and/or metalliferous drainage to occur as a result of exposing various waste rock types common to mining operations in the Pilbara. The geochemical characterisation process aims to assess sulfur content as an indicator of acid generation potential, and to undertake static (acid base accounting) and, if appropriate, kinetic testing of materials. This information is applied to the geological block model and subsequent mining model, to ensure materials posing potential geochemical risks are identified prior to mining and managed appropriately. This work is in accordance with the *Rio Tinto Iron Ore (WA) Mineral Waste Management Plan for Undeveloped Resources and Studies* and the *Spontaneous Combustion and Acid Rock Drainage (SCARD) Management Plan*.

The most significant geochemical risk posed by mining iron ore deposits in the Pilbara is associated with the sulfide mineral pyrite (FeS_2), which can form sulfuric acid when exposed to oxygen and water. The Mount McRae Shale (MCS), most commonly associated with pyrite and acid and metalliferous drainage in the Pilbara, is not expected to be exposed during mining at Mesa H, Mesa J and Mesa K based on the current proposed pit shells for each deposit; mining is confined to CID materials.

A review of the geochemical risk assessment for each deposit was undertaken in 2015/16 which assessed the sites to be a low risk for acid and/or metalliferous mine drainage (AMD). A further review of Mesa H in 2017 utilising new drilling data supported the Mesa H assessment as low risk. Based on the proposed final pit shells for each deposit it is not anticipated that any moderate or high risk material types will be exposed.

Table 7: Assessed Geochemical risk in the Mesa J Hub mining areas

Mining Area	Geochemical Risk
Mesa H	Low
Mesa J	Low
Mesa K	Low

In terms of potential for metalliferous drainage, minor and trace elements that were enriched compared to average crustal abundances were Fe, As, Sn, Co, Cr, Cu, Mn, Pb, Se, Te, V, Zr and Zn. However, whilst concentrations of some trace elements were elevated these elements are unlikely to mobilise into ground water.

10.3.3 Fibrous minerals

Fibrous minerals present a health hazard if fibres of a (defined) respirable size become airborne and are inhaled. The most common mineral associated with fibrous minerals encountered within the iron formations present in the Robe Valley area is riebeckite. Riebeckite is usually found in fresh (unweathered) BIF. The asbestiform variety of riebeckite is crocidolite, or blue asbestos. The presence of riebeckite does not necessarily pose a fibrous mineral risk but it is a precursor mineral to crocidolite, therefore, there exists a likelihood of encountering crocidolite.

If present, crocidolite seams would primarily occur within the unmineralised Marra Mamba Iron Formation that underlies the CID at Mesa H and Mesa J. In addition, crocidolite may also occur in BIF clasts found within overlying alluvium cover or within the tertiary basal pisolite horizon (i.e. TPB).

Crocidolite has not been intersected in any drillholes within the Mesa H, Mesa J and Mesa K mining or project areas (based on historical drillhole information up to October 2016). However, the underlying basement formation, which includes the Marra Mamba Iron Formation, as well as the TPB horizon in the Mesa H area, is considered to pose a potential fibre risk if exposed in the footwall. However the current mining sequence does not intersect this material.

The *Rio Tinto Iron Ore (WA) Fibrous Minerals Management Plan* describes guidelines for the management of fibrous minerals encountered during mine production, however, based on current drilling and mine planning information, which indicates that basal or basement lithologies can generally be avoided during operations, potentially hazardous or designated hazardous areas are not expected within the life of mine or upon closure in these areas.

10.4 Local soils

Topsoil is recognised as an important factor is achieving high quality rehabilitation results. Characterisation of soils provides an indication of soil properties and their potential impacts on vegetation establishment, growth and landform stability; although it is important to recognise that they are expected to be altered as a result of mining processes. Appropriate characterisation can also help ensure soils with adverse properties are avoided in landform design.

The physical and chemical properties of Robe Valley topsoil are provided in Table 8. Soil properties are within the range typical of that found elsewhere in the Pilbara. It is generally classified as sandy clay loam to medium clay with a coarse material fraction value of up to 81.7%. It is neutral pH, non-saline and non-sodic (below exchangeable sodium percentage of <6%). Both organic carbon and nutrient levels vary according to landscape position: they are typically very low in the higher portions of the landscape, but are present in slightly higher levels in low-lying areas and drainage lines. Robe Valley soils possess low hydraulic conductivity indicating that they could be naturally susceptible to increased surface run off, less water availability to plants and surface erosion. Overall Robe Valley topsoil is consistent with Pilbara soil parameters.

Subsoil has physical properties suitable for plant growth and generally has chemical properties amenable to plant growth, although it does lack the nutrient content, organic matter and soil seed bank of topsoil.

Table 8: Comparison between Robe Valley soils and typical Pilbara soil parameters[7]

Properties		Pilbara Soils	Robe Valley Topsoil
Physical Properties	Soil texture (<2mm soil fraction)	Sand – Clay Loam	Sandy clay loam – Medium heavy clay
	Coarse material content (%)	0 - 93	0.0 – 81.7
	Aggregate stability (Emerson Class[1])	2 - 6	2 – 5
	Soil Strength (Modules of Rupture (kPa))	0 - 267	13.9 – 112.4
	Plant available water holding capacity	-	Low
	Hydraulic conductivity (Ksat(mm/h))	-	0.5 – 1.6
Chemical Properties	Soil pH	5.3 – 9.5	6.0 – 8.6
	Salinity (dS/m)	0.007 – 0.233	0.012 – 0.080
	Organic Carbon (%)	0.07 – 3.74	0.14 – 1.69
	Macro-nutrient status	-	Low
	Micro-nutrient status	-	Low
	Effective Cation Exchange Capacity (meq/100g)	1.9 – 16.8	3.6 – 17.68
	Exchangeable Sodium Percentage (%)	0.21 – 6.39	1.39 – 5.90
	Total metal concentrations	Low	Low

10.5 Soil inventory

Topsoil is often a limited resource in the Pilbara with topsoil recovery often being restricted due to the nature and terrain of the landscape. The goal of soil management is to maximise the collection of topsoil and subsoil, and to store it to maximise its viability and productivity to ensure there is sufficient soil for subsequent use in rehabilitation.

Where practical, a minimum of 200mm of topsoil and 600mm of subsoil is collected when new areas are disturbed. Mesa K currently has a shortfall of material, as the existing stockpiles were moved to Mesa J. As a result, the soil balance for these sites should be considered collectively. It is anticipated that sufficient soil volumes will be available to meet rehabilitation requirements for the deposits.

Table 9 to Table 11 provide the current and projected soil inventory for the Mesa J Hub. Mesa H disturbance is limited to exploration activities, and although some areas have been disturbed the topsoil remains available for collection from the future pit areas.

Table 9: Predicted LOM soil balances for Mesa H

Material	Current volume (m^3)	Predicted total volume LOM (m^3)	Predicted volume required for rehabilitation (m^3)
Topsoil	0	1,764,720	1764,720
Subsoil	0		
Total	0	1,764,720	1,764,720

Table 10: Predicted LOM soil balances for Mesa J

Material	Current volume (m^3)	Predicted total volume LOM (m^3)	Predicted volume required for rehabilitation (m^3)
Topsoil	600,000	3,390,043	2,977,500
Subsoil	2,782,657		
Total	3,382,657	3,390,043	2,977,500

[7] Note that the typical ranges above apply to topsoil and may not be representative of subsoil properties.

Table 11: Predicted LOM soil balances for Mesa K

Material	Current volume (m^3)	Predicted total volume LOM (m^3)	Predicted volume required for rehabilitation (m^3)
Topsoil	0	5,060	254,060
Subsoil	0		
Total	0	5,060	254,060

Whilst it is predicted that Mesa J Hub will have sufficient soil resources to complete rehabilitation works, each project is assessed to determine the type and amount of soil used. This could include an assessment of:

- current soil inventory;
- landform and rehab type;
- potential for trials;
- distance to soil stockpiles; or
- potential upcoming rehabilitation.

10.6 Alternative growth media

Whilst rehabilitation areas have proven to generally perform better with topsoil application, absence of topsoil does not necessarily mean that rehabilitation will fail, or that completion criteria will not be achieved. Trials have been conducted on waste dump rehabilitation without topsoil application (e.g. S Dump and T Dump at Mesa J, see Section 13.1). The trials were performing strongly against most success indicators, however these waste dumps have been re-disturbed due to additional ore being located under the waste dumps.

In 2009, Rio Tinto commissioned a study into the use of waste fines storage facility material as an alternative rehabilitation growth medium, using Mesa J TSF1 materials. A more extensive study in 2010 investigated additional types of mine waste materials. The studies reviewed soil, waste fines and mineral waste characteristics from select Pilbara mining operations, to identify material combinations that may be suitable as a topsoil substitute or supplement in cases where topsoil volumes may be insufficient for rehabilitation requirements. In these cases, topsoil would be applied to high impact and visibility areas such as waste landforms first and lower impact areas such as laydown areas may receive alternative growth media.

The studies showed plant-available nutrients held within the waste materials, although variable and characteristically low, were comparable to natural soils in the region. The majority of the waste materials had macro and micro nutrient concentrations within the range or above the levels measured in benchmark Pilbara topsoil and rehabilitated soils. The pH and phosphorus buffering index of most waste materials were also comparable to that of the benchmark topsoil materials.

In general, Pilbara mineral wastes were non-saline and non-sodic, with no sample presenting above the 15% threshold for exchangeable sodium percentage (ESP), the indicator of high sodicity. The soil structure of waste materials were relatively stable, with only slight or no dispersion upon re-moulding, indicating a structure that is not easily degraded, and is not prone to hard setting. However, estimated plant available water content of the waste materials ranged from 3% to 25%.

Four material classes were analysed from Mesa J and Mesa K, including surficial waste, alluvial waste, weathered waste and waste fines storage material. All material classes were assessed as suitable waste materials for use as a surface growth medium, from both a physical and chemical perspective. A further study in 2015 tested additional waste fines storage material samples from Mesa J, finding them also suitable.

In summary, alternative growth media options are available for consideration in the Mesa J Hub rehabilitation, should a shortfall of available topsoil and subsoil be encountered. Options for utilising the alternative growth media will be considered as the site comes closer to closure. Opportunities to utilise the growth media in field trials will be considered as part of progressive rehabilitation planning.

11. Water

11.1 Surface water

The Mesa J and K mines are located immediately downstream of the confluence of Robe River and Jimmawurrada Creek (Figure 14).

The Robe River is the major river system in the region and covers a linear distance of approximately 260 km, with a catchment area of approximately 7,500 km^2. The Robe River catchment generally drains east to west through the high relief areas of the Hamersley Ranges onto the more gently sloping areas in the coastal plain before discharging into the Indian Ocean. Surface flows are intermittent, typically once per year after significant and intense rainfall. The river has significant underflow in its alluvial bed which maintains a number of permanent pools in the river channel.

Mesa K is located at the top of a local sub-catchment and there are no tributaries that originate in or cross the project area. Two historic waste dumps are situated close to the Robe River, which show limited impacts from past flood events. Existing regional 1 in 100 annual exceedance probability (AEP) – previously referred to as a 1 in 100 year average recurrence interval (ARI) – flood modelling for Mesa K suggests that these dumps are located outside 1 in 100 AEP floodplain of the Robe River (Figure 15), however this will be re-assessed as part of the planned hydrological modelling of the final landforms for Mesa J Hub.

Surface water management at Mesa J operations currently employs a “sump and pump” and “diversion” strategy. The southern cutback pits at Mesa J, including Pit 11, Pit 12, Pit 14, Pit 7 and Pit 6, are exposed to surface water flows from the surrounding catchment, with dumps protecting a majority of the southern cutback, and the remaining runoff flowing into Pit 11 South. Levees and waste dumps to the south and east protect Mesa J from local flooding of the Jimmawurrada Creek. A diversion drain also exists on the western side of Mesa J to direct flows from the adjacent small western catchment, as well as breakout flows from a larger southern catchment, around Pit 11 North and into the natural drainage line to the west of Mesa J.

Although Mesa H deposit is located outside the 1in 100 AEP floodplain of the Robe River, flood protection will be required during operations to manage the runoff from a 24 km^2 local catchment that currently discharges directly over the south-eastern extent of the Mesa H deposit and floods Pit 11 at Mesa J (Figure 15). Diversion drains have been designed, with the preferred design option to divert the local catchment westwards into the central watercourse that bisects Mesa H.

At closure it is expected that any diversion structures that were used to control surface water flows during operations at Mesa J Hub would undergo a slow and inevitable collapse, resulting in runoff from the local catchments draining into the backfilled pit voids. With the exception of the waste dump proposed to the south of Mesa J, all waste dumps at Mesa H and Mesa J are located outside of the current 1 in 100 AEP floodplain (Figure 15). The long-term, post-closure stability of the dump proposed to the south of Mesa J could potentially be compromised if water were to permanently pool against the dump, depending on the waste type. A large portion of these flows can be diverted and the requirement for these diversion structures to meet closure objectives will be further assessed as part of the planned hydrological modelling of the final landforms for Mesa J Hub.

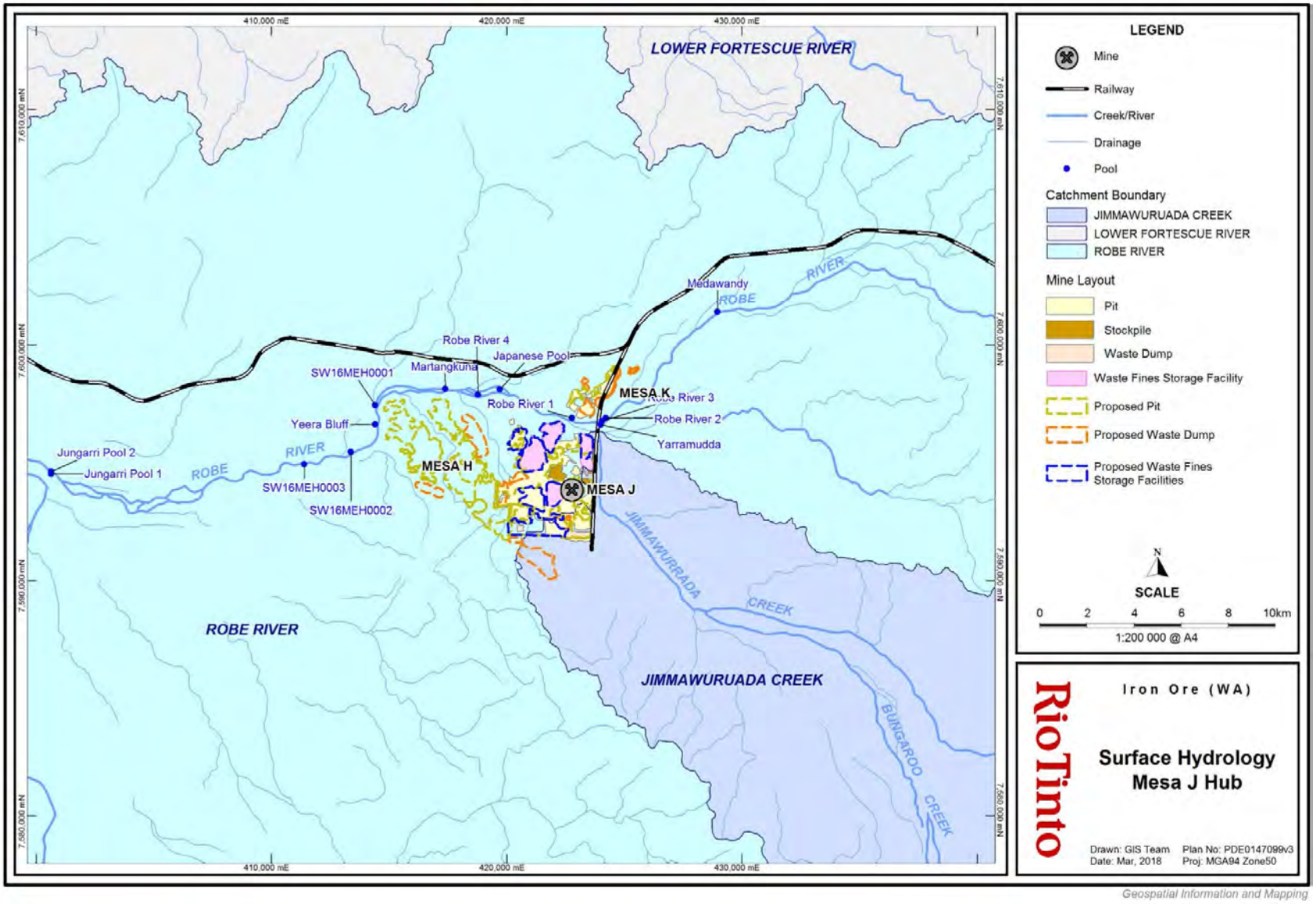


Figure 14: Surface hydrology surrounding Mesa J Hub

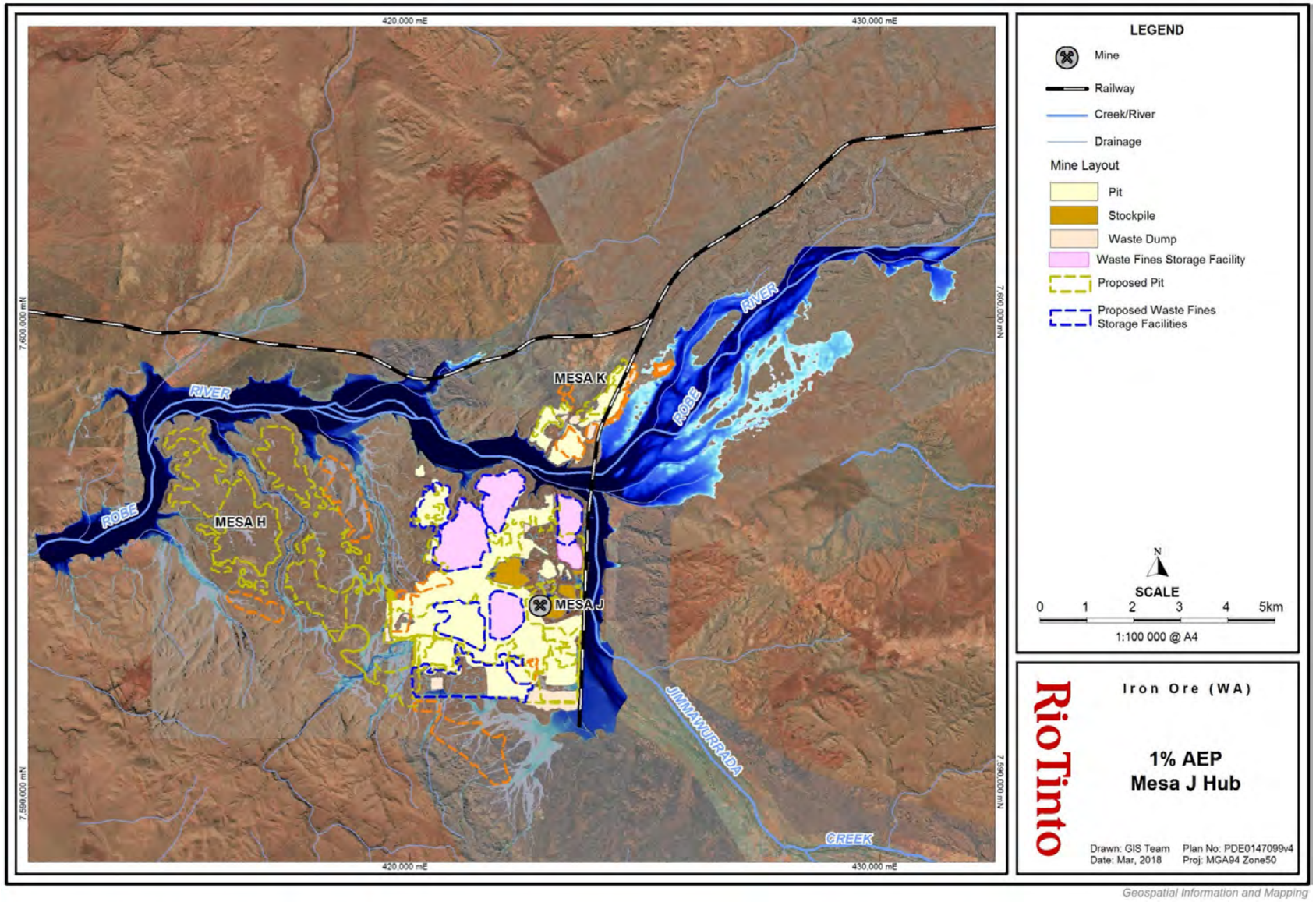


Figure 15: Mesa J Hub 1% AEP Flood Extent

11.2 Groundwater

Dewatering via in-pit sumping has occurred at Mesa J since 1995. Approximately 34% of the Mesa H scheduling inventory occurs below the pre-mining water table (water table prior to Mesa J's operation), however due to the passive dewatering of Mesa H caused by the dewatering of Mesa J, only ~13% of the scheduling inventory is below the present-day water table.

The existing Mesa J Hub borefield (Southern Cutback borefield) is situated in the southern part of Mesa J mine site and is used in conjunction with dewatering volume reuse to supply water for the wet plant. To enable the ongoing operation of a wet plant to process ore extracted at Mesa J and Mesa H, water demand is estimated to be between broadly 4 and 9 GL/year.

The Mesa J Hub is situated downstream from the confluence of the Robe River and Jimmawurrada Creek. The local catchment is defined by three major aquifers: the weathered basement aquifer, overlaid by the CID aquifer, and the alluvium aquifer which occurs along the Robe River.

A major alluvial aquifer underlies the lower Robe River. It consist of gravels beds with a saturated thickness of up to 20-25 m adjacent the river; gradually reducing in thickness laterally from the river and downstream, locally creating surface expressions of groundwater as pools. Based on available data and pumping test results, the highly permeable Robe River alluvium is conceptually in partial hydraulic connection with the underlying aquifers. The localised alluvium/colluvium overburden found on top of the mesas occurs above the water table and is unsaturated.

The mineralised section of the CID forms a semi-confined aquifer of variable permeability due to the juxtaposition of solution cavities and CID (highly permeable) and horizontal lenses of clay and clay alteration near fractures (low permeability). Groundwater in the ore body tends to flow from the southeast in the Bungaroo Valley aquifer under the Jimmawurrada Creek catchment (Figure 14), to the north and northwest towards the Robe River.

Beneath the Robe Pisolite is the confined basement aquifer consisting of the Wittenoom and Marra Mamba Iron Formations. The basement units are intruded by several dolerite dykes and bounded by fault structures formed during three major deformation events.

Long term water quality monitoring indicates that groundwater and surface water is predominantly fresh across the Mesa J Hub. The chemistry of the Robe River pools is primarily influenced by significant rainfall, stream flow events and evapotranspiration.

Salinity levels recorded in permanent pools are generally considered fresh (<2000 µS/cm) with some seasonal variation identified by short duration changes in chloride concentration associated with rainfall events and pool evaporation cycles. The pH values are within the typical range for Pilbara inland waters, slightly alkaline (7.4 - 8.2). The only proposed pit lake in the post closure landform will be located in the Mesa J Pit 15 area, which is planned to be used as a water storage dam. Further investigation is required to determine the risk, extent, quality and management of this pit lake. If required, mitigation actions will be implemented, potentially including backfilling.

Recharge to local aquifers currently occurs as a result of multiple inputs; rainfall and cyclonic event recharge, seepage leakage from the existing waste fines storage facilities and water reservoir, Robe River and Jimmawurrada Creek recharge through stream-flow events, and operational surplus discharge into the Jimmawurrada Creek and the west creek located between Mesa H and J.

Based on the water balance for the area, groundwater recovery is expected to begin after groundwater abstraction activities cease. Recovery will be to the pre-mining water table level and recovery timeframes are currently estimated in the order of ~60 years post mine closure within the pit areas. Recovery of Robe River pools and Jimmawurrada Creek is expected to predominantly happen within the first or second major rainfall events, historically between 5 and 10 years.

Predicted groundwater recovery levels and the modelled time to recovery are listed in Table 12[8].

Table 12: Predicted groundwater level and approximate time to recovery.

Deposit	Pre-mining level (mAHD)	Estimated maximum drawdown level (mAHD)	Recovery level (mAHD)	Time (years)
Mesa H	120-144	110 (34m drawdown)	120-144	60
Mesa J	142-155	110 (45m drawdown)	142-155	60
Mesa K	144-146	No change – AWT mining	N/A	N/A

11.3 Robe River Pools

Permanent and semi-permanent pools exist along the Robe River due to the significant subsurface flow in the alluvium. The number and permanency of pools are controlled by rainfall and groundwater levels. When a rainfall event occurs, the underlying aquifer is recharged causing the water table to rise and replenish the pools. During a dry period the water table will lower resulting in shallower pools or disconnection from groundwater. The Robe River pools remain as the only surface water source during dry periods, and therefore are an important refuge for aquatic ecosystems in the region. Permanent and deep pools are the most stable and consequently have the greatest diversity and stability of species. These pools also have significant value for the local Traditional Owners.

Environmental and hydrological monitoring occurs at various pools and stream locations along the Robe River in the vicinity of the Mesa J Hub, including Medawandy, Yarramudda, Martangkuna, Yeera Bluff, Japanese Pool, four stream locations near Mesa J and three stream locations near Mesa H (Figure 14). This long-term monitoring of the Robe River includes an integrated assessment of ecological parameters including freshwater fauna (i.e. macroinvertebrates and fish), channel/pool morphology, riparian/bank condition and water quality, utilising an upstream/downstream approach. Over 25 years of monitoring to date indicates any detectable changes to the ecology of the Robe River pools has been influenced by climate, and could not be attributed to mining operations. Work is ongoing to improve knowledge and predict groundwater level and quality changes that may occur in the future.

12. Biodiversity

12.1 Terrestrial fauna habitat

There are 16 terrestrial habitat types identified at the Mesa J Hub. These habitats are broadly grouped into six main habitat types, including breakaways & gullies, mesa plateaus, rocky ranges, plains, water-courses and ‘disturbed’ (Figure 16). Characteristics of these habitat types are provided in Table 13.

Breakaways & gullies have been recognised as high value habitat for species of conservation significance, such as Pilbara Olive Python, Northern Quoll, Pilbara Leaf-nosed Bat and Ghost Bat. The Water-courses habitat is recognised as high value habitat as it supports a greater diversity and abundance of fauna than other habitats, provide foraging habitat and provide potential dispersal routes for conservation significant fauna.

[8] Recovery levels are based on the continuation of current climate conditions.

Table 13: Description of pre-mining habitats identified at Mesa J Hub

Landform	Habitat	Basic description
Breakaways & Gullies	Breakaways	• Eucalyptus leucophloia over mixed Acacia tumida var. pilbarensis and Acacia bivenosa shrubland over Triodia wiseana hummock grassland. • Breakaway or ridge line, falling away to steep scree slope. Stony compact soils, low levels of leaf litter, sparse open vegetation; small caves and crevices.
Breakaways & Gullies	Gullies	• Scattered Eucalypts over Acacia shrubland over hummock or tussock grassland. • Deep often rocky gorges, sometimes with semi-permanent or permanent pools. Rocky structures providing large opportunities of refuge and foraging for a wide suite of vertebrate fauna species; numerous rock ledges, crevices and caves. Some semipermanent water pools.
Mesa Plateaus	Mesa Plateaus	• Scattered Eucalyptus leucophloia over mixed Acacia ancistrocarpa, Acacia bivenosa, Acacia maitlandii, shrubland over Triodia wiseana hummock grassland. • Elevated flat hill top on stony soils.
Plains	Grassland Plains	• Corymbia hamersleyana woodland over Acacia ancistrocarpa shrubland over Triodia wiseana grassland. • Broad flat low lying plains to undulating plain on soft loamy soils.
Plains	Loamy Plains	• Scattered to open Corymbia hamersleyana woodland over mixed Acacia ancistrocarpa, A. inaequilatera, A. bivenosa, A. colei var. ileocarpa, Grevillea pyramidalis subsp. leucadendron shrubland over Triodia wiseana or T. epactia hummock grassland or *Cenchrus ciliaris and *C. setiger grassland. • Low-lying undulating loamy to stony plain within Bungaroo valley floor.
Plains	Stony Plains	• Mixed Acacia shrubland over Triodia Hummock grassland. • Low-lying undulating Stony plain. Stony compact soils, low levels of leaf litter, sparse open vegetation.
Plains	Stony Shrubland Plain	• Trees (usually Corymbia hamersleyana) are few and shrubs are generally openly scattered. Dominant shrub species include Acacia inaequilatera, A. orthocarpa, A. ancistrocarpa and A. atkinsiana. • Relatively flat, stony plains covered by shrublands over spinifex hummock grasses with scattered emergent trees. The substrate comprises firm, red-brown fine clay-sand under loose pebbles and stones. Wood and leaf litter is sparse to moderate, and is generally concentrated under shrubs and trees.
Plains	Undulating Plains	• Corymbia spp. scattered low trees over Acacia spp. tall open shrubland to open shrubland over Triodia epactia, T. wiseana hummock grassland. • This landform comprised the stony undulating plains and wetter plains that were dominated by a clayey substrate.
Rocky Ranges	Hill Tops	• Scattered Eucalypts over sparse Acacia shrubland over hummock or tussock grassland. • Stony hills on high ranges with dissected valleys and gullies. Stony compact soils, low levels of leaf litter, sparse open vegetation, small overhangs.
Rocky Ranges	Low Hills	• Corymbia hamersleyana scattered low trees over mixed Acacia shrubland over Triodia hummock grassland. • Low rolling stony hills and valleys. Stony compact soils, low levels of leaf litter, sparse open vegetation.

Landform	Habitat	Basic description
Rocky Ranges	Stony Hills and Rises	• Scattered Corymbia hamersleyana over mixed Acacia inaequilatera, Acacia pyrifolia var. pyrifolia shrubland over Triodia wiseana hummock grassland. • Low stony hills and slopes with dissected valleys and drainage on stony soils.
Water-courses	Drainage Line	• Scattered Eucalyptus camaldulensis and E. victrix over mixed Acacia shrubland over mixed herbs and grasses. • Broad valley or drainage line. Range from soft sandy soils with surface cobbles and pebbles, diversity of microhabitats leaves logs and twigs to rocky structures with ephemeral drainage lines sometimes containing small semipermanent water pools.
Water-courses	Minor Creekline	• Corymbia hamersleyana low open woodland over Acacia spp. tall shrubland to shrubland over Triodia wiseana, T. epactia hummock grassland. • Permanent or semi-permanent water is not expected to occur within the creeks or flowlines; they are only likely to flow during significant rainfall events and thus do not represent true riverine landforms.
Water-courses	Riverine	• Melaleuca argentea and Eucalyptus camaldulensis over mixed Acacia colei var. colei, Acacia trachycarpa, Acacia tumida var. pilbarensis shrubland over mixed herbs. • Part of the Robe River riparian zone containing a diverse vegetation and with semipermanent or permanent pools. Dense diverse vegetation with significant level of leaf litter providing large opportunities of refuge and foraging for a wide suite of vertebrate fauna species; permanent pools of water.
Disturbed	Disturbed	• Cleared - Disturbed habitat within mining area, mainly attributed to exploration activities. • Little value as fauna habitat.

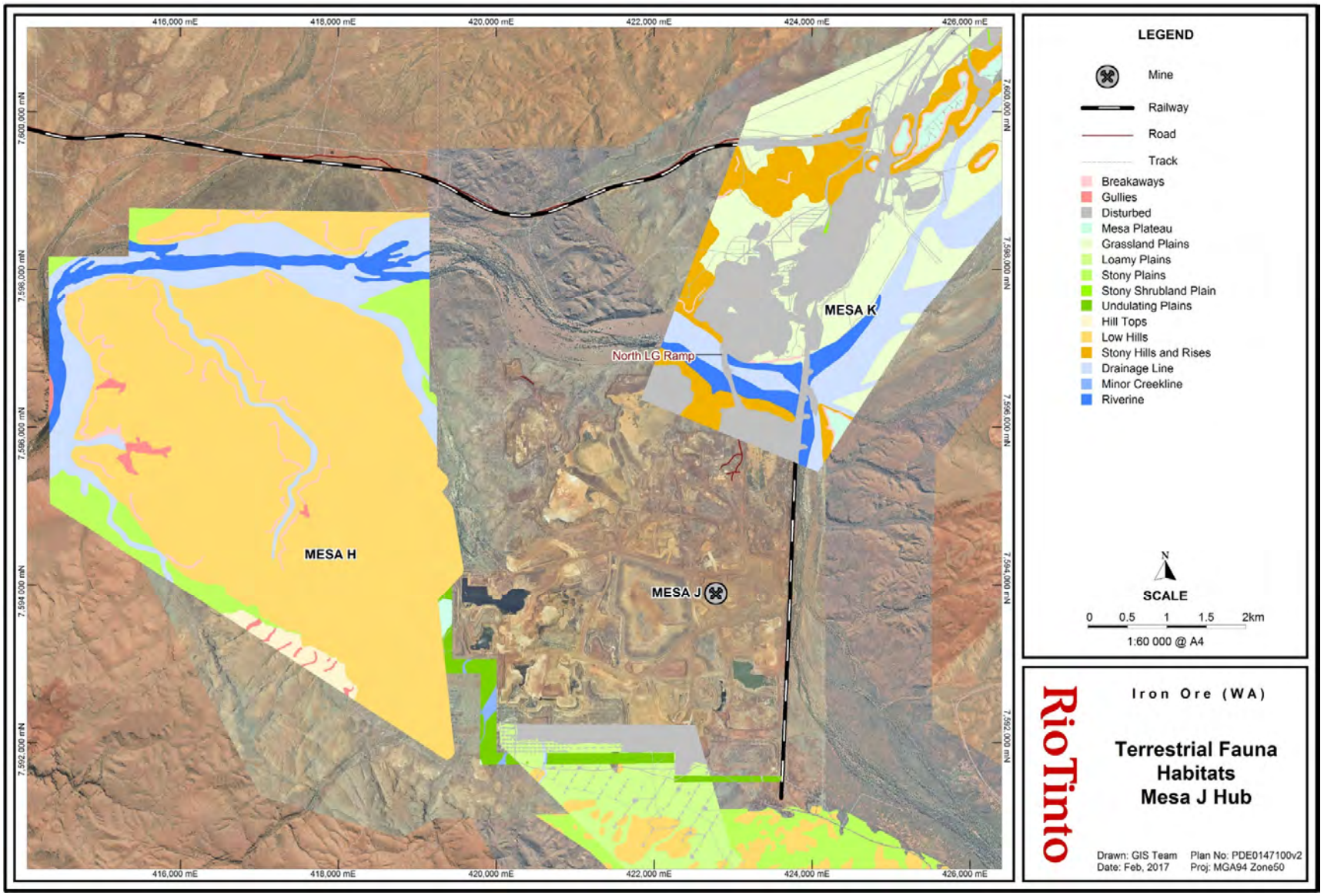


Figure 16: Terrestrial fauna habitats of Mesa J Hub

12.2 Fauna habitat

Re-introduction of fauna is not considered as part of this closure plan. Instead, natural migration of fauna species into rehabilitated land is encouraged by creating habitats with similar composition to pre-mining communities in appropriate locations and with consideration of the post-closure soil and landforms design.

Habitat elements that are considered as part of the closure landform design include:

- vegetation known to provide preferred food or shelter preference;
- retaining and replacing woody debris;
- rapid generation and retention of leaf litter using small-scale topography (e.g. furrows created from ripping);
- introducing or leaving rocky features such as oversized waste burden or scree slopes;
- creating greater depths of friable soil (or suitable mineral wastes) for burrowing fauna;
- preserving connectivity with unmined areas, and maintaining the quality of these habitats; and
- managing feral predators and herbivores across both reference and rehabilitated areas.

Species associated with plains, drainage line or disturbed habitats have the potential to benefit from the rehabilitation of mine, as a consequence of returned or expanded habitat post-closure.

12.3 Conservation significant fauna

Eight species of conservation significance have been recorded or evidence found of their presence within the Mesa J Hub mining area.

A summary of the species, conservation status and habitat is presented in Table 14.

Table 14: Species of conservation significance and associated habitats at Mesa J Hub

Fauna species	Conservation status WA	EPBC Act status	Habitat occurrence
Dasyurus hallucatus (Northern Quoll)	Schedule 2	Endangered	Breakaways & Gullies Rocky Ranges Water-courses
Liasis olivaceus barroni (Pilbara Olive Python)	Schedule 3	Vulnerable	Breakaways & Gullies
Macroderma gigas (Ghost Bat)	Schedule 3	Vulnerable	Breakaways & Gullies Water-courses
Rhinonicteris aurantia (Pilbara) (Pilbara Leaf-nosed Bat)	Schedule 3	Vulnerable	Breakaways & Gullies Water-courses
Merops ornatus (Rainbow Bee-Eater)	Schedule 5		Breakaways & Gullies Water-courses Plains
Ardea modesta (Eastern Great Egret)	Schedule 5		Water-courses
Pseudomys chapmani (Western pebble-mound mouse)	Priority 4		Rocky Ranges
Notoscincus butleri (Lined soil-crevice skink)	Priority 4		Plains

12.4 Feral animals

Feral carnivores (e.g. cats, dogs, foxes) can create locally increased predation pressure on native fauna as well as increase competition with native species for resources such as space (territory), water and food. Feral herbivores (e.g. cattle, camels, donkeys) can also have a significant impact in Rangeland areas, such as the Pilbara. In dry times, grazing pressure reduces the abundance of palatable native species, impacting biodiversity and can create conditions that encourage weeds to grow. Foot traffic impacts the soil conditions, and in combination with over grazing, can encourage erosion. Foot traffic has also been the cause of damage to cultural landmarks and Aboriginal sites. Overgrazing and damaged soils has a flow-on effect to native fauna species that rely on this vegetation for food and shelter. Should management of feral animals be required at closure, a management plan will be developed. Feral animal control is an operational requirement, however it is not expected to be required post closure.

12.5 Conservation significant flora

Table 15 describes the Priority flora that have been identified in or near the Mesa J Hub. No Declared Rare or Threatened flora have been recorded in or near the Mesa J Hub area, nor are any expected to occur.

Table 15: Conservation significant flora identified in or near the Mesa J Hub.

Flora taxon	Conservation status WA	Habitat comments
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367)	Priority 3	Ironstone substrates, sometimes with a clay loam content, most commonly on the crests of mesas (particularly around the rocky margins) and sometimes in in flowlines dissecting these areas.
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	Priority 3	Drainage lines, creeks in hills or plains. Brown silty loam.
Rhynchosia bungarensis	Priority 4	Pebbly coarse sand and amongst boulders on the banks of flowlines.

12.6 Invasive flora

Flora and vegetation surveys have recorded 24 introduced species (Table 16), with 20 species on the Department of Parks and Wildlife Impacts and Invasiveness Ratings list for the Pilbara.

Table 16: Weed species recorded at Mesa J Hub

Scientific Name	Common Name	Ecological Impact	Invasiveness
**Aerva javanica*	Kapok Bush	High	Rapid
**Argemone ochroleuca*	Mexican Poppy	Unknown	Rapid
**Bidens bipinnata*	Bipinnate Beggartick	Unknown	Rapid
**Cenchrus ciliaris*	Buffel grass	High	Rapid
**Cenchrus setiger*	Birdwood Grass	High	Rapid
**Chloris barbata*	Purpletop Chloris	High	Rapid
**Citrullus colocynthis*	Colocynth	Unknown	Moderate
**Cucumis melo*	Ulcardo Melon	Unknown	Moderate
**Cynodon dactylon*	Couch	High	Rapid
**Datura leichhardtii*	Native Thornapple	Unknown	Unknown
**Echinochloa colona*	Awnless Barnyard Grass	High	Rapid

Scientific Name	Common Name	Ecological Impact	Invasiveness
**Euphorbia hirta*	Asthma Plant	Low	Slow
**Flaveria trinervia*	Speedy Weed	-	-
**Lactuca serriola*	Prickly Lettuce	-	-
**Malvastrum americanum*	Spiked Malvastrum	High	Rapid
**Melochia pyramidata*		-	-
**Ocimum basilicum*	Basil	-	-
**Passiflora foetida*	Stinking Passion Flower	High	Rapid
**Phoenix dactylifera*	Date Palm	High	Rapid
**Rumex vesicarius*	Ruby Dock	High	Rapid
**Setaria verticillata*	Whorled Pigeon Grass	High	Rapid
**Solanum nigrum*	Black Berry Nightshade	Low	Rapid
**Sonchus oleraceus*	Common Sowthistle	Low	Rapid
**Tribulus terrestris*	Caltrop	Unknown	Moderate
**Vachellia farnesiana*	Mimosa Bush	High	Rapid

12.7 Priority and/or Threatened Ecological Communities

No Threatened Ecological Communities have been recorded in or near the Mesa J Hub area. Three Priority Ecological Communities (PEC) occur within the Mesa J Hub area as described in Table 17. However, vegetation which is considered analogous to the Priority 3 PEC '*Triodia sp. Robe River assemblages of mesas of the West Pilbara'* has been mapped at Mesa H.

Table 17: Priority and/or threatened ecological communities in or near the Mesa J Hub area

Community Name	Conservation status WA	Description	Location in respect to Mesa J Hub
Subterranean invertebrate communities of mesas in the Robe Valley region	Priority 1	A series of isolated mesas occur in the Robe Valley in the Pilbara Region. The mesas are remnants of old valley infill deposits of the palaeo Robe River. The troglobitic faunal communities occur in an extremely specialised habitat and appear to require the particular structure and hydrogeology associated with mesas to provide a suitable humid habitat. Short range endemism is common in the fauna. The habitat is the humidified pisolitic strata.	Central and northern sections of Mesa J and all of Mesa K
Subterranean invertebrate community of pisolitic hills in the Pilbara	Priority 1	A series of isolated low undulating hills occur in the Pilbara region. The troglofauna are being identified as having very short range distributions.	Southwestern potion of Mesa J and all of Mesa H
Stygofaunal community of the Bungaroo Aquifer	Priority 1	A unique assemblage of aquatic subterranean fauna including eels, snails and other stygofauna.	South-eastern corner of Mesa J, extending south

13. Progressive rehabilitation

Regular reviews of the mine plan are used to identify disturbed areas of the site where mining activity has been completed. These areas are then reviewed for potential to undertake progressive rehabilitation works. Lessons learnt during these activities and from subsequent monitoring campaigns are used to inform and update our standard management practices and provide input into suitability of final closure criteria for the site.

To date, approximately 310ha of rehabilitation has been completed at the Mesa J and Mesa K operations. Approximately 105ha of previously rehabilitated areas have been re-disturbed to facilitate ongoing mining activities, with 205ha remaining. Table 18 and Figure 17 provide an overview of the main areas of progressive rehabilitation undertaken at Mesa J and Mesa K to date.

Table 18: Progressive rehabilitation details

Site	Location	Category	Area rehabilitated (ha, approximate)	Year of Rehabilitation (estimated)
Mesa J	Calcium Dump	Waste Dump	6.57 Disturbed	1996
Mesa J	A Dump	Waste Dump	10.77 Disturbed	2004
Mesa J	North West Dump	Waste Dump	7.08 Partially disturbed 5.40 remaining	2002-2004
Mesa J	North East Dump	Waste Dump	4.86 Disturbed	2002
Mesa J	S Waste Dump	Waste Dump	31.10 Planned to be reclaimed	2004-2008
Mesa J	T Waste Dump	Waste Dump	28.70 Planned to be reclaimed	2004-2008
Mesa J	Pit 10	Pit Floor	13.26	2014
Mesa J	TSF1	Waste Fines Storage Facility	44.87	2014
Mesa J	CLBB	Rail (Construction)	1.62	2014
Mesa K	K Pit	Pit Floor	142.00 Partially disturbed 62.22 remaining	1994-1996
Mesa K	West WD	Waste Dump	3.87	1996
Mesa K	Haul Rd	Haul Road	11.23	1997
Mesa K	Gravel Pit	Pit Floor	4.48	2013

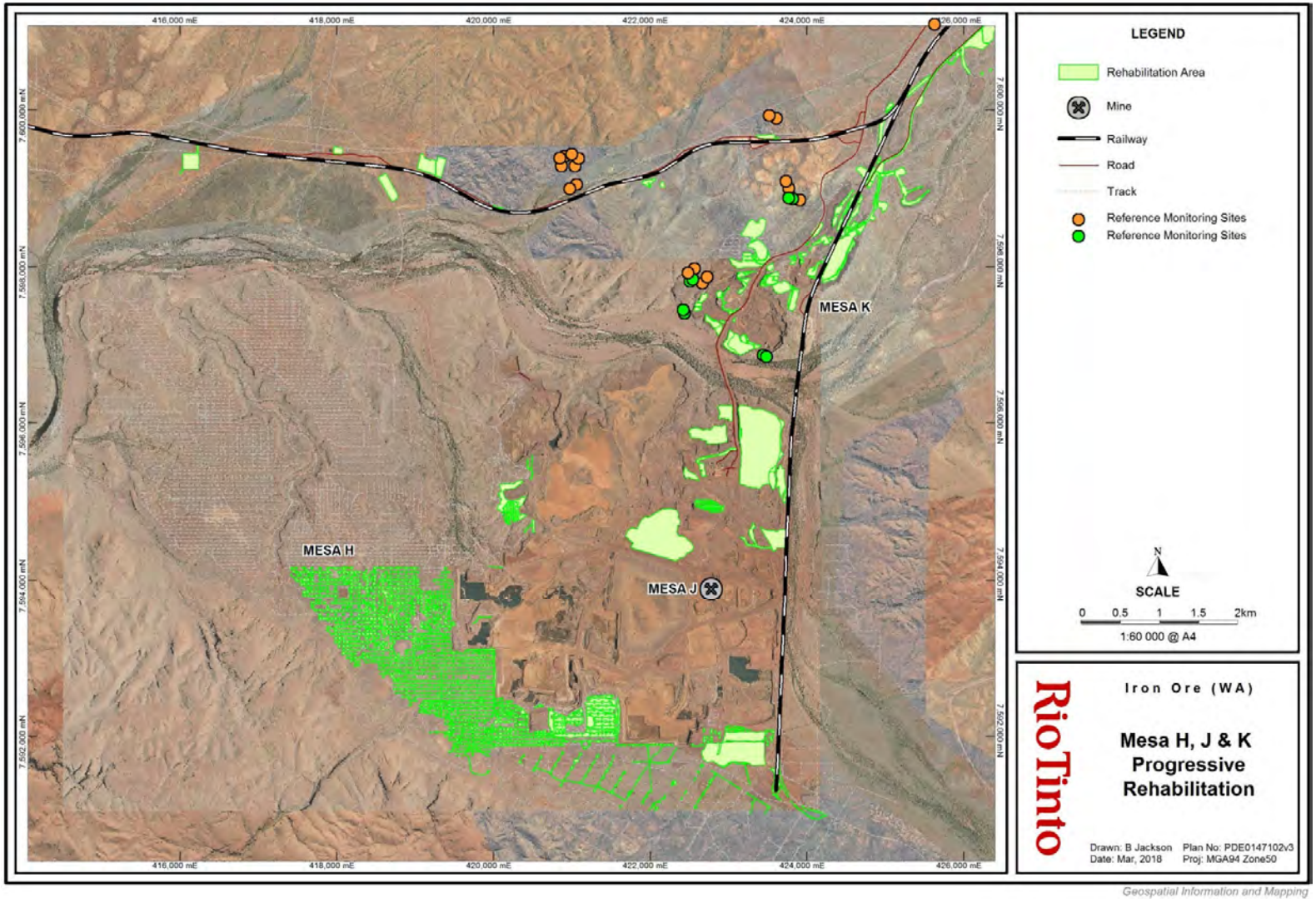


Figure 17: Progressive rehabilitation areas at Mesa J and Mesa K

13.1 Seed provenance and selection

Locally collected seed is needed to assist in revegetation and the creation of a self-sustaining ecosystem. Over time the viability of seeds in stockpiled topsoil decreases, and thus the quality of the topsoil deteriorates. In addition, the topsoil that was salvaged prior to disturbance may not contain seeds of all the target species of its new location / habitat.

Seed mixes for rehabilitation are of local provenance where possible. Specific seed mixes are selected to provide a range of species appropriate to the desired habitat, taking into consideration landscape position and slope. In areas where erosion risks are identified, seed mixes may be modified to include or increase the portion of species that provide rapid cover.

Rio Tinto purchases seeds from commercial seed suppliers, with emphasis on ensuring that there are appropriate local provenance seeds available for rehabilitation of each of its sites. Seeds are stored in purpose-built, climate controlled storage facilities to maximise long term viability.

The inclusion of rare and threatened species in rehabilitation programmes is limited by:

- habitat preference (preference for drainage lines, gullies, calcretes or other habitat not suitable or similar to those likely to be present in the rehabilitation landscapes);
- abundance – very few populations or small populations from which to source seed;
- difficult taxonomy / unresolved taxonomy issues and thus status of species highly uncertain;
- growth form – e.g. short lived annual species with preference for growth under woodland canopies;
- seed production – some species do not regularly produce seed;
- propagation methods – some species are not able to germinate from seed and cuttings are required which is not a suitable method for broad scale application in an arid environment;
- availability of seed at the time when rehabilitation occurs; and/or
- seed dormancy.

Given these issues, the main focus of rehabilitation programs is to restore vegetation complexes that include the more common species present in the particular habitat type, and to achieve a diverse range of strata. Seed mixes may include species of conservation significance if they are available, but presence of these species in rehabilitation areas is more likely to result from natural recruitment from surrounding areas.

13.2 Pits

The majority of Mesa K Pits were rehabilitated between 1994 and 1996. Some topsoil was spread on the area, followed by shallow ripping and seeding. Monitoring locations were installed in 1999, at 25 different locations around the pit. A suite of sites were monitored on six occasions, the most recent of which was in 2013. The rehabilitation was compared to local undisturbed reference sites. Vegetation is well established, reflecting the maturity of the rehabilitation.

Mesa J Pit 10 was rehabilitated in 2014. The pit was ripped and seeded, with topsoil only spread on the northern area of Pit 10. Monitoring locations were installed in 2014 on both the top-soiled and non-top-soiled areas of Pit 10. Development of the rehabilitation was monitored in 2014 and 2015 (Figure 18). The rehabilitation is compared to local undisturbed reference sites. Pit 10 North has good vegetation establishment with a range of native vegetation species. Pit 10 South has limited native perennial vegetation establishment, due to both the young age of the rehabilitation and the lack of topsoil. Over time, it is expected to perform similarly well to Mesa K Pit rehabilitation (Figure 19), with differences attributed to topsoil, particularly at Pit 10 South. Buffel Grass and Birdwood Grass are present at Pit 10 North and Ruby Dock at Pit 10 South. Weeds in rehabilitation are managed under the company's *Weed Management Strategy* which has control measures such as periodic spraying and equipment hygiene procedures.

The Gravel Pit at Mesa K was rehabilitated in 2013 by reshaping, ripping, and seeding. Good regrowth had occurred on the area prior to rehabilitation, so the soil and vegetation were collected and respread during rehabilitation. Monitoring locations were installed in 2014, one on the upper area and one on the lower area. These were monitored in 2014 and 2015. The rehabilitation was compared to local undisturbed reference sites. Vegetation is establishing well, with vegetation parameters comparable to the reference sites (Figure 20).

13.3 Waste dumps and waste fines storage facilities

Mesa K West waste dump and a haul road were rehabilitated in 1996 and 1997 respectively. Both locations had topsoil spread on the area. Monitoring locations were installed in 2013; two at the Waste Dump and one at the Haul Road. These were monitored in 2013. The rehabilitation was compared to local undisturbed reference sites. Vegetation is well established at both rehabilitation areas, reflecting the maturity of the rehabilitation; however density and cover are slightly lower than reference sites.

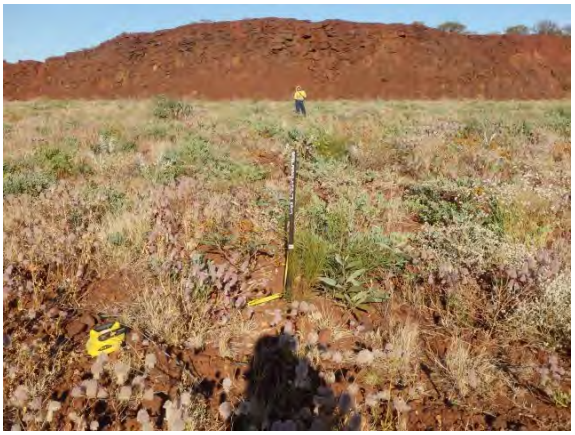
The S and T Waste Dumps at Mesa J were rehabilitated between 2004 and 2008 by reshaping, ripping, and seeding the dump slopes and tops. S Dump received topsoil, whilst T Dump received subsoil. Monitoring locations were installed in 2008, including both sloped and flat areas. Development of the rehabilitation was monitored on five occasions, the most recent of which was in 2015. The rehabilitation is compared to local undisturbed reference sites. At S Dump, vegetation cover and density had been increasing since completion, with an upper storey developing since 2010. The flat areas on top of the dump had plant density and cover plateauing in 2015, indicating the rehabilitation had completely established. T Dump also increased vegetation cover and density in the early stages, and plateaued around 2010. S Dump had higher cover and density than the compared reference sites, while T Dump had lower values (Figure 21). Minor erosion occurred on the sloped sides of both dumps; however monitoring data demonstrates it was not active and had stabilized. Buffel Grass was present at S Dump and Ruby Dock at T Dump; both are sparse and not outcompeting native vegetation. Weeds in rehabilitation are managed under the company's weed management strategy which has control measures such as periodic spraying and equipment hygiene procedures.

Mesa J Waste Fines Storage Facility 1 (TSF1) was rehabilitated in 2014 as a trial of WFSF closure without the use of a capping layer. TSF1 was ripped and seeded, taking care to avoid large trees established in the area. Topsoil was not spread on TSF1, as growth media studies supported the surface material being suitable for vegetation growth. Monitoring locations were installed in 2014 on the upper and low-lying (periodic inundation) areas of TSF1. Development of the rehabilitation was monitored in 2014 and 2015. The rehabilitation is compared to local undisturbed reference sites. Vegetation establishment has been variable across TSF1 (Figure 22); however vegetation metrics have mostly increased since 2014. Minor subsidence has been noted, although is expected to stabilize as vegetation establishes and waste fines settle. Birdwood Grass is present in the low-lying areas and Buffel Grass in the upper areas. Ruby Dock is present across TSF1; however in general, introduced species are declining in density. Weeds in rehabilitation are managed under the company's weed management strategy which has control measures such as periodic spraying and equipment hygiene procedures.

13.4 Low impact disturbance areas, roads and borrow pits

The construction areas along the rail line at Mesa J were rehabilitated in 2014. Topsoil was respread and the areas were shallow ripped; no seeding occurred due to the direct return of fresh topsoil. Three monitoring locations were installed and monitored in 2015; two next to the rail line and one along the access road. The rehabilitation was compared to local undisturbed reference sites. Vegetation establishment along the access road was comparable to reference sites, even at a young age, with no weeds present. Good results are attributed to the lack of disturbance and traffic surrounding the area. Vegetation establishment along the rail line is beginning to occur, however vegetation parameters are low, reflecting the young age of the rehabilitation. Buffel Grass, Birdwood Grass, Ruby Dock, Kapok and Pie Melon are present in these areas; Birdwood Grass, Spiked Malvastrum and Mimosa Bush were also present in nearby reference sites. Weeds in rehabilitation are managed under the company's *Weed Management Strategy* which has control measures such as periodic spraying and equipment hygiene procedures.

After rehabilitation (January 2014)



Monitoring (September 2015)

Figure 18: Progressive rehabilitation of Mesa J Pit 10 North

Mesa K Pit (2013 – 17 years)

Mesa J Pit 10 South (2015 – 1 year)

Figure 19: Recently completed rehabilitation of the pit floor at Pit 10 Mesa J is expected to reach similar successful rehabilitation outcomes as 17 year old rehabilitation at Mesa K.

After rehabilitation (March 2014)

Monitoring (September 2015)

Figure 20: Progressive rehabilitation of the Mesa K Gravel Pit without topsoil.

S Dump (2015 – 7 years)

T Dump (2015 – 7 years)

Figure 21: Mesa J Waste Dump rehabilitation – comparison of success utilising topsoil and subsoil

TSF1_T1 (2015 – 1 years)

TSF1_T4 (2015 – 1 years)

Figure 22: Mesa J TSF1 showing variability in vegetation establishment, although the area is still young.

14. Contaminated sites

Rio Tinto maintains registers for potentially contaminating activities and known or suspected contaminated sites which have been formally reported under s11 of the *Contaminated Sites Act 2003* (WA). The registers are informed by regular review of operations and where required preliminary site investigations to assess contaminants associated with such activities and assess their risk of harm to human health, the environment and environmental values. Potentially contaminating activities and land uses as described in the guideline '*Assessment and management of contaminated sites'* (DER, 2014), that may be associated with mining activities onsite include, but not limited to:

- Airport facilities;
- Automotive repair workshops (light and heavy machinery);
- Substations and transformers;
- Fertiliser and explosives storage;
- Landfill sites;
- Mineral processing, mining, screening and crushing facilities;
- Rail transport corridors;
- Hydrocarbon storage, handling and dispensing facilities;
- Sewage waste water treatment plants and irrigation areas; and
- Disturbance of potentially acid forming materials during the course of mining.

All potentially contaminating activities and land uses identified on the site register are managed as part of the ongoing mining operation. Prior to closure as part of the decommissioning process, a contaminated site assessment will be undertaken. Based on this assessment, specific plans will be developed to remediate or manage contaminants, where required, to support the final land use.

15. Cultural heritage

Rio Tinto recognises and respects the significance of Australia's cultural heritage, and in particular the cultural heritage of Aboriginal people who have traditional ownership of, and/or cultural connections to, the land on which it operates. Extensive archaeological and ethnographic surveys have been undertaken in the Mesa J Hub area, and these surveys help to inform the heritage values of the area. Rio Tinto takes all reasonable and practicable measures to prevent harm to cultural heritage sites, this includes during works associated with rehabilitation and closure. Where this is not possible, steps are taken to minimise or mitigate impacts and ensure required statutory approvals are obtained. Closure works consider issues such as post closure access requirements to culturally significant sites and appropriate return of any materials salvaged during mining operations.

15.1 Relevant Aboriginal groups

The Mesa J Hub lies within the traditional country of the Kuruma Marthudunera (K&M) people. The K&M currently have a large native title claim area over the Robe Valley, which includes the Mesa J Hub, and K&M also possess a native title determination (Part A) over a large area east of the claim into the western Hamersley ranges, which abuts the native title claim.

The extent of Kuruma Marthudunera country in relation to Mesa J Hub is shown on Figure 5. A Claim Wide Participation Agreement (CWPA) was signed by Rio Tinto and K&M in 2011, and an Indigenous Land Use Agreement (ILUA) registered in 2013. A Cultural Heritage Management Plan is scheduled to be completed in 2017, and is due for review every 5 years.

15.2 Ethnographic and archaeological values

Heritage surveys (in alignment with the Heritage Protocol within the CWPA) with nominated Kuruma Marthudunera representatives and external consultants have identified archaeological and ethnographic sites and made recommendations on the significance and management of each site. Sites of significance within the Mesa J Hub area include:

- 3 Law Grounds (Thalartna, Yarramarda and Buggumadda);
- Old Deepdale Homestead;
- 3 important ethnographic (thalu/increase) sites (Jirti Thalu, Parkunyji and Yunta);
- one large rockhole at Mesa J with high ethnographic significance (Mesa J Rockhole);
- one permanent waterhole in the Robe River with high ethnographic significance (Yeera Bluff);
- numerous named (ethnographic) waterholes spread along the Robe River. Some permanent, some semi-permanent;
- a burial site north of Mesa H on the terrace between the mesa escarpment and the Robe River;

- the Robe River is viewed by K&M as a whole system, which includes its general health and waterholes, vegetation and fauna;
- the existing Mesa Façades are used as navigational landmarks; and
- multiple archaeological sites (including several gender restricted sites).

In some cases where disturbance is unavoidable, artefacts and cultural material may be disturbed and removed under Section 18 consent of the *Aboriginal Heritage Act* 1972 and placed into storage to facilitate mining activity. A number of such sites at the Mesa J Hub have either been cleared or nominated to be cleared under these provisions, with material stored in the Mesa J Keeping Place located at the Mesa J minesite In some circumstances, when objects or artefacts have been salvaged from a site, the K&M people have expressed the desire to repatriate the artefacts to the land from which they were removed post closure and rehabilitation. The particular circumstances where this may be required is captured in the Cultural Heritage Management Plan (CHMP) for the Mesa J Hub area

16. Regional Community

The town of Pannawonica is 16 kilometres north-west of the mine. Pannawonica was established in 1970 specifically to support the adjacent mines, and is one of a limited few closed towns remaining in the Pilbara whereby all facilities are owned by a mining company, in this case Rio Tinto, and are maintained and operated on its behalf. It has a resident population of over 700 people.

Approximately 350 people work at the Mesa J and K operation. Employees either reside permanently in the town of Pannawonica or reside in the town on a fly-in, fly-out (FIFO) roster. The FIFO workforce utilise the Karratha airport and travel to Pannawonica via the North West Highway. The town falls within the Yarraloola pastoral lease.

There are no permanent Aboriginal communities in close proximity to the Mesa J Hub. The nearest Aboriginal community is a small settlement known as “The Block” which is located 3km north of Mesa H. The Block is seasonally occupied by some families from the K&M and contains limited permanent infrastructure. There is potential for the occupation of the community to increase over time.

IDENTIFICATION AND MANAGEMENT OF CLOSURE ISSUES

17. Risk evaluation process

A closure risk assessment was completed to identify and assess closure issues for Mesa H, J and K. The risk assessment is included in Appendix D. The assessment was completed by an internal panel of multi-disciplinary subject matter experts with the aim of:

- identifying hazards, aspects and opportunities that could influence the successful closure of the site;
- evaluating the resulting risks to people, property and the environment; and
- defining the actions required to reduce the risk to below the risk acceptance threshold.

Risk was evaluated on the basis of the maximum reasonable outcome consequence and the likelihood of that consequence occurring. Risks were evaluated inclusive of current management and commitments, and represent current residual risk.

Issues are assessed against the following consequence criteria:

- **Costs:** economic impacts if the risk were to eventuate ranging from low to very high, determined as a percentage of the projected closure cost for the operation;
- **Health:** reversible health effects of little concern (very low) to multiple fatalities (very high);
- **Personal safety:** inconvenient first aid treatments (very low) to multiple fatalities (very high);
- **Environment:** reversible impact (very low) to widespread, long-term impacts (very high). These risks are separated into two categories – during decommissioning/active closure implementation or post closure.
- **Community trust:** mistrust amongst a small section of the wider community (very low) to widespread mistrust with key stakeholders (very high). Also includes potential heritage impacts ranging from reparable damage to a site of low cultural significance (very low) through to irreparable damage to a site of international cultural significance (very high); and
- **Compliance:** non-conformance to internal requirements (very low) to prosecution for breach of regulatory licence(s) (very high).

Risks are classified as follows:

- **Class I:** Risks that are below the risk acceptance threshold and do not require further active management.
- **Class II:** Risks that lie on the risk acceptance threshold and require active monitoring to ensure management remains adequate and fit-for-purpose.
- **Class III:** Risks that, based on the current level of knowledge, could exceed the risk acceptance threshold and require proactive management and / or resolution of knowledge gaps.
- **Class IV:** Risks that, based on the current level of knowledge, will exceed the risk acceptance threshold and need urgent and immediate action.

Actions are assigned to risks that exceeded the risk acceptance threshold and therefore require additional control measures to reduce the risk to an acceptable level. Actions are also assigned to address knowledge gaps where it is assessed that further information is required to better understand and/or adequately assess the risk presented by an issue. This would typically be the case in the early stages of closure where the detailed knowledge of the issues may be low. These actions are captured in Appendix E.

18. Management of key issues

The DMP/EPA *Guidelines for Preparing Mine Closure Plans* lists a number of rehabilitation and closure issues that may be relevant for mine sites. An evaluation of the relevance of each of these issues to the Mesa J Hub is presented in Table 19. The information in this table is intended to compliment that contained in the risk assessment presented as Appendix D.

Table 19: Relevance of potential closure and rehabilitation issues to Mesa J Hub

Issue	Evaluation of relevance to Mesa J Hub	Further discussion
Acid and metalliferous drainage	The geochemical evaluation has determined that the sites are a low AMD risk.	Not addressed further in this chapter.
Challenges associated with rehabilitation and revegetation	The Mesa J and K areas have had areas of successful rehabilitation undertaken in both waste dumps and pits. Progressive backfill of pits to meet closure commitments and other opportunistic rehabilitation will be undertaken during operations, however the majority of rehabilitation will be completed at closure. A significant proportion of Mesa J will be covered by in-pit waste fines storage facilities. Management of waste fines rehabilitation is discussed in Section 18.2.	Section 18.1 and 18.2
Dispersive, sodic and erosive materials	The sites have a proportion of material which is of high erodibility.	Section 18.3.
Radioactivity	Not a significant issue for this site	Not addressed further in this chapter.
Mine pit lakes	A small pit lake is proposed at the Mesa J reservoir, (pit 15) a small water storage area during operations.	Section 18.4
Geotechnical instability	The waste dumps planned to remain at closure are not within the zone of instability of any pit voids. To ensure long term stability of the Mesa façades, the pit design incorporates pit wall design parameters and minimum façade width based on geotechnical assessment	Section 18.5
Inadvertent public access	There is potential for public access to the area post closure. Options are being considered for each mining area to address the risk of inadvertent public access.	Section 18.6
Hazardous materials	Hazardous materials (e.g. hydrocarbons, ammonium nitrate) will be removed prior to or during decommissioning.	Not addressed further in this chapter.
Hazardous and unsafe facilities	All infrastructure will either be demolished during decommissioning, or handed to the State in accordance with State Agreement requirements.	Not addressed further in this chapter.
Contaminated sites	There are no reportable contaminated sites.	Not addressed further in this chapter.
Fibrous materials	The geological evaluation has determined that the sites are a low fibrous materials risk.	Not addressed further in this chapter.
Non-target metals and target metal residues in mine wastes	No chemical processing occurs at the site.	Not addressed further in this chapter.

Issue	Evaluation of relevance to Mesa J Hub	Further discussion
Adverse impacts on surface and groundwater quality	Surface and groundwater quality are not expected to be significantly impacted as a result of the closure strategy. Monitoring of the Robe River Pools occurs regularly to assess water quality.	Section 18.7
Design and management of surface water structures	Surface water diversions and flood protection features will be present. No major creek diversion is required.	Section 18.8.
Dust emissions	This is not considered to be a significant closure issue for the site due to its remote location and no specific sensitive receptors identified.	Not addressed further in this chapter.
Flora and fauna diversity/threatened species	Subterranean Fauna Priority Ecological Communities (PECs) intersect the mining footprint. Mining exclusion zones have been established to ensure sufficient troglofauna habitat will remain at closure. The Bungaroo community does not require management at this stage.	Section 18.9
Visual amenity	The results of a visual impact assessment have been considered during planning of waste dump locations and height.	Section 0
Heritage issues	Management of cultural heritage values is conducted through processes established under the Indigenous Land Use Agreement, and strategies incorporated into Cultural Heritage Management Plans (CHMP). The CHMP for the Mesa J Hub will be drafted in 2017 and reviewed annually.	Not addressed further in this chapter.
Alteration of the direction of groundwater flow	Alteration of groundwater flow direction is not expected in the long term.	Not addressed further in this chapter.
Alteration of the depth to water table of the local aquifer	Dewatering will suppress groundwater levels at the operation. Ongoing and adaptive management will occur in response to modelling and monitoring indicating an impact to the Robe River pools.	Section 18.7
Alteration of the hydrology and flow of surface waters	No major creek diversion are required. Landform design takes into account surface water impacts and changes to hydrology.	Section 18.8.

18.1 Challenges with progressive rehabilitation

Rio Tinto has formal processes for identifying areas which are no longer required for operational activity and are therefore available for rehabilitation. However, mine plans are dynamic and subject to continuous revision, and rehabilitation may need to be re-disturbed for mining or operational use. Progressive rehabilitation opportunities are reassessed regularly as part of the planning process.

A legacy area review workshops was conducted at Mesa J and K in early 2017. The workshops focus on all areas of the mine, particularly the older lesser known areas. The current mine plan for Mesa J incorporates progressive backfill of pits where practical as required by Ministerial Statement 208, and proposed mining for Mesa H also incorporates progressive backfill of pits. The majority of backfill is undertaken during operations, however some backfill may not be possible until the end of mine life due to mine sequencing. Some backfill areas require additional landform design which has been included as an action in the closure task list.

Rehabilitation is conducted in accordance with the *Rio Tinto Iron Ore Rehabilitation Handbook*, which is reviewed and updated periodically to reflect changes in industry standards, reflect new knowledge obtained through research and development, and to adopt learnings from ongoing rehabilitation projects. The Handbook addresses:

- soil resource management;
- rehabilitation techniques;
- local provenance species seeding practices;
- records and data management; and
- on-going monitoring.

Rehabilitation typically involves:

- removal of rubbish, redundant equipment and infrastructure, ensuring the area is not contaminated;
- reshaping and contouring land to blend with natural relief to manage drainage to ensure stability;
- ensuring that appropriate controls are in place to manage hazardous mineral wastes, including encapsulation of PAF and fibrous wastes (not applicable in the Mesa J Hub), and installation of store and release covers where required;
- installation of abandonment and drainage management bunds where required;
- application of soil to a depth of 200mm where practical to promote vegetation growth;
- deep rip to an appropriate depth prior to seeding;
- seeding to ensure a suitable vegetation cover and composition, generally using a mechanical seeder;
- recording rehabilitated areas on internal GIS databases; and
- inclusion within the rehabilitation monitoring program where appropriate.

Topsoil and subsoil is managed in accordance with the *Rio Tinto Iron Ore Soil Resource Management Work Practice* in order to ensure appropriate material is available for rehabilitation activities. Where practical, a minimum of 200mm of topsoil and up to 600mm of subsoil is collected whenever new ground is disturbed. Reconciliations of topsoil volumes are undertaken to confirm that sufficient material is available to spread across the rehabilitated area, assuming a spreading depth of 200mm. Locations for soil stockpiles have been identified and incorporated into the mine plan. Topsoil stockpiles are planned to be up to 2m tall to maintain viability, and will be used to rehabilitate areas cleared for mining and infrastructure, including pit voids.

18.1.1 Revegetation challenges

The use of topsoil in rehabilitation is generally linked to improved revegetation outcomes. The soil seed bank quality within the stockpiled soil is known to reduce over time. Given the long mine schedules in Iron Ore operations it is anticipated that the soil quality may be reduced. Field trials been undertaken in the business to gauge results of using reduced soil quality, no soil or alternative growth media. It is likely that the reduced viability of the seed bank is a key concern in achieving the range of key species desired in the rehabilitation in a cost effective process.

Supplementary seeding is commonly undertaken in rehabilitation of medium and high disturbance areas. The ability to meet seed requirement volumes for closure is captured as a risk in achieving successful revegetation. A long term seed procurement strategy requires development to ensure sufficient volumes of seed are available for use when required. Seed used in rehabilitation is local provenance where possible, and availability can be limited by seasonal variation and a lack of suitable collectors. Currently seed procurement is focused on meeting the requirements of progressive rehabilitation targets.

Actions have been included in the sites closure task register relating to improving rehabilitation and revegetation success.

18.2 Management of waste fines storage facilities

The Mesa J Hub will utilise the existing Mesa J wet plants for processing. All waste fines are proposed to be contained in in-pit Waste Fines Storage Facilities (WFSF). Waste fines are scheduled to be contained entirely within the Mesa J in-pit facilities. As WFSF's reach capacity they will be capped with a layer of waste rock, when safe to access with heavy equipment.

The final landform design of these areas assumes a minimum 2m capping layer of inert material will be placed over the facilities. The capping layer thickness may be increased to facilitate disposal of waste rock, and enable utilisation of the surface of the WFSF for operational purposes. Given the designs for the future WFSF are still conceptual, further work will be required to review the interaction between pit walls and the WFSF's. Updates to the landform will be included in closure plan updates.

A closure task has also been identified to assess the potential for seepage from WFSF into the aquifer and potential impact to groundwater quality and subterranean habitats.

Rehabilitation of the existing TSF1 has been completed. This area was rehabilitated without capping as a trial. It is anticipated that all other waste fines storage facilities may be capped to reduce the heights and expanse of waste dumps and meet the project commitment to backfill as much waste rock within the pit limits as possible.

18.3 Management of erodible mineral waste

18.3.1 Principles of waste dump design

Mineral waste dumps located on mine sites that are operated by Rio Tinto are designed and rehabilitated in accordance with internal Landform Design Guidelines, which provides guidance on:

- the objectives of waste dump design, which is to achieve dumps that are:
  - safe;
  - stable;
  - aesthetically compatible with the surrounding landscape;
  - vegetated;
  - non-polluting;
  - compatible with the agreed post-mining land use; and
  - progressively rehabilitated;
- appropriate locations for the siting of waste dumps;
- appropriate shapes and designs of waste dumps;
- appropriate surface treatments; and
- links to other relevant internal and external guidance material.

These Guidelines are updated on a regular basis to incorporate learnings from research, studies and rehabilitation implementation projects. The most significant update occurred in 2012 to provide design criteria for waste dumps based on the specific waste types present. This was the result of several years of materials testing and landform evolution modelling studies of wastes typically found in the Pilbara including those at the Mesa J Hub, with design recommendations based on the assumption that an average erosion rate of 5/ha/year (with a maximum of 10/ha/year) will be acceptable. Further studies have since been undertaken on additional waste types, and this resulted in further minor updates in 2014 and 2016.

It should be noted that erosion modelling is conducted on the conservative assumption that slopes are not vegetated. However, vegetation is expected to establish on all slopes, thereby further reducing the erosion potential.

18.3.2 Erosion risk

The Mesa H and Mesa J deposits have a proportion of higher erodibility waste materials, include Tertiary Pisolite Clay (TPC) and Alluvials. Waste disposal via in-pit backfill, and location of several waste dumps in-pit, reduces the erosion risk associated with these materials, as sedimentation would be contained in-pit. The main erosion risk is associated with ex-pit dumps. Erodibility testing and landform modelling of the alluvial materials has been completed and testing is currently underway for the TPC material. To ensure long term stability of waste dumps, design parameters are based on erodibility testing of specific material types, as documented in the *Rio Tinto Iron Ore Batter Selector Tool*. Waste dumps in the project area are generally limited to 40m height, to ensure long-term stability and to reduce visual impact.

The Mesa H external waste dumps have been designed to incorporate a capping layer of competent material on the external surface, to enable 20 degree batter angle and 20m lift height, and a reduction in dump footprint. A competent waste stockpile area has been included in the mine plan, separate to the waste dumps. The Hardcap or HTP geo zone as illustrated in Figure 12 comprises suitable low erodibility waste that will be utilised for capping.

The Mesa K waste dumps contain a large proportion of low erodibility hydrated waste, that present a low erosion risk. Generally the waste dumps have maximum 20 meter lift heights, 20 degree slopes and 10 meter wide berm, based on recommended parameters within the batter selector tool.

A portion of waste at Mesa J and H will be utilised to cap the waste fines facilities to a minimum thickness of 2m. The capping layer thickness may be increased to facilitate disposal of waste rock, and to enable utilisation of the surface of the WFSF for operational purposes. Mine planning to support this closure plan has assumed waste fines will receive a minimum 2m capping depth, if this increases there would be an associated reduction in the final waste dump configurations.

18.4 Management of pit lakes

The water management strategy for Mesa J requires a water reservoir to store water from various sources (including pit dewatering, and WFSF decant), that is used for operational purposes, primarily in the wet processing plants. A small pit lake is currently proposed at the Mesa J Pit 15 reservoir, which is planned as a water storage area from 2020. This may be subject to change over time dependant on changes to the waste and waste fines deposition strategy and designs. Water quality modelling is required to confirm an acceptable environmental outcome. The water quality is anticipated to remain acceptable in the long term with seasonal flushing events contributing to this. Should water modelling outcomes be unfavourable, mitigation actions to address the impact would be implemented, including potential backfilling.

Consideration will need to be given on the accessibility of this area in terms of cattle and other livestock. Further detailed design will be provided in future updates to the closure plan.

18.5 Management of pit void stability

As the Mesa landforms have landscape, visual, heritage and ecological value, it is important to ensure they remain stable in the long term. To ensure long term stability of the Mesa façades, the pit design incorporates pit wall design parameters and minimum required façade width based on geotechnical assessment. A mining exclusion zone (MEZ) protects the façade (Figure 26).

The predicted zones of instability from the pit floors are illustrated in Figure 23, Figure 24 and Figure 25. All permanent landforms such as external waste dumps will be located outside these zones. Abandonment bund locations are conceptual only at this stage, and require further refinement however they will be located outside the zones of instability. Actions to address void stability are included in the sites closure task register.

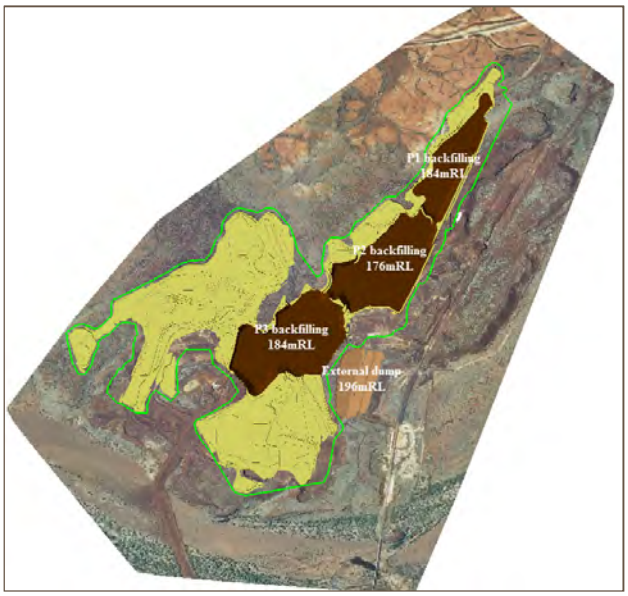


Figure 23: The Mesa K predicted zones of instability

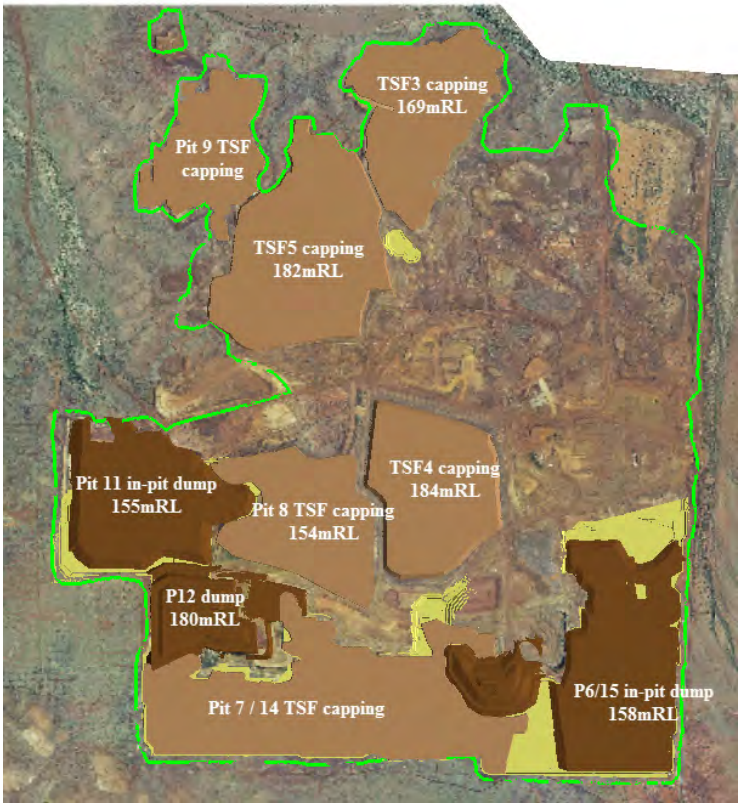


Figure 24: The Mesa J predicted zones of instability

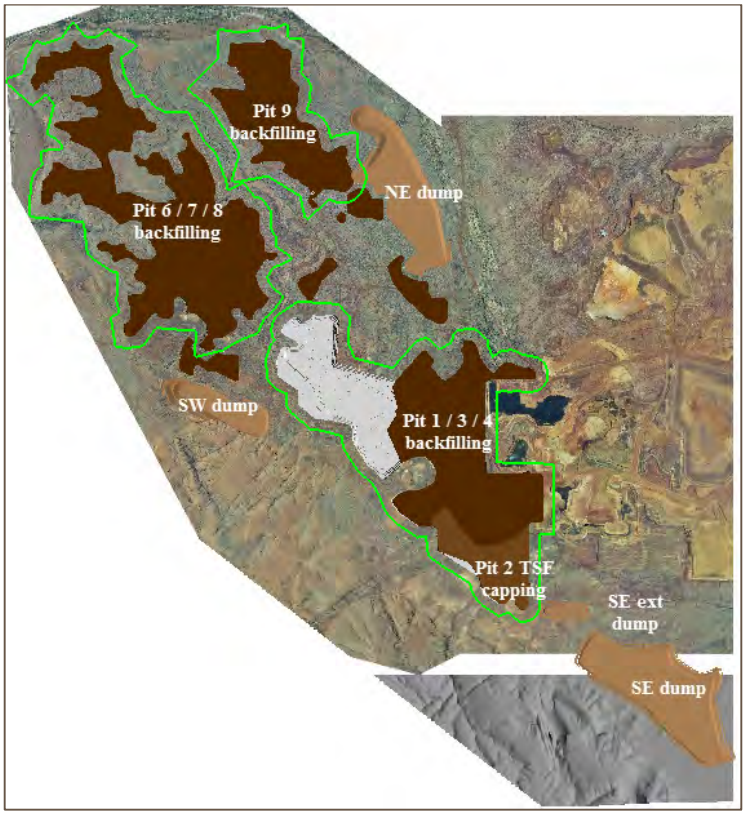


Figure 25: The Mesa H predicted zones of instability

18.6 Management of inadvertent public access

Inadvertent access to the site footprint post closure poses a safety risk due to the following circumstances:

- parts of the area are likely to be suitable to return to pastoral activities post closure;
- there will be pit voids not backfilled to the surface topography;
- there will be a pit lake at Mesa J; and
- access by Traditional Owners to significant heritage and ethnographic sites in the area.

This risk is considered to be reduced to an acceptable level and appropriately managed by the following:

- the area is remote from population centres;
- infrastructure will be decommissioned prior to relinquishment;
- the pits will be predominantly surrounded by the steep mesa façades, providing an effective barrier to inadvertent vehicle access;
- abandonment bunds will be established in areas where the mesa façade does not provide a barrier to inadvertent vehicle access to pits;
- tracks not required for post closure monitoring will be rehabilitated during closure implementation and prior to relinquishment all remaining tracks will be rehabilitated; and
- potential handover of ownership and maintenance requirements for post closure access by stakeholders such as pastoralists and Traditional owners.

18.6.1 Abandonment bunds

The Department of Mines and Petroleum (DMP) Abandonment Bund Guidelines require a 5 meter wide by 2 meter high abandonment bund be placed around a completed pit outside the zone of instability. The purpose of the guidelines is to reduce the likelihood of inadvertent access to the pit. Abandonment bund scenarios will be discussed for each mining area.

The mesa landform and mining method for Robe Valley deposits presents a relatively unique circumstance in regards to requirements for abandonments bunds. The retention of the breakaway landform around the edge of the mesa as a façade up to 20m in height, after mining out the central portion of the mesa, provides an effective barrier to inadvertent access to the pit. Where the façade does not provide an effective barrier to pit access, an abandonment bund is warranted. Consultation with the DMP has commenced on this, including members of the Environment and Safety Divisions.

The nearby Mesa A deposit at the Mesa A Hub provides a precedent of a pragmatic approach to abandonment bunds that is proposed to be adopted at the Mesa J Hub. Mesa A has a steep mesa face to the east, that gradually reduces in elevation to the west to the same height as the surrounding plain. An abandonment bund design for Mesa A was approved under an *Environmental Protection Act* Section 45C approval, and by the District Inspector DMP. Vehicle access to the pit was considered unlikely where the façade was retained at the western end of the mesa, due to the steep terrain. Therefore no abandonment bund is required where the mesa façade is retained. An abandonment bund was required around the flat eastern extent of the deposit, joining to the mesa façade to the west. The abandonment bund has been constructed and the majority of it is already in place. A bund to block vehicular access points onto the mesa is also required.

The majority of the Mesa H pit perimeter will be contained within a steep mesa façade, and no abandonment bund is currently proposed where this façade provides an effective barrier to vehicular access. The south east of the deposit is not bordered by a mesa landform, and will require an abandonment bund. The project will have a conceptual abandonment bund design completed at feasibility stage. During the approvals process for this area, mining exclusion zones may be amended, therefore a bund location design cannot be completed at this time.

Following initial consultation of the project with DMP officers, the company has a project proposed during 2017 to incorporate abandonment bund requirements for new pits and deposits into the required project outputs. Mesa H is likely to be one of the first sites to complete this process during 2017 and should enable a bund design that can be implemented during construction.

The Mesa J and K mining areas do not currently have abandonment bunds in place. An action in the closure task register for the site is to develop these designs with a view to include them in the next update to the closure plan. Specifics of Abandonment bund locations will be discussed with the DMP Environment and Safety Divisions as appropriate.

18.7 Management of dewatering impacts

Dewatering of below water table pits and abstraction at borefields creates a cone of depression in the water table which, depending on geological and hydraulic boundaries, can extend up to several kilometres beyond the area dewatered. This can reduce the amount of groundwater available for any groundwater dependent vegetation and local permanent pools, and therefore efforts are made to reduce the zone of this impact as much as practical.

At Jimmawurrada Creek, the cumulative drawdown along the creek during operations as a result of the Mesa J dewatering, abstraction from the Southern Cutback borefield and the adjacent Coastal Water Project is proposed to be reduced by the implementation of a thickener plant, which will reduce the water demand by approximately 35% and therefore reduce the overall time for the groundwater to recover.

Although poorer water quality may affect the riparian vegetation, terrestrial, subterranean and aquatic fauna around the permanent pools in the Robe River, groundwater abstraction from the CID and basement aquifers has been consistently of fresh quality with chloride concentrations lower than concentrations recorded in the down gradient pools; surplus water discharge monthly quality monitoring data also support this finding.

Semi-permanent and permanent pools exist along the Robe River and have high biodiversity and heritage value. As detailed in Section 11.2, Mesa H and Mesa J aquifers are a continuity of the same system, discharging to the Robe River alluvium aquifer to the north. Annual monitoring of Robe River pools and vegetation since 1993 has reported no measurable impact on the ecology of pools north of Mesa J due to mine-related dewatering. Supplemental discharge may potentially need to continue for a period of time after cessation of active mining at Mesa J Hub to support maintaining environmental and heritage values, this period is largerly dependent on climate. Once mining starts, the aquifer is further stressed and more data becomes avalibale the existing groundwater model will be continuously revised to assess the impacts of dewatering and determine appropriate mitigation requirements.

Groundwater is expected to recover to pre-mining water table levels once dewatering has ceased in the area. Modelling of ground water draw down and recovery timeframes will continue to be updated during the life of the project. Should any potential significant impact to the environmental or heritage values associated with the pools be predicted, mitigation strategies such as direct / optimised discharge to key pools, and avoiding mine pit dewatering below a 120m RL in pit 7 will be considered in consultation with stakeholders.

18.8 Management of surface water

Landforms need to consider the surrounding hydrology of the area, as landforms can have an impact in catchments both upstream and downstream of their location. Both situations need to be considered when conducting a hydrological study. Waste dumps and other landforms can act as a diversion or dam for upstream surface water, reducing flow to the downstream catchment. Likewise, these landforms can erode with surface water flow, destabilising the landform and impacting the downstream environment with sediment.

At the Mesa J Hub, waste dumps and other landforms are generally built outside the 1 in 100 AEP flood plain, consider material characterisation and often include surface water management structures such as diversions, bunds and surface water retention cells. There are, however, two historic waste dumps associated with Mesa K that are potentially constructed within the 1 in 100 AEP flood plain of the Robe River. Preliminary investigation shows that the waste dumps have survived a 1 in 20 to 1 in 50 AEP event in 2009 with minimal disturbance. Further hydrologic/hydraulic modelling and investigation will inform an appropriate closure strategy for these dumps.

Surface water diversions to the south of Mesa H and J pits are not intended to continue to function post-closure. Post-closure drainage will report to backfilled pits, which is likely to intercept 0.5% of the Robe River catchment area. Diversions may be deliberately breached at closure so that surface flows enhance recovery of the groundwater table; alternatively the diversions will likely be breached by large events post-closure that exceeds design criteria. Further assessment will be required to determine the optimal closure strategy for these diversions.

The impacts of the final landform design on surface drainage flows at a site level will require assessment prior to final closure planning

18.9 Management of threatened flora and fauna

As detailed in Section 12.7, there are two PEC's associated with troglofauna communities in mesa landforms of the Robe Valley. Impacts to troglofauna communities during mining of the Mesa J Hub are primarily managed via establishment of avoidance areas or mining exclusion zones. At Mesa K, several avoidance areas to preserve troglofauna habitat have been agreed with regulators as part of environmental assessment and approval. At Mesa J, MS 208 requires protection of the mesa façade adjacent to the Robe River north of the mine to protect heritage values, which will also protect significant fauna and troglofauna habitat. Mesa H pit designs have incorporated mining exclusion zones to protect heritage and biological values including retention of troglofauna habitat. The retention of the Mesa facades during operations will ensure that significant fauna and troglofauna habitat is retained in the final landform upon closure. Proposed mining exclusion zones are shown in Figure 26.

The Bungaroo stygofauna PEC community lies outside the scope of proposed mining operations, and any management of stygofauna will largely be completed during the operational phase.

18.10 Management of social surroundings

The mesa landforms have high cultural value to the K&M, particularly when viewed from within or near the Robe River. The facades also support important Matters of National Environmental Significance (MNES) species habitat and also serve to preserve intact troglofauna habitat. At Mesa J, MS 208 requires retention of the mesa façade adjacent to the Robe River north of the mine to protect environmental and heritage values. At Mesa H, the façades adjacent to the Robe River will also be retained to protect heritage values. Visual impact is a key consideration during waste dump design, generally waste dumps are similar height to the surrounding topography, with a focus on minimising the visual impact of any waste landforms when viewed from the Robe River.

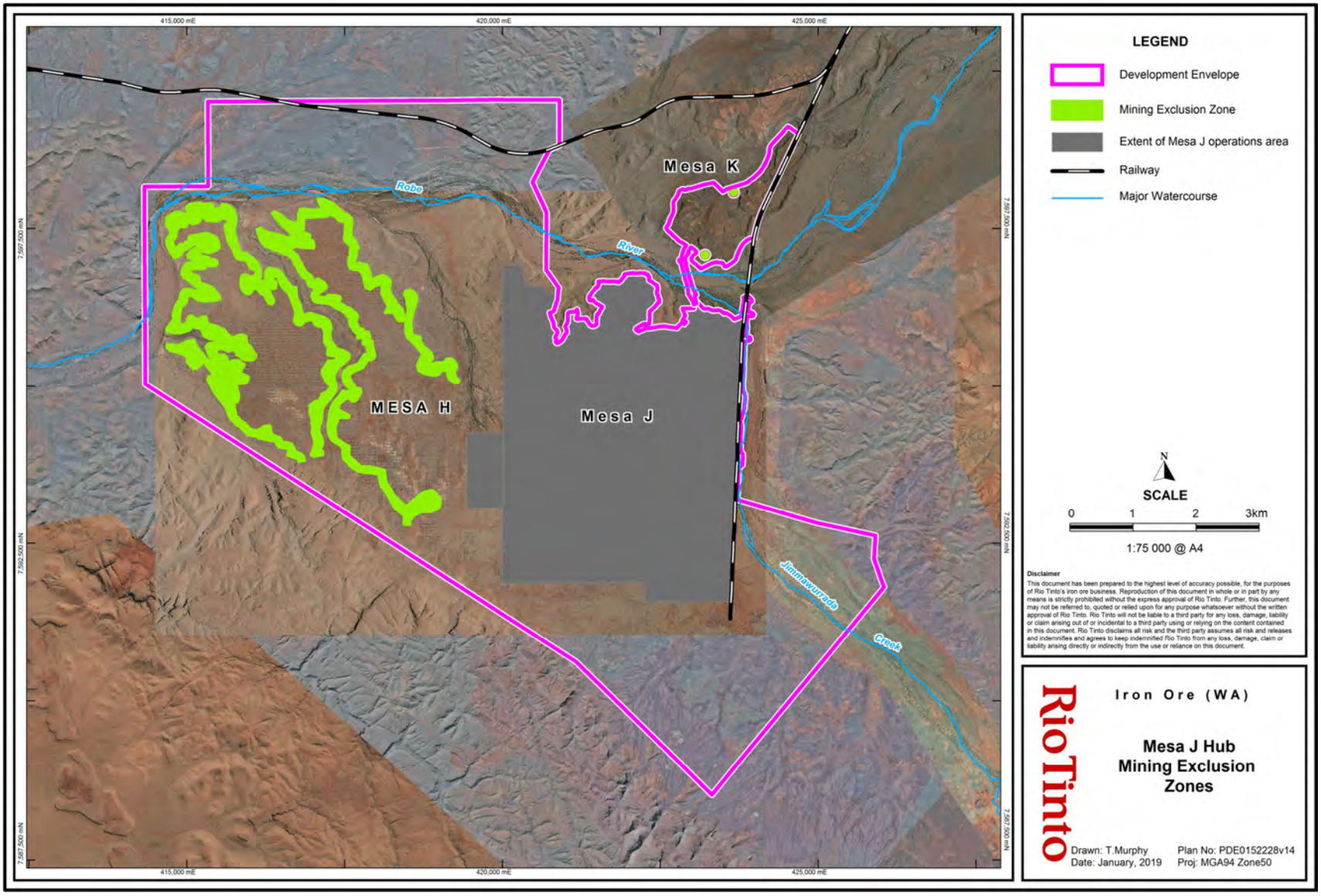


Figure 26: Mesa J Hub Mining Exclusion Zones

CLOSURE IMPLEMENTATION

Rio Tinto uses closure domains to group areas with common features, rehabilitation and decommissioning requirements at closure. Detailed closure strategies for the rehabilitation and decommissioning of individual closure domains, beyond those of current standard management practices, will be documented in the Mine Closure Plan to be prepared as the site approaches closure. The closure measures identified below consider the methods used to manage key risks as discussed in the previous section.

19. Closure Measures

Proposed closure measures for each of the closure domains are included in Table 20. The distribution of closure domains are illustrated in Figure 27. Designs and key criteria for all major landforms are included in Appendix F.

Table 20: Mesa J Hub general area implementation strategies by closure domain.

Domain class	Domains	Closure measures
Pits		
Above water table (AWT) pits	Mesa H Pit 9 Mesa J Pit 1 Mesa J Pit 2 Mesa J Pit 3 Mesa J Pit 4 Mesa J Pit 5 Mesa K Pit 1 Mesa K Pit 2 Mesa K Pit 3 Mesa K Pit 4 Mesa K Pit 5 Mesa K Pit 6	• Pits may be partially backfilled where possible to minimise the volume of waste in out of pit waste landforms. • Prior to final closure, appropriate evaluation and implementation of measures to restrict public access will be undertaken. • Rehabilitate final surface of pit floors in accordance with standard procedures (as per infrastructure areas) (Note. pit walls will remain).
Below water table pits (geochemical risk: low)	Mesa H Pit 1 Mesa H Pit 2 Mesa H Pit 3 Mesa H Pit 4 Mesa H Pit 5 Mesa H Pit 6 Mesa H Pit 7 Mesa H Pit 8 Mesa J Pit 6 Mesa J Pit 7 Mesa J Pit 8	• Undertake opportunistic backfill during operations and if required post-closure to prevent the formation of pit lakes in the final landform (excluding pit 15)[9]. • Rehabilitate final surface of pit floors in accordance with standard procedures (as per infrastructure areas) (Note. pit walls will remain). • Mesa J pit 15 will have an area partially left as a pit lake.

[9] Below water table pits (not differentiated in Figure 27 as each Pit is a section of the wider mining area) may not be backfilled uniformly across the entire surface. Sections of the pit may remain above water table during mining, and therefore not require backfill. All areas with a recovering water table at risk of forming a pit lake are backfilled (as indicated in orange)

Domain class	Domains	Closure measures
	Mesa J Pit 9	
	Mesa J Pit 10	
	Mesa J Pit 11	
	Mesa J Pit 12	
	Mesa J Pit 14	
	Mesa J Pit 15	
Waste dumps and stockpiles		
In-pit waste dumps (inert)	Mesa H Pit1 backfill Mesa H Pit2 backfill Mesa H Pit3 backfill Mesa H Pit4 backfill Mesa H Pit6/8 backfill Mesa H Pit9 backfill Mesa J Pit 11 inpit WD Mesa J P12 WD Mesa J P6 WD Mesa J P7/15 WD Mesa K Pit 1 backfill Mesa K Pit 2 backfill Mesa K Pit 3 backfill Mesa K Gravel Pit WD	• Reshaping outer slopes to appropriate angles/profiles based on design criteria suitable for waste type. • Rehabilitate final surface in accordance with standard procedures (as per infrastructure areas).
Free standing inert waste dumps	Mesa H NE Dump Mesa H SW Dump Mesa H SE Dump Mesa J Boondock WD Mesa K North WD Mesa K WD	• Where practicable, construct dumps in accordance with criteria outlined in Appendix F. • Reshaping outer slopes to appropriate angles/profiles based on design criteria suitable for waste type. • Application of subsoil/topsoil. • Rip and seed using appropriate native species.
Other domains		
Haul roads		• Push slopes at either side of the haul road to a maximum gradient of 20 degrees with berms at 10 metre intervals. • Install cross bunds where appropriate (at approximately 50m to intervals if the gradient of the reshaped road corridor is <10 degrees). • Rehabilitate final surface in accordance with standard procedures (as per inert waste dumps).
ROM pad	ROM pad	• Remove infrastructure. • Utilise earthen mound for pit backfill OR rehabilitate as a free standing inert waste dump.
Landfill	Landfill	• Cap landfill with a layer of inert material to a minimum thickness of 2 metres. • Rehabilitate final surface in accordance with standard procedures (as per infrastructure areas).

Domain class	Domains	Closure measures
Waste fines storage facility	Mesa J TSF 1 Mesa J TSF 3 Mesa J TSF 4 Mesa J TSF 5 Mesa J Pit7/14 TSF Mesa J Pit 8 TSF Mesa J Pit 9 TSF	• Cap waste fines storage facility with a layer of inert material to a minimum thickness of 2 metres. • Rehabilitate final surface in accordance with standard procedures (as per infrastructure areas). • TSF1 will remain uncapped.
Infrastructure areas	Plant Maintenance Buildings Roads Laydown Conveyors (etc.)	• Retain or remove infrastructure in accordance with State Agreement requirements. • Undertake contaminated sites evaluation and clean up if required. • Where infrastructure requires removal, remove all structures and footings that is above surface or within 1m of the final land surface. • Drain pipelines and remove hazardous materials (from pipelines and elsewhere across the site) in accordance with Controlled Waste Regulations. • Actively seek reuse and recycling opportunities for decommissioned infrastructure. • Dispose of inert materials are not retained, reused or recycled in an inert landfill area (may be a used pit area) and then cap with at least 2 metres of inert material. • Where linear infrastructure is removed, reinstate drainage lines where appropriate. • Rehabilitate final surface in accordance with standard procedures, which includes: o add a layer of topsoil where available and appropriate; o deep rip the surface where required to address compaction; o revegetate with an appropriate mix of native species.

20. Post-mining and post-closure landforms

The post mining landform is the landform that would be generated as a result of implementation of the mine plan assuming no progressive rehabilitation activities are conducted. A conceptual image of the post mining landform is shown in Figure 28 and Figure 30.

The post closure landform is the final expected landform at the completion of the closure measures outlined in Table 20 above. A conceptual image of this landform is shown in Figure 29, Figure 31 and Figure 32.

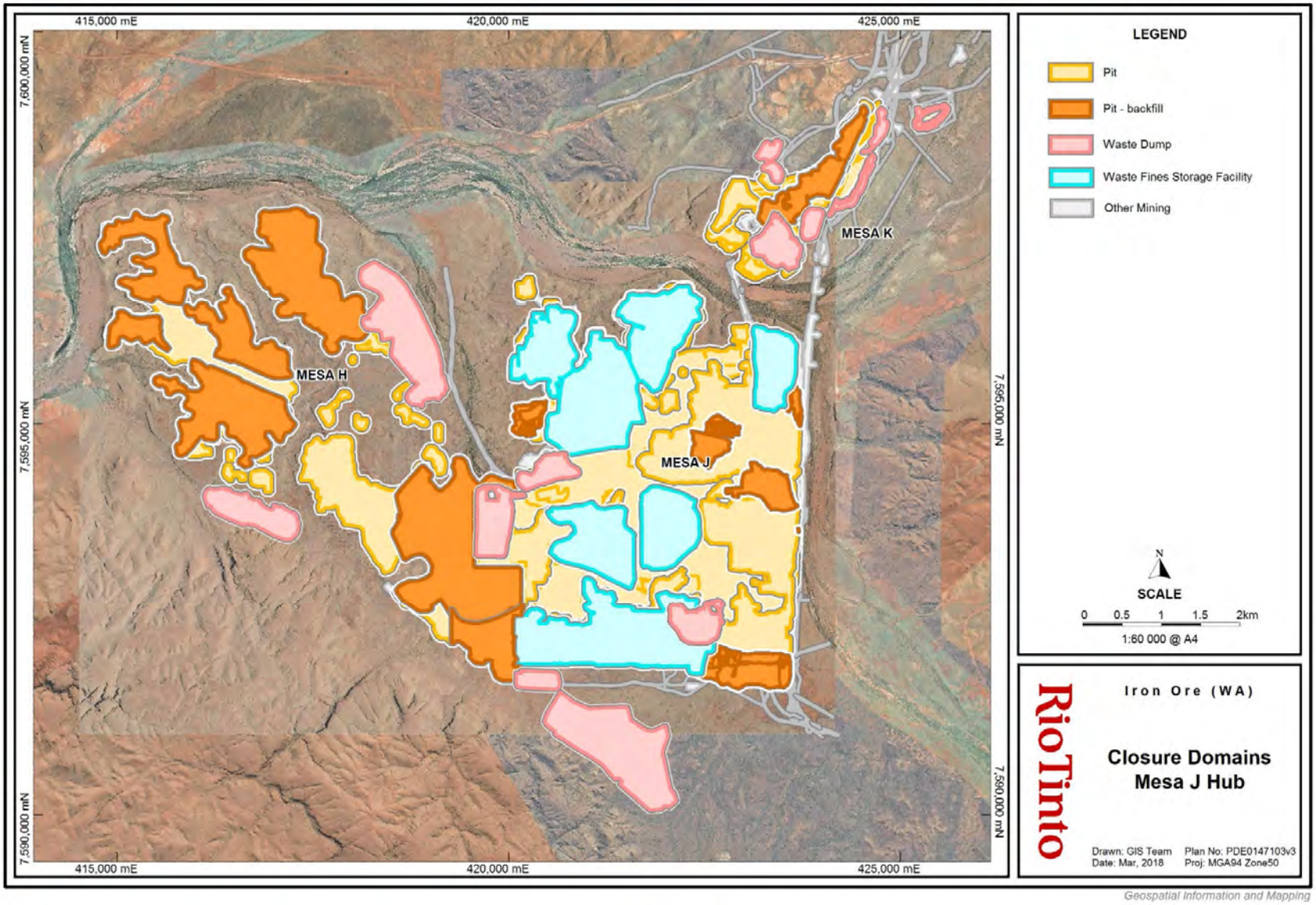


Figure 27: Closure Domains

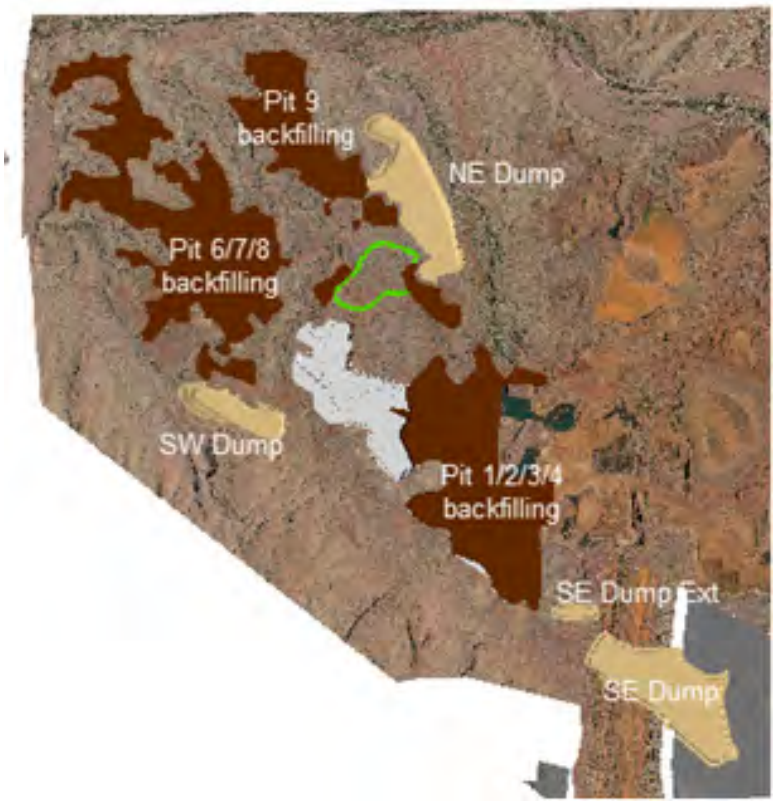


Figure 28: Mesa H post mining landform

Figure 29: Mesa H post closure landform

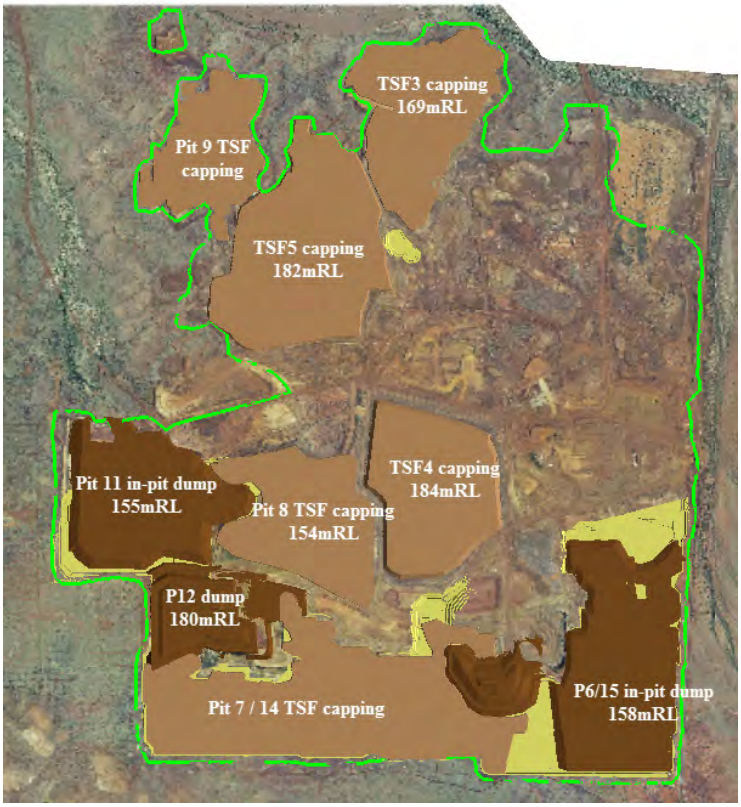


Figure 30: Mesa J post mining landform

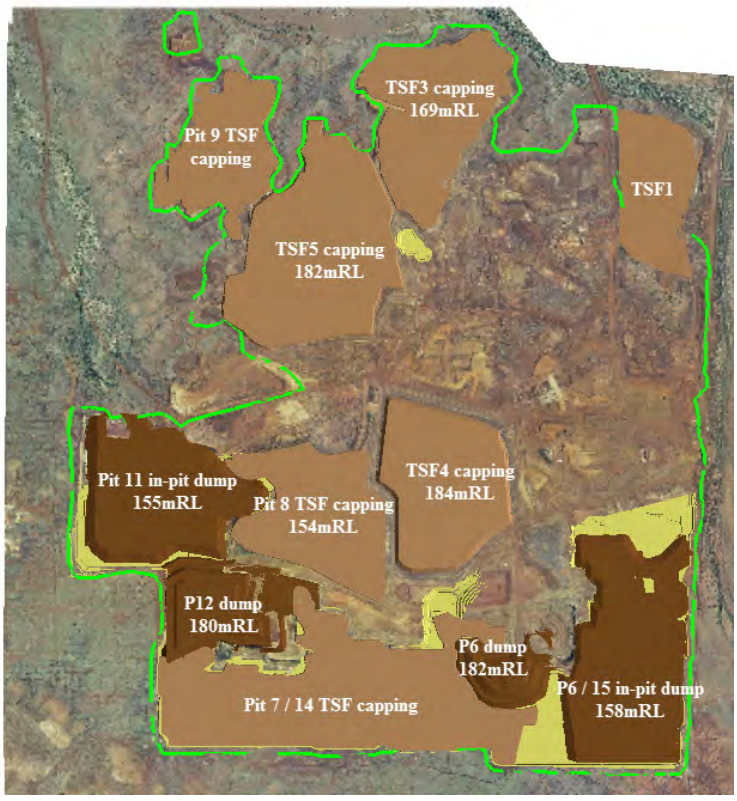


Figure 31: Mesa J post closure landform

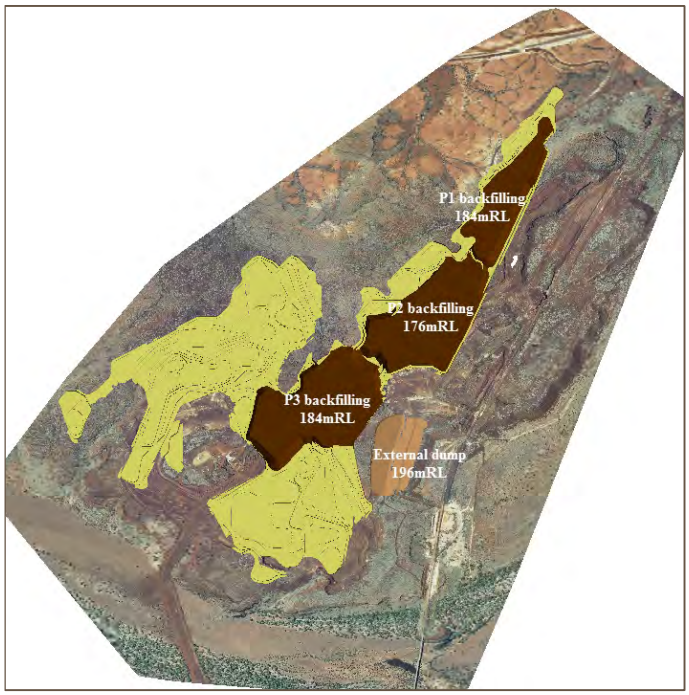


Figure 32: Mesa K post closure landform

21. Premature closure and other factors

The closure implementation schedule may be influenced by factors outside of the current mine plan. These factors include:

- suspension of operations under care and maintenance: this could occur if production costs exceed product value e.g. due to commodity price changes;
- unexpected closure: this could occur if there was major change in global demand for iron ore; and
- future proposals: there are multiple deposits in proximity to Mesa J that are likely to be developed in the future.

21.1 Care and maintenance

In the event of temporary closure, measures will be undertaken to transfer the site from operations into a care and maintenance regime and relevant authorities notified. A Care and Maintenance Plan would be developed prior to the care and maintenance period which demonstrates how on-going environmental obligations associated with the site will continue to be met during the period of care and maintenance. Social obligations and responsibilities will also be addressed in this plan.

21.2 Unexpected closure

Whilst the Company considers the risk of unexpected closure to be minimal, there are numerous factors that could force early closure of one or several sites. Even if some level of contraction were to occur, it is reasonable to assume that the Robe JV would continue to operate in the Pilbara and that it could continue to manage closure of its sites. It should be noted that the Company is one group within the global Rio Tinto group of companies, which further mitigates this risk.

In the event of unplanned or sudden closure, the Company will notify all relevant authorities including the DMP. The existing closure plan for the site would then be revised and a Decommissioning Plan prepared and submitted to the DMP and other relevant authorities within three months of notification of closure. The Decommissioning Plan will include undertaking detailed consultation with stakeholders. Once the plan is approved by the relevant authorities, work will commence on closure implementation activities.

21.3 Future proposals

The Robe JV hold mineral leases pursuant to the Agreement Act over multiple undeveloped deposits in the Robe Valley. Development of several of these deposits will potentially require continued utilisation of the Mesa J Hub infrastructure after completion of mining at the Mesa J, K and H deposits. These future developments are excluded from the scope of this current Mesa J Hub closure plan, but will be included in future closure plan updates with improved certainty of the specifics of these developments.

CLOSURE MONITORING AND MAINTENANCE

22. Closure monitoring program

The primary purpose of closure monitoring is to assess whether closure criteria have been met for the Mesa J Hub. A specific monitoring program will be finalised as the site approaches closure, and this current plan outlines the principles that will be employed rather than specific details.

22.1 Phases of monitoring

For the purposes of this plan, monitoring is assumed to be conducted in several phases including:

- Baseline monitoring, which is conducted as operations expand into new mining areas. Results that are relevant to closure are summarised in the environment knowledge base;
- Operational monitoring, which occurs throughout the life of the mine, in line with regulatory requirements and the Rio Tinto operational standards. Results that are relevant to closure are incorporated in the environment knowledge base when it is reviewed;
- Pre-closure monitoring, which occurs as the site approaches closure to underpin assessment of post-closure performance;
- Closure monitoring, which is conducted during the period of active site closure (approximately two years following the cessation of mining); and
- Post-closure monitoring, which is conducted on a regular basis until either:
  - There is a demonstration that closure objectives have been met and that the site is able to be relinquished; or
  - Parameters being monitored reach a steady state.

This plan considers pre-closure, closure and post-closure monitoring.

22.2 Indicative monitoring program

The monitoring program will be finalised during development of a Final Closure Plan as the site approaches closure. Specific and appropriate monitoring will be conducted to ensure data is obtained to allow assessment of performance against completion criteria (Section 8). The monitoring programme is likely to contain specific monitoring of the following key areas, as a minimum.

22.2.1 Rehabilitation monitoring

The purpose of the rehabilitation monitoring program is to evaluate successional development of rehabilitation areas and thereby provide useful feedback for the improvement of rehabilitation techniques, and to help assess progress towards long term rehabilitation objectives.

Rehabilitation monitoring also provides vital information which can be used to set realistic and achievable completion criteria. This can be achieved by examining changes in key parameters over time, and by comparing results from the rehabilitation with those from corresponding reference sites. Reference sites, also known as Controls or Analogues, are positioned within local areas of uncleared native vegetation.

Rehabilitation monitoring occurs on a scheduled basis, aimed at establishing trends for the locations return to self-sustaining status. The rehabilitation development is compared to the reference site values. Data analysis is undertaken to assess progress towards an acceptable outcome and a report produced to document findings.

22.2.2 Water monitoring

Water monitoring during closure will focus on confirming groundwater recovery and quality, and pit lake modelling predictions. A specific program of monitoring will be developed prior to decommissioning.

22.3 Heritage surveys

Heritage assessments are undertaken prior to closure to ascertain potential cultural heritage impacts of closure implementation, and inform the development of alternative strategies if required. Assessments are also undertaken post-closure to confirm that implementation has been undertaken in an appropriate manner.

23. Post-closure maintenance

Post closure, maintenance will continue as required until it is determined that the closure objectives have been met or it is otherwise agreed with Government to allow relinquishment of the site.

FINANCIAL PROVISION FOR CLOSURE

Rio Tinto considers specifics of the closure cost estimate to be commercially sensitive information. This section outlines the general process used to develop the closure cost estimate.

24. Principles of Rio Tinto closure cost estimation

Closure cost estimates are determined based on methods outlined in the Rio Tinto Closure Standard and the Rio Tinto Accounting Policy. Closure costs are considered in two formats:

- a Present Closure Obligation (PCO) which is indicative of costs associated with closure of the mine given its current footprint, this accounts for the progressive development of a site over time; and
- a Total Projected Closure (TPC) cost which predicts the cost (in current terms) associated with closure at the end of the life of the mine. The TPC includes areas that are not currently approved, but that feature within the life of mine plan and that are considered likely to be developed in the future.

The cost estimates consider the following components[10]:

- decommissioning (i.e. removal of infrastructure)[11];
- final landform construction;
- rehabilitation and biodiversity management;
- heritage management;
- workforce management (i.e. training costs and redundancy payments)[12];
- monitoring costs;
- costs associated with the development of a final closure plan;
- costs associated with undertaking a final shutdown of operations;
- allowance for failed rehabilitation or pollution that may necessitate rework of rehabilitation areas;
- assignment of indirect costs in accordance with Rio Tinto Accounting Policy; and
- a contingency factor.

25. Closure cost estimation methods

The closure cost estimation methodology is based on methods outlined in the Rio Tinto Closure Standard and Rio Tinto Accounting Policy, with the level of accuracy increasing as the site approaches closure[13]. The closure cost estimates are conducted based on the most recent information of mine plans and infrastructure. Closure costs estimate are generally undertaken by specialist external consultants. The PCO estimate for each site is revised on an annual basis to account for incremental mine development during the year. The TPC estimate is revised whenever a formal closure plan review is conducted to capture any changes to life of mine design. As part of Rio Tinto assurance processes these costs are audited by external financial auditors annually to ensure adequate closure provisions are maintained.

Note that for commercial reasons the actual estimate is not documented in this closure plan.

[10] Costs associated with decontamination are assessed during closure plan development but are costed separately as they are classified as operating costs, not closure costs.

[11] The decommissioning cost estimate assumes that infrastructure will be demolished and buried on site. The site is sufficiently remote that deconstruction for the purposes of materials salvage and recycling is likely to be cost prohibitive. However; opportunities for salvage and recycling will be sought as the site approaches closure.

[12] Workforce management costs have only been included in the TPC.

[13] The level of accuracy applied to Rio Tinto estimates is as follows:

- greater than 10 years from closure: ±30%;
- between 10 years and 5 years from closure: ±20%; and
- less than 5 years from closure: ±15%.

MANAGEMENT OF INFORMATION AND DATA

26. Data and information management

26.1 Iron Ore Document Management System (IODMS)

The Company operates a comprehensive document management system, with electronic records of all key information and data. The document system, known as Iron Ore Document Management System (IODMS) is linked to other business units within the Rio Tinto group of companies, and processes are in place to ensure that the data contained within this system is appropriately backed up and protected. Each document stored within this system is given a unique document number which identifies the document and enables it to be accessed. This system will continue to operate following site closure, and all relevant data will be retained according to appropriate data retention requirements.

An audit will be conducted prior to closure to ascertain whether there is any additional information stored in hard copy form at the site. Such data will be scanned and entered into IODMS to ensure that it is appropriately retained post-closure.

26.2 Closure knowledge base

The closure knowledge database is a knowledge management process designed to bring closure related research and monitoring outcomes together into one searchable location. It uses a single entry form to capture where the report is stored, and how and where the research can be applied for all new ongoing and completed closure related studies. This information is then managed by the Closure team within a secure database.

26.3 EnviroSys

EnviroSys is an environmental database that is used by Rio Tinto to manage environmental and hydrogeological data. The tool is used to store, monitor and analyse those parameters and report trends on data collections.

Data collected currently includes:

- groundwater – biological, chemical, field, levels, production;
- marine water – biological, chemical, field;
- soil chemistry;
- surface water – biological, chemical, field, levels, production;
- tonnes and moisture;
- rehabilitation;
- water meters; and
- weather (rainfall, temperatures etc.).

EnviroSys is used to support the building of closure knowledge bases, as well as ensure compliance with operating licenses pertaining to data management. At closure this data would be appropriately stored to allow for review of post closure completion criteria.

26.4 Legal and other requirements system

The Legal and Other Requirements System (LAORS) is used by the Company to manage the following:

- Approval and Legislation Reports which provide a high level snapshot of approvals and legislation and is used to check the status and expiry dates of approvals.
- Approval and Legislative Requirements Reports which lists
  - accountabilities for specific conditions within approvals and clauses within legislation;
  - required actions to comply with approvals and or legislation; and
  - due dates for specific requirements.
- Statutory Position Appointed Persons reports which list individuals appointed to a statutory position.
- Statutory Position Accountabilities Reports which identify clauses of legislation that the statutory position is accountable for.

This information is used to track legal requirements associated with closure and will be maintained during closure activities to ensure all requirements and obligations are met.

Appendix A – Register of key closure obligations

Ministerial Statement 208 (Mesa J Iron Ore Development)	
Condition No.	**Closure conditions**
4-1	Prior to construction at the site, the proponent shall prepare a Drainage Management Programme, to protect the Robe River - Jimmawurrada Creek system from the deleterious impacts of sedimentation and pollution from the project, to the satisfaction of the Minister for the Environment on advice of the Environmental Protection Authority, the Department of Conservation and Land Management and the Water Authority of Western Australia. The plan is to include but is not necessarily limited to: 1. a monitoring programme to detect impacts; 2. procedures for protecting the ecology of the system; 3. procedures for reporting on the programme; and 4. a commitment to ameliorate environmental impacts to the satisfaction of the Environmental Protection Authority if impacts are detected which are deemed unacceptable by the Environmental Protection Authority.
4-2	Subsequent to condition 4-1, the proponent shall implement the approved Drainage Management Programme to the satisfaction of the Environmental Projection Authority on advice of the Water Authority of Western Australia and the Department of Conservation and Land Management.
5-1	Prior to the commencement of dewatering, the proponent shall prepare a Dewatering Management Programme, to protect the Robe River - Jimmawurrada Creek system, to the satisfaction of the Environmental Protection Authority on advice of the Department of Conservation and Land Management and the Water Authority of Western Australia. The plan is to include but is not necessarily limited to: 1. a monitoring programme to detect impacts; 2. procedures for protecting the ecology and water quality of the permanent pools and associated vegetation; 3. procedures for reporting on the programme; and 4. a commitment to ameliorate environmental impacts to the satisfaction of the Environmental Protection Authority if impacts are detected which are deemed unacceptable by the Environmental Protection Authority.
5-2	Subsequent to condition 5-1, the proponent shall implement the approved Environmental Management Programme to the satisfaction of the Environmental Protection Authority on advice of the Water Authority of Western Australia and the Department of Conservation and: Land Management.
6-1	Within 12 months of the date of this statement, the proponent shall prepare a Rehabilitation Management Programme to the satisfaction of the Environmental Protection Authority on advice of the Department of Mines and the Department of Conservation and Land Management. The programme shall include but not necessarily be limited to: 1. proposals for rehabilitation of the project area; and 2. a monitoring programme to determine success of the rehabilitation. **CLOSED COMPLETE: Rehabilitation Management Plan satisfies this condition**
6-2	The initial programme shall be submitted to the Environmental Protection Authority, with subsequent programmes for the project to be updated annualy in conjunction with reporting requirements under the Iron Ore (Robe River) Agreement Act.
6-3	At least twelve months prior to the decommissioning, the proponent shall prepare a plan for decommissioning and rehabilitating the site, to the satisfaction of the Environmental Protection Authority on advice of the Department of Mines and the Department of Conservation and Land Management.

Ministerial Statement 208 (Mesa J Iron Ore Development)	
6-4	Subsequent to conditions 6-1 and 6-3, the proponent shall implement the approved programmes for rehabilitating and decommissioning the site, to the satisfaction of the Environmental Protection Authority on advice of the Department of Mines and the Department of Conservation and Land Management.
Commitment No.	**Closure commitments**
Commitment 6	The proponent will implement landform stabilization and revegetation programs in the project area for the duration.
Commitment 11	At the completion of the project, the proponent will prepare the site for abandonment in accordance with the requirements of the Mines Department and in recognition of the requirements of the Iron Ore (Robe River) Agreement Act, 1964, including, as applicable: 1. Re-establishment of pre-existing drainage patterns as far as practicably achieved; 2. The initiation of stabilisation and revegetation activities to stabilise structures and communities; and, 3. The mining plan will be modified to incorporate the return of as much waste rock to the mined out pit as can be practically achieved during the life of the project.

Ministerial Statement 776 (Mesa K Remnant Mining Project)	
Condition No.	**Closure conditions**
7-1	The proponent shall implement the proposal to achieve stable, self-sustaining and functioning ecosystem(s) that is/are consistent with the surrounding landscape and maintain(s) key environmental values over the long-term and to the satisfaction of the CEO of the Department of Environment and Conservation.
Commitment No.	**Closure commitments**
Schedule 1 - Mine and Mining	Waste Rock Disposal: Initially directed to surface waste dumps and, thereafter, used in progressive backfilling of mine pits as far as practicable

Iron Ore (Robe River) Agreement Act 1964	
Clause No.	**Closure obligations**
Schedule 1 10 e)	on the cessation or determination of any lease license or easement granted hereunder by the State to the Company or (except as otherwise agreed by the Minister) to an associated company or other assignee of the Company under clause 13 hereof of land for the plant site or the Company's wharf for any installation within the harbour for the Company's railway or for housing at the port or port townsite the improvements and things erected on the relevant land and provided for in connection therewith other than plant and equipment shall remain or become the absolute property of the State without compensation and freed and discharged from all mortgages and encumbrances and the Company will do and execute such documents and things (including surrenders) as the State may reasonably require to give effect to this provision. In the event of the Company immediately prior to such expiration or determination or subsequent thereto deciding to remove its locomotives rolling stock plant and equipment or any of them from any land it shall not do so without first notifying the State in writing of its decision and thereby granting to the State the right or option exercisable within three months thereafter to purchase at valuation in situ the said plant and equipment or any of them. Such valuation shall be mutually agreed or in default of agreement shall be made by such competent valuer as the parties may appoint or failing agreement as to such appointment then by two competent valuers one to be appointed by each party or by an umpire appointed by such valuers should they fail to agree;

Mining Act 1978	
Tenement No. AML70/00248 (ML248SA)	
Condition No.	**Closure conditions**
n/a	No conditions relevant to closure

Permit No. CPS4397	
Condition No.	**Closure conditions**
13	Retain vegetative material and topsoil, revegetation and rehabilitation The Permit Holder shall: (a) retain the vegetative material and topsoil removed by clearing authorised under this Permit and stockpile the vegetative material and topsoil in an area that has already been cleared; (b) within 12 months following clearing authorised under this Permit, revegetate and rehabilitate the area(s) that are no longer required for the purpose for which they were cleared under this Permit by: i) re-shaping the surface of the land so that it is consistent with the surrounding 5 metres of uncleared land; ii) ripping the ground on the contour to remove soil compaction; and iii) laying the vegetative material and topsoil retained under Condition 13(a) on the cleared area; (c) within 4 years of laying vegetative material and topsoil on the cleared area in accordance with Condition 13(b) of this Permit: i) engage an enviromnental specialist to determine the species composition, structure and density of the area revegetated and rehabilitated; and ii) where, in the opinion of an enviromnental specialist, the composition structure and density determined under Condition 13(c) (i) of this Permit will not result in a similar species composition, structure and density to that of pre-clearing vegetation types in that area, revegetate the area by deliberately planting and/or direct seeding native vegetation that will result in a similar species composition, structure and density of native vegetation to pre-clearing vegetation types in that area and ensuring only local provenance seeds and propagating material are used.
Permit No. CPS4442	
Condition No.	**Closure conditions**
12	Retain vegetative material and topsoil, revegetation and rehabilitation The Permit Holder shall: (a) retain the vegetative material and topsoil removed by clearing authorised under this Permit and stockpile the vegetative material and topsoil in an area that has already been cleared; (b) at an optimal time within 12 months following completion of works authorised under this Permit, revegetate and rehabilitate the area(s) that are no longer required for the purpose for which they were cleared under this Permit by: i) re-shaping the surface of the land so that it is consistent with the surrounding 5 metres of uncleared land; ii) ripping the ground on the contour to remove soil compaction; and iii) laying the vegetative material and topsoil retained under Condition 12(a) on the cleared area; (c) within 24 months of laying vegetative material and topsoil on the cleared area in accordance with Condition 12(b) of this Permit: i) engage an enviromnental specialist to determine the species composition, structure and density of the area revegetated and rehabilitated; and ii) where, in the opinion of an enviromnental specialist, the composition structure and density determined under Condition 12(c) (i) of this Permit will not result in a similar species composition, structure and density to that of pre-clearing vegetation types in that area, revegetate the area by deliberately planting and/or direct seeding native vegetation that will result in a similar species composition, structure and density of native vegetation to pre-clearing vegetation types in that area and ensuring only local provenance seeds and propagating material are used.

Permit No. CPS4598

Condition No.	Closure conditions
7	Retain vegetative material and topsoil, revegetation and rehabilitation The Permit Holder shall: (a) retain the vegetative material and topsoil removed by clearing authorised under this Permit and stockpile the vegetative material and topsoil in an area that has already been cleared; (b) within 12 months following completion of works authorised under this Permit, revegetate and rehabilitate the area(s) that are no longer required for the purpose for which they were cleared under this Permit by: i) re-shaping the surface of the land so that it is consistent with the surrounding 5 metres of uncleared land; ii) ripping the ground on the contour to remove soil compaction; and iii) laying the vegetative material and topsoil retained under Condition 7(a) on the cleared area; (c) within 4 years of laying vegetative material and topsoil on the cleared area in accordance with Condition 7(b) of this Permit: i) engage an enviromnental specialist to determine the species composition, structure and density of the area revegetated and rehabilitated; and ii) where, in the opinion of an enviromnental specialist, the composition structure and density determined under Condition 7(c) (i) of this Permit will not result in a similar species composition, structure and density to that of pre-clearing vegetation types in that area, revegetate the area by deliberately planting and/or direct seeding native vegetation that will result in a similar species composition, structure and density of native vegetation to pre-clearing vegetation types in that area and ensuring only local provenance seeds and propagating material are used.

Relevant Legislation

Closure planning and implementation requires consideration of general legislative requirements beyond those that apply to a specific site. A list of potentially relevant legislation is provided below, but is not necessarily exhaustive. A comprehensive legal review will be required as closure approaches to ensure that all relevant legislative requirements are identified.

Australian Commonwealth Legislation	**Western Australian State Legislation**
Environmental Protection and Biodiversity Conservation Act 1999	*Environmental Protection Act 1986*
Native Title Act 1993	*Environmental Protection Regulations 1987*
Aboriginal and Torres Strait Islander Heritage Protection Act 1984	*Environmental Protection (Controlled Waste) Regulations 2004*
Workplace Relations Act 1996	*Environmental Protection (Unauthorised Discharges) Regulations 2004*
	Contaminated Sites Act 2003
	Contaminated Sites Regulations 2006
	Conservation and Land Management Act 1984
	Mining Act 1978
	Mining Regulations 1981
	Parks and Reserves Act 1895
	Rights in Water and Irrigation Act 1914
	Wildlife Conservation Act 1950
	Aboriginal Heritage Act 1972
	Aboriginal Affairs Planning Authority Act 1972
	Mines Safety and Inspection Act 1994
	Mines Safety and Inspection Regulations 1995
	Occupiers Liability Act 1985
	Criminal Code Compilation Act 1913

Relevant Guidelines and Standards

Closure planning and implementation requires consideration of relevant guidelines and standards, some of which may have regulatory consequence through being referenced in regulatory documents. A list of key guidelines and standards that are routinely considered is provided below, but is not exhaustive due to the breadth of the closure planning discipline. This closure plan has been prepared so as to be considered with relevant content of these guidelines and standards.

Guideline or Standard	**Author**
Guidelines for the Preparation of Mine Closure Plans (2015)	Western Australian Department of Mines and Petroleum and Environmental Protection Authority
Mine Closure: Leading Practice Sustainable Development Program for the Mining Industry (2016)	Commonwealth Department of Industry, Innovation and Science
Mine Rehabilitation Handbook (1998)	Minerals Council of Australia
Guideline for the Assessment of Environmental Factors: Rehabilitation of Terrestrial Ecosystems (2006)	Western Australian Environmental Protection Authority
Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2000)	Agriculture and Resource Management Council of Australia and New Zealand and the Australian and New Zealand Environment and Conservation Council
Mine Void Water Resource Issues in Western Australia (2003)	Western Australian Water and Rivers Commission
Contaminated Sites guideline series	Western Australian Department of Environment Regulation
Environmental Notes on Mining: Acid Mine Drainage (2009)	Western Australian Department of Mines and Petroleum
Environmental Notes on Mining: Waste Rock Dumps (2009)	Western Australian Department of Mines and Petroleum
Safety Bund Walls Around Abandoned Open Pit Mines (1997)	Western Australian Department of Industry and Resources
Global Acid Rock Drainage Guide (2014)	International Network for Acid Prevention
Australian Standard 2601: The Demolition of Structures (2001)	Standards Australia
Australian Standard 4976: The Removal of Underground Petroleum Storage Tanks (2008)	Standards Australia
Demolition Work Code of Practice (2015)	Safe Work Australia

Appendix B – Communications Register

Consultation Stage	Stakeholder	Date	Subject	Summary of discussion relevant to closure	Response
Referral	Environmental Protection Authority Service Unit	1991	Robe referral to EPA	Formal referral of the Mesa J Iron Ore development, Pannawonica under Clause 7A of the Iron Ore (Robe River) Agreement	
Ministerial Statement	Environmental Protection Authority Service Unit	1992	Acceptance of MS208	Formal acceptance of all conditions on Ministerial Statement 208.	
Operations	Environmental Protection Authority Service Unit	2005	Extension of Mesa J Pit Area-Section 45C	CALM: The proposal to retain the pit extension area as a deep water pit and not backfill it to groundwater level is no longer acceptable to CALM. The Ministerial approval for the original Mesa J mine was over 13 years ago, and is no longer consistent with current best practice environmental management, which is to ensure that mine pits are backfilled to the water table in order to mitigate any adverse water quality issues. Given that this is a new development, Pilbara Iron should improve its standards for environmental management and mine closure and decommissioning in order to comply with what is acceptable best practice today.	The material from the pit extension area will be used to backfill other parts of the pit. As stated in the original approvals documents for Mesa J, there will be insufficient material available to backfill all pits to above water table level. Robe is currently preparing a closure plan for the Mesa J mine site, with the aim to backfill as many pits as practicable at Mesa J to above water table level. Calculations to determine the amount of material which will be available for backfilling pits are currently underway and a study will be commissioned to model impacts of the proposed final landform on water quality. Under Conditions 6-3 and 6-4 of Ministerial Statement 208, Robe is required to prepare and implement a decommissioning and rehabilitation plan to the satisfaction of the Environmental Protection Authority on advice of DolR and CALM.
Ministerial Statement	Office of the Environmental Protection Authority	2005	Change to MS208	Pit extension and boundary update	Section 45C
Ministerial Statement	Office of the Environmental Protection Authority	2006	Change to MS208	New rail siding at Green Pool	Section 45C
Ministerial Statement	Office of the Environmental Protection Authority	2007	Change to MS208	Installation of fibre optic cable for railway communications system from the Cape Lambert administration offices to the 5km peg and from the 71km peg to the Mesa J mine operations at Pannawonica	Section 45C
Referral	Environmental Protection Authority Service Unit	2007	Robe referral to EPA	Formal referral of the Mesa K Remnant Mining Projecton Ore Mine under Section 38 of the EP Act.	
PER	Environmental Protection Authority Service Unit	2008	Bulletin 1283 - Initial EPA assessment of Environmental Impact Assessment	The EPA acknowledges that the proponent has committed to finalising the PRP included with the EPS and implementing the PRP prior to commencement of productive mining. Mesa K and the PRP will be incorporated into the Greater Pannawonica Closure Study prior to completion of mining at Mesa K. The EPA notes the relatively short project life of the Mesa K Remnant Mining proposal of 2 – 3 years. The PRP includes rehabilitation strategies designed to contribute to maintenance free closure over the long term. The EPA supports the objective of the PRP to ensure mine rehabilitation and closure planning commences in the early stages of project planning and is integrated with mine development planning and operations. The PRP includes a schedule for timing of closure, rehabilitation and monitoring. The PRP will be regularly reviewed during site operations to ensure it remains accurate and relevant.	
Ministerial Statement	Office of the Environmental Protection Authority	2009	Acceptance of the PRP to satisfy Condition 7-1 of MS776	As per our discussion, there is no formal requirement in Ministerial Statement 000776 for the EPA to sign off on the management plans prepared for the Mesa K proposal. The EPA Board were provided with copies of the draft management plans in its consideration of the Mesa K proposal and acknowledged in Bulletin 1283 that Robe were committed to finalising the management plans prior to commencement of productive mining, and specifically that the PRP will be incorporated into the Greater Pannawonica Closure Study prior to completion of mining at Mesa K.	
Operations	Department of Mines & Petroleum	2009	Mesa J Inspection 2008	Several erosion qullies were observed on the north face of T Dump and they should be monitored and mitigation measures implemented if they are observed to grow over time or effect the stability of the dump. The eastern end of the dump had yet to be rehabilitated and this area should be closed out as soon as possible to prevent erosion and/or weeds on the eastern end spreading to the rehabilitated areas. The south side of T dump has limited revegetation and significant erosion problems. It is likely that this side of the dump will have to be reworked to meet closure criteria.	Rehabilitation monitoring on the T dump is scheduled for June 2009 and will include an erosion assessment. Mitigation measures will be implemented if the monitoring demonstrates unacceptable stability of the landform. The eastern end of the T dump was not included in the original rehabilitation design due to the proximity of the dump to the rail line. An assessment of rehabilitation design which can be completed whilst the rail is operational will be assessed prior to the end of 2009. Regular weed inspections will be carried out and management programs implemented if an outbreak is recorded.

Consultation Stage	Stakeholder	Date	Subject	Summary of discussion relevant to closure	Response
Operations	Department of State Development	2010	Response to State Agreement reports 2009	No significant comments. DMP Comments: Areas displaying Improvements: • The establishment of reference sites to be used for the development of conceptual completion criteria at operating sites • The commencement of a 5 year seed science programme • Corrective actions requested as part of the 2008 DMP inspection have been completed or progressed Areas deficient in information I area of concern at several sites: • Limited progressive rehabilitation was noted • Although there was an improvement from the previous AER, for most sites there was limited information on rehabilitation monitoring results • Limited detail of erosion monitoring results	Positive aspects noted. • For concerns regarding limited progressive rehabilitation, a rehabilitation and closure team has been formed and is working to improve our planning and implementation of progressive rehabilitation projects. • Whilst there may not of been earthworks conducted at an individual site, a large proportion of works are involved in the planning stage for rehabilitation, including making improvements to historic designs, haulage of clean inert waste fill to enable future rehabilitation projects and a range of research and development activities to inform and guide future rehabilitation programs. • RTIO operations will not be able to demonstrate rehabilitation works being conducted at every site every year, due to the large and long time frames in which our operational areas remain active. • Identification and scheduling of areas available for rehabilitation across our operations are conducted over a 5 year time frame. This 5 year plan is updated through the 5 year mine planning and quarterly mine planning processes.
Operations	Department of State Development	2011	Response to State Agreement reports 2010	No significant comments. DMP Comments: A number of areas of improvement were noted across the RTIO sites. These include: • The Land Data Improvement Project continued during 2010, aiming to improve assessment and monitoring of disturbance footprints and rehabilitation areas; • Investigation of pit lake bioremediation options in conjunction with Edith Cowan University. • The commencement of investigations into alternative growth mediums. The concerns include: • RTIO are not planning to develop completion criteria for the closure of sites during the early stages of project development. The DMP encourages completion criteria to be developed during the early stages of the project because it sets a goal for the rehabilitation of the site and ensures closure is considered during the construction and operational phases of the project. It is acknowledged however, that during the early stages of project development the criteria can be quite conceptual and be further developed and refined as the project progresses. • Progressive rehabilitation is being carried out at some sites, with plans for future rehabilitation works noted. However a greater commitment to progressive rehabilitation should be achievable across most sites. It should be noted that progressive rehabilitation not only involves achieving actual rehabilitation on the ground but also includes researching knowledge gaps which may include setting up rehabilitation trials, gaining a better understanding of material characterisation etc.	RTIO agrees that completion criteria need to be developed and agreed prior to closure implementation (including progressive rehabilitation undertaken during the course of operations), but considers that any criteria drafted early in the development of a long-life mine need to be considered indicative only. RTIO is currently undergoing a project to develop criteria to measure the success of progressive rehabilitation, the status of which was included in the overview section of the report. RTIO has included indicative completion criteria in closure plans submitted to Government since publication of the new closure plan reporting guidelines, and will continue to do so. Over the past 3 years RTIO has increased the amount of rehabilitation planning, earthworks and research and development projects considerably. Areas available for progressive rehabilitation are identified for the RTIO business and scheduled as part of mine planning and business planning processes. The RTIO approach for sign off on rehabilitation areas ensures a reduction in the areas of rehabilitation being re-disturbed. This planned approach means that only areas that are scheduled for closure will undergo rehabilitation, thus not all sites will have rehabilitation occurring every year. RTIO is also planning on the achievement of quality hectares of rehabilitation rather than achieving hectares which may require rework in future. The RTIO closure planning and rehabilitation efforts and procedures are being informed by the learning's from our rehabilitation.
Operations	Department of State Development	2011	Response to State Agreement reports 2010	DMP Comments: The closure plan for the site dates back to 2005, with the next review not scheduled until 2012. As a guide, the DMP's new guidelines for Mine Closure Plans require a review every 3 years.	A decision was taken in 2010 to review the remaining reserves to inform the next closure plan. This work is in progress, and thus the timing for the closure plan has been delayed to ensure the correct data is utilised. The mine Mesa J/K operations do not have a requirement for a 3 year update schedule in their approvals.
Operations	Office of the Environmental Protection Authority	2012	Annual Audit Compliance Report 2011		Condition 6-1: Review of the Mesa J Environmental Management Programme including the rehabilitation management plan was conducted in 2011. At this time the Mesa J and Mesa K Environmental Management Programmes have been integrated. The Mesa JK integrated environmental management plan [RTIO-HSE-0013059] was submitted to the OEPA on the 29 October 2011 [RTIO-HSE-0127414].
Operations	Office of the Environmental Protection Authority	2012	Annual Audit Compliance Report 2011		Condition 7-1: Mesa K Preliminary Rehabilitation Plan [RTIO-HSE-0044852] was submitted to EPA on 14 January 2009 for formal sign-off following acceptance by DEC Environmental Management Branch [RTIO-HSE-0058967].

Consultation Stage	Stakeholder	Date	Subject	Summary of discussion relevant to closure	Response
Operations	Department of Mines & Petroleum	2012	Robe Valley Inspection 2012	Much of the rehabilitation on these dumps is progressing well. Investigation of some sections where vegetation has not established may be required. In the event that these dumps are removed to allow for mining, make sure that the topsoil and vegetation is pre-stripped from the rehabilitated areas. Rehabilitation of the Pit 7 Dump has been largely unsuccessful. Remedial work will be required. Despite the failings of this dump, any knowledge gained from this trial would assist in future waste dump designs.	
Ministerial Statement	Office of the Environmental Protection Authority	2013	Acceptance of the OEMP to satisfy Condition 6-1 of MS208 and 7-1 of MS776	The revised Plan has been reviewed by the OEPA and is considered to address the relevant implementation conditions above, relating to the Environmental Management Plan (MS 208) and the protection of troglofauna (MS776).	
Ministerial Statement	Office of the Environmental Protection Authority	2013	Change to MS776	Increase in disturbance footprint and removal of mine life	Section 45C
Operations	Office of the Environmental Protection Authority	2013	Annual Audit Compliance Report 2012		Condition 6-1: The Rehabilitation Management Plan for Mesa J and Nearby Mesas, Deepdale Area was submitted in November 1993 [RTIO-HSE-0043199]. This completed this preconstruction requirement. Refer below for on-going requirements.
Operations	Office of the Environmental Protection Authority	2013	Annual Audit Compliance Report 2012		Condition 7-1: Mesa K Preliminary Rehabilitation Plan [RTIO-HSE-0044852] was submitted to EPA on 14 January 2009 for formal sign-off following acceptance by DEC Environmental Management Branch [RTIO-HSE-0058967]. No rehabilitation was conducted at the Mesa K mine site during 2012. However work toward progressive rehabilitation and closure continued with the backfill of waste rock into Gravel Pit.
Operations	Department of State Development	2014	Response to State Agreement reports 2012	No significant comments. DMP Comments: DMP is very supportive of the proposed and existing research projects, including the seed provenance study, and request that updates and results relating to these projects are included in future TERs.	Noted
Closure Management	Office of the Environmental Protection Authority	2014	General correspondence from the OEPA regarding a joint BHP Billiton and Rio Tinto rehabilitation presentation	Correspondence from OEPA commending BHP Billiton and Rio Tinto on their joint presentation on rehabilitation success in the Pilbara. In its letter OEPA recognised that mine closure and rehabilitation is an important strategic issue and recognised the significant challenges remaining in this area. The OEPA referred to the Department of Mines and Petroleum/EAP Joint Mine Closure Guidelines as the primary document guiding mine closure and rehabilitation across all land tenures and sought written confirmation from both companies that they would abide by any contemporary version of the guidelines, irrespective of what the current Ministerial Statement conditions required in regard to closure and rehabilitation, or similarly what State Agreement Act conditions require on the same matter. OEPA indicated its desire to discuss the updating of existing Ministerial Statements to ensure they are contemporary with respect to mine closure and rehabilitation with both parties in future.	Rio Tinto acknowledged the feedback form OEPA and indicated it looked forward to continued involvement with government and industry partners in developing sustainable, long term improvements for rehabilitation and closure in Western Australia. In response to the request for mine closure plans to conform to the contemporary version of the Department of Mines and Petroleum/EAP Joint Mine Closure Guidelines, it is noted that Rio Tinto iron ore closure plans drafted to support new proposals are prepared in accordance with the Guidelines. These plans are prepared in consultation with the Department of Mines and Petroleum and other key stakeholders. To date eight closure plans have been prepared in accordance with the Guidelines and submitted to Government. Rio Tinto iron ore will continue with this process going forward. For existing Ministerial Statements, closure planning is undertaken in accordance with approval conditions and Rio Tinto standards. Of particular note, compliance to the Rio Tinto standard is required irrespective of what the current Ministerial Statement conditions and State Agreement requirements are on this matter. Rio Tinto's standards require the preparation of closure plans for each aspect of an iron ore operation, and plans are revised at a frequency that is appropriate to the life and scale of the operations, and take into consideration the objectives and intended outcomes of the contemporary Guideline. We will continue our closure planning in accordance with our approval conditions, and Rio Tinto standards. This process will ensure that our plans are progressively updated to align with contemporary Guidelines. Rio Tinto iron ore considers this a practical approach which is consistent with requirements for closure planning in Western Australia. (Our reference: RTIO-HSE-0229340).

Consultation Stage	Stakeholder	Date	Subject	Summary of discussion relevant to closure	Response
Operations	Office of the Environmental Protection Authority	2014	Annual Audit Compliance Report 2013		Condition 6-1: The Rehabilitation Management Plan for Mesa J and Nearby Mesas, Deepdale Area was submitted in November 1993 (Our ref: RTIO-HSE-0043199).
Operations	Office of the Environmental Protection Authority	2014	Annual Audit Compliance Report 2013		Condition 7-1: Mesa K Preliminary Rehabilitation Plan [Our ref: RTIO-HSE-0044852] was submitted to EPA 14 January 2009 for formal sign-off following acceptance by DEC Environmental Management Branch [Our ref: RTIO-HSE-0058967]. Note that a subsequent change to the Project approved by the OEPA through a section 45C application 25 February 2013 [Your ref: A579133: OEPA 2012/000541][Our ref: RTIO-HSE-0178454] changed the project life element. This change renders rehabilitation timeframes proposed in the Mesa K Preliminary Rehabilitation Plan [Our ref: RTIO-HSE-0044852] no longer applicable. Rehabilitation of 4.48ha occurred at Mesa K Gravel Pit during the reporting period.
Operations	Department of State Development	2014	Response to State Agreement reports 2013	No significant comments. DMP Comments: It should be mentioned that the information provided relating to rehabilitation monitoring offers a good overview of the progression of historical rehabilitation.	Noted
Operations	Office of the Environmental Protection Authority	2015	Annual Audit Compliance Report 2014		Condition 6-1: The following documents were submitted and approved: The Rehabilitation Management Plan for Mesa J and Nearby Mesas, Deepdale Area, November 1993 (Our ref: RTIO-HSE-0043199). The Rehabilitation Management Plan for Mesa J and nearby Mesas, Deepdale Area Addendum, June 1994 (Our ref: RTIO-HSE-0115345), The Rehabilitation Management Plan Addendum Report, November 1994 (Our ref: RTIO-HSE-0043199).
Operations	Office of the Environmental Protection Authority	2015	Annual Audit Compliance Report 2014	Proponent stated in correspondence dated 19 January 2015 that no mining or associated activities occurred at this site during the 2014 calendar year and that no rehabilitation occurred at Mesa K during this time (2015-0001039637). The OEPA strongly encourages the proponent to commence rehabilitation in areas of the mine site where operational activities are unlikely to recommence.	Condition 7-1: Mesa K Preliminary Rehabilitation Plan [Our ref: RTIO-HSE-0044852] was submitted to OEPA 14 January 2009 for formal sign-off following acceptance by DEC Environmental Management Branch [Our ref: RTIO-HSE-0058967]. Note that a subsequent change to the Project approved by the OEPA through a section 45C application 25 February 2013 [OEPA ref: A579133: OEPA 2012/000541] [Our ref: RTIO-HSE-0178454] changed the project life element. This change renders rehabilitation timeframes proposed in the Mesa K Preliminary Rehabilitation Plan [Our ref: RTIO-HSE-0044852] no longer applicable. No rehabilitation was undertaken at Mesa K during the reporting period.
Operations	Department of State Development	2015	Response to State Agreement reports 2014	No significant comments. DMP Comments: It is positive to note that all the AER's provide information on rehabilitation monitoring and offer a good overview of the progress of rehabilitation towards analogue sites. It is also positive to note the continuation of research and trials, including (but not limited to): • The Seed Provenance Study in collaboration with the Department of Parks and Wildlife for collection of material occurred in 2014 and it is noted that support from a second Pilbara mining company was secured for the project. DMP supports a collaborative and targeted research approach; • Final Landform Project; • Priority Flora Species establishment; • Native Pivot Trial; and • Pit Void Guidance.	

Consultation Stage	Stakeholder	Date	Subject	Summary of discussion relevant to closure	Response
Operations	Department of Mines & Petroleum	2015	Mesa J Inspection 2015	1) Check the due date for the closure plan and advise DMP of when it will be provided for comment. 2) RTIO to consult with RSD regarding closure options for pit areas (for example, the steep pit face on the northern end of Pit 10) and provide written evidence to DMP that: a) consultation has taken place; and, b) what action will be undertaken at closure. 3) RTIO to provide a plan to DMP of areas that will be rehabilitated at Mesa J and Mesa K and evidence that commitment has been sought from the LOM planners to designate and sign off areas for rehabilitation.	1) The closure plan is currently under review as part of a potential referral. Submissions of the closure plan will comply with the relevant Ministerial Conditions. 2) Initial conversations have been held with the Resources Safety Division generally. One issue discussed is the use of natural features to aid in access restrictions as an alternative to construction of bunds. A directed engagement on abandonment bunds is planned for 2016. 3) Identification of areas for progressive rehabilitation informs all RTIO Closure Plans, and will be part of the closure plan review currently being undertaken. The need to better integrate closure planning into site mine planning is noted. RTIO has recently made organisation changes that see the closure function now co-located with the mine planning function to improve integration.
Operations	Kuruma Marthudunera Working Group	2016	Robe River pool impacts	Key concerns relate to Robe Pools at Mesa H Details of pumping rates from CWP and sites requested.	RTIO will continue to provide updates on study progress, including details of the proposals, hydrogeological outputs and visual impact assessment input. Heritage surveys and support will continue to be requested through the normal channels. The GWOS set strategies for maintaining and running the borefield, with the final level of control being closure of the borefield.
Operations	Office of the Environmental Protection Authority	2016	Annual Audit Compliance Report 2015		Condition 6-1: The following documents were submitted and approved: The Rehabilitation Management Plan for Mesa J and Nearby Mesas, Deepdale Area, November 1993 (our ref: RTIO-HSE-0043199). The Rehabilitation Management Plan for Mesa J and nearby Mesas, Deepdale Area Addendum, June 1994 (our ref: RTIO-HSE-0115345), The Rehabilitation Management Plan Addendum Report, November 1994 (our ref: RTIO-HSE-0043199).
Operations	Office of the Environmental Protection Authority	2016	Annual Audit Compliance Report 2015		Condition 7-1: Mesa K Preliminary Rehabilitation Plan (our ref: RTIO-HSE-0044852) was submitted to OEPA 14 January 2009 for formal sign-off following acceptance by DEC Environmental Management Branch (our ref: RTIO-HSE-0058967). Note that a subsequent change to the Project approved by the OEPA through a section 45C application 25 February 2013 (OEPA ref: A579133: OEPA 2012/000541, our ref: RTIO-HSE-0178454), changed the project life element. This change renders rehabilitation timeframes proposed in the Mesa K Preliminary Rehabilitation Plan (our ref: RTIO-HSE-0044852) no longer applicable. No rehabilitation was undertaken at Mesa K during the reporting period as future mining is planned for Mesa K.
Operations	Kuruma Marthudunera Working Group	2016	Mesa Facades	Retention of mesa facades along Robe River key requirement. Preference facades are 50m width rather than 30m. Preference to retain facades along central watercourse.	Mesa facades along Robe River will be retained. Will further assess geotech stability and resource impact of 50m vs 30m facades. Central watercourse: will assess impacts to resource and discuss options further with K&M.
Closure Management	Department of State Development	2016	General mine closure plan discussions held with DSD. (Formal written communication from Rio Tinto to DSD dated 11th July 2016).	DSD held discussions and sent various correspondence to Rio Tinto requesting that all State Agreement proponents: • Prepare and submit mine closure plans in accordance with the Guidelines for Preparing Mine Closure Plans (compliant mine closure plans) for all mine operations, including those where there is no current legal obligation to do so; and • Report land disturbance data consistent with Mining Rehabilitation Fund (MRF) categories in our State Agreement Annual Environmental Reports (AER).	In relation to mine closure plans Rio Tinto indicated that it was willing to voluntarily provide the State with the material requested on the following basis: • A timeframe of at least three years to progressively prepare and lodge compliant mine closure plans for operations where modern closure conditions do not currently apply; • Assurance that Mine Closure Plans will only be reviewed on a triennial basis by the Department of Mines and Petroleum (DMP) in accordance with the Guidelines; and • Confirmation that mine closure plans will not be connected in any formal way with the operation of our State Agreement mining approvals, such that changes to our mine plan will not mandate the need for revision of our mine closure plans, except at the regular triennial review period. As part of this Rio Tinto provided a suggested submission schedule which was subsequently agreed to by the DSD. Mesa A was nominally planned for submission in 2017.
Closure Management	Department of Mines & Petroleum	2016	Robe referral to EPA	Clarification sought whether the diversion controls being considered will apply for operation only or will they remain post closure, and would pooling/damming of surface flow occur.	Further modelling and consideration being undertaken for closure requirements, but the current design is intended for the diversion structures to allow for surface flows coming off the hills to be diverted into existing drainage into Robe River. Low risk of pools being created and structures not designed for damming flows.

Consultation Stage	Stakeholder	Date	Subject	Summary of discussion relevant to closure	Response
Closure Management	Department of Mines & Petroleum	2016	Abandonment bund placement prior to disturbance	Comment that abandonment bund placement and actual installation need to be considered early in mine planning and mine development to ensure they are not precluded from being installed at closure	RTIO acknowledged closure plans would reflect current requirements.
Closure Management	Department of Mines & Petroleum	2016	PMP/PMF modelling for closure planning	DMP acknowledged that achieving stability of large waste landforms is challenging, even under current 'reasonable climatic conditions'. DMP has observed many cases across the Pilbara and the State more broadly where rehabilitation areas have performed poorly or failed, often over a reasonably short time frame. Guidance is expected to be risk based and not a 'one size fits all' approach. It was suggested that high risk dumps (e.g. those containing designated fibrous or PAF waste) may need to be designed to withstand larger or more intense rainfall events than small, inert, low risk waste dumps.	RTIO will wait for the landform design document which will include guidance on the PMP/PMF issue.
Operations	Department of State Development	2016	Response to State Agreement reports 2015	DMP supports the inclusion of rehabilitation monitoring data and photographs. Rehabilitation appears to be progressing well with only a small number of sites yielding poor results. Rework should be monitored for success and an update provided in future AERs and TERs.	
Operations	Kuruma Marthudunera Working Group	2016	Jirti Thalu access	The importance of Jirti Thalu to the K&M people was highlighted, and that they had concerns about the safety of certain community members if the place was impacted.	Mine planning will run options to test the impact with Jirti Thalu removed form the mine schedule.
Closure Management	Department of Mines & Petroleum	2016	Public safety risk mitigation requirements for closed mine sites	Environmental inspectors regulate safety through Mining Regulations 1981 Regulation 28 "…all holes, pits, trenches and other disturbances to the surface of the land made whilst mining which in the opinion of an environmental officer are likely to endanger the safety of any person or animal will be filled in or otherwise made safe to the satisfaction of the environmental officer". The DMP intends to revise its abandonment bund guidance to become less prescriptive and more outcomes focused. There would not be an expectation to batter down and rehabilitate large faces – abandonment bunds to prevent inadvertent access would be more appropriate. Vegetation on a slope would help prevent access, but should not be relied upon as a primary control as it could be lost to fire etc. Similarly, fences should not be considered a permanent control.	RTIO is considering options.
Operations	Department of Mines & Petroleum	2017	2017 Robe Valley closure plan overview	RTIO presented an overview of the Mesa A Hub and Mesa J Hub closure plans, including scope, risks, gaps and actions. The DMP feedback was positive and they look forward to receiving the plans. Their interest was in the waste dump designs and management of erodible material and abandonment bunds. They were happy to hear that the business has a project planned for this year to incorporate the inclusion of abandonment bund considerations into study outputs (likely at FS level).	The closure plans will likely contain some discussion on abandonment bund options but not detailed designs for all areas at this stage. Completion of this is included in the closure task list.
Closure Management	Department of Environmental Regulation	2017	Contaminated Sites		Contaminated sites are managed as an operational issue, using a risk based approach. Closure is considered in the risk rating based on estimated closure dtae. Focus is currently on the higher risk areas, with 19 locations to be investigated and managed in the next five years.
Operations	Kuruma Marthudunera Working Group	2017	Water monitoring Site Visit	Traditional owners attended a monitoring run with the hydrology team to download dataloggers in pools along the Robe River. A summary of the locations visited and photos of the monitoring work were provided to KMAC for awareness.	

Consultation Stage	Stakeholder	Date	Subject	Summary of discussion relevant to closure	Response
Closure Management	Department of Water and Environmental Regulation	2017	General Closure Plan schedule	Overview provided of closure plans that Rio Tinto (iron ore) is currently working on in 2017 and planning for 2018 to either support approvals in process, for compliance purposes or to meet commitments made to the Department of State Development in 2016 to submit closure plans for all operations over a three year period. These include: - Silvergrass East - Hope Downs 1 - Mesa A hub - Mesa J hub - Paraburdoo - Tom Price - Brockman 4 - Hope Downs 4 - Eastern Range - Channar	

Appendix C – Closure knowledge database (Confidential)

Rio Tinto Mesa J hub closure knowledge database

The closure knowledge database is a summary of the technical reports that directly or indirectly contribute to the development of the closure plan. These documents do not form part of the report and are for indicative purposes only.

The knowledge and understanding of closure issues and management strategies evolve and improve over time, coincident with the development of the mining operation. As a result, some components of some reports and studies may be superseded by new research or studies. While the closure plan addresses the current state of understanding and strategy for closure, the closure knowledge database captures the historical development of closure knowledge, and demonstrates how experience and knowledge developed at other Rio Tinto sites has been considered during the development of the closure plan and across the life of the operation. Accordingly, some information presented in the closure knowledge database may be obsolete.

Technical reports supporting the closure of the operation will be presented as part of the last plan produced prior to the implementation of closure (also known as the Decommissioning Plan).

CONFIDENTIAL

Geochemical characterisation

Review of Waste Rock Geochemistry a) General Overview of Acid Base Accounting **2006**

This report contains a general overview of acid base accounting and a summary of the geochemical test work that has been previously completed for various sites and lithologies.

Internal reference: RTIO-PDE-0021130

There are large discrepancies in the total sulfur concentration measured using XRF and LECO machines. The XRF machine underestimates the sulfur concentration at values greater than 2%. Materials with total sulfur concentrations less than 0.1% can contain low capacity PAF material, however, it is considered only to be low additional acid and metalliferous risk if the boundary for inert material and potentially acid forming material is shifted from 0.02%S to 0.1%S. A paste pH result of less than 7 should be sent to the black shale dump and a paste pH result of greater than 7 can be sent to an inert material waste dump.

Mineralogical Analysis of Potentially Acid Forming Materials **2008**

Quantitative mineralogy (QEM-Scan) for samples of rock collected from Tom Price, Channar, West Angelas, Brockman, Paraburdoo, East Extension, Western Turner Syncline and Hope Downs 1 North was undertaken. Comparisons were made between two methodologies use to characterise potentially acid forming materials; acid base accounting and mineralogical analysis.

Internal reference: RTIO-PDE-0053725

All samples contained elevated total sulfur concentrations and the lithologies were either shale, banded iron formation or dolomite. Pyrite was the dominant mineral contributing to acidity and the dominant sulfate secondary mineralisation consisted of alunite and jarosite.

Determination of ARD potential of Rio Tinto Iron Ore (WA) Waste Rock Samples **2008**

This report investigates the use of mineralogy to predict acid and metalliferous drainage potential. Analysis of numerous rocks was undertaken using QEM-SCAN.

Internal reference: RTIO-PDE-0051613

Areas of waste rock which have underdone oxidation can be identified where sulfur-bearing minerals vary between samples in the form of pyrite, alunite and jarosite. The variability of gangue mineral phases suggest that some areas of composite waste rock pile may provide some neutralising potential while other areas will have no neutralising potential. Variable textural and mineralogical controls on sulfide mineral occurrence result in decreased accessibility of pyrite to oxidising fluids.

Environmental Status of Selenium (Se) in the Pilbara Region of Western Australia – Potential Risk from Iron Ore Mining **2011**

This report includes information about Selenium geochemistry, distribution in the environment, occurrence in rocks in the Pilbara and potential risks to the environment.

Internal reference: RTIO-PDE-0103857

The Selenium (Se) content of shales containing significant pyrite should be recorded as part of the overall risk assessment for acid and metalliferous mine drainage. However, it should also be noted Se solubility is far less constrained by pH than in the case of metals and near neutral drainage may contain significant Se concentrations in solution. It would be most useful to study the Selenium budget of the wetlands in the Pilbara as, apart from the chance poisoning of livestock from the consumption of plants that have taken up high concentrations of Selenium, impacts are most likely to be felt in wetlands receiving mine site drainage.

Contaminant Leaching from Non-Sulfidic Waste Material **2011**

The available leach extract data and information pertaining to the distribution of metals and metalloids in non sulfur materials at neutral pH was reviewed. Based on this review conceptual models for controls on their leaching and mobility were developed.

Internal reference: RTIO-HSE-0145041

The review found that contaminant leaching from non-sulfidic materials was generally very limited. Usually the pH in leach tests was near-neutral (pH 6 to 8), and dissolved contaminant concentration were at or below detection limits. It is believed that a primary leachable contaminant source is the oxidation of sulfide minerals. Release from oxidising sulfides leads to release of soluble reaction products. Under neutral pH conditions, there is the potential for release of these contaminants when those products dissolve.

Contaminant Leaching from Low-Sulphur Waste Minerals (Summary) **2011**

Internal reference: RTIO-PDE-0090689

RTIO's Geochemical Database was reviewed and based upon this data, conceptual models for controls on the leaching and mobility of a range of metals and metalloids were developed. This summary also describes potential controls on the amount of dissolved element that may be released. This is a summary of a comprehensive report RTIO-PDE-0100104.

For most contaminants, dissolved concentrations at circum neutral pH (pH 6 to 8) were very low, typically at or below detection limit. Geochemical modelling indicates that water-rock interactions are controlled by equilibrium, for salt, carbonates and sulphates this equilibrium is often source term limited whilst hydroxyl-sulphates and hydroxides are solubility controlled. Results also indicate that sorption plays an important role in solute concentration; weak (but detectable) sorption occurred for selenium and zinc whilst the strongest sorption was evident for cobalt. The review suggested that storage waste facilities containing low-sulfur materials pose a low level of environmental risk however, there is a small risk of increased in mobility of some contaminants if acidic conditions arise. Acidic conditions can sometimes arise from the interactions between iron and aluminium hydroxyl-sulphates and hydroxides.

Geochemical Assessment of Tailings from Yandi, Paraburdoo, Tom Price, Brockman 4 and Mesa J **2014**

Internal reference: RTIO-PDE-0123030

This report presents the results from geochemical testing and saline solution extraction of tailings samples from Yandi, Paraburdoo, Tom Price, Brockman 4 and Mesa J deposits.

Overall the tailings from these operations are unlikely to generate acid and are not expected to leach significant levels of metals under oxidising or saline conditions.

Oxidation and solute accumulation in dewatered pit wall rocks **2014**

Internal reference: RTIO-PDE-0109045

Dewatering and removing the water table may result in de-saturation of sulphide-bearing lithologies. This study was undertaken to review how oxygen ingress and consequent sulphide oxidation of Mount McRae Shales could impact water quality when the groundwater table rebounds after mining.

Large Scale Column Construction Procedure and Initial Chemistry **2014**

Internal reference: RTIO-PDE-0123894

Large scale column experiments have been constructed to examine the reactivity of hot and cold black shale material in an operational environment. The memo describes the construction of the columns and the first geochemistry data collected after small rainfall events at Rhodes Ridge.

Initial results suggest that effluent water retains the chemistry of the incident rainfall. Constituents to note in the initial chemistry include nitrate and ammonia detected in the hot black shale effluent. This study provides an important comparison between laboratory characterisation studies and field reactivity of waste rock. Data from the large scale column tests can be applied to reactivity of in pit waste/talus as well as waste rock dumps. It can be used as an intermediate to predict long term reactivity of waste rock.

Robe Valley AMD Risk Assessment **2015**

Internal reference: RTIO-PDE-0061933

This report presents an updated (from 2000) risk assessment associated with acid and metalliferous drainage in past, current and possible future deposits at the Robe Valley. Note, conservative assessment values have been assigned where drilling information is sparse and subsequent material characterisation understanding is limited. These risks will be reviewed as more information becomes available.

Sites with a low to no risk for acid and metalliferous drainage (AMD) are Warramboo, Highway, Tod Bore, Dinner Camp Bore, Mesa A, Mesa B, Mesa C, Mesa F, Mesa G, Mesa H, Mesa I, Mesa J, Mesa K, Mesa L, Mesa M, Mesa N, Middle Robe and Omega. Sites with moderate AMD risk are Bungaroo and Jimmawurrada Creek.

Robe Valley Geochemical Assessment **2016**

Internal reference: RTIO-PDE-0142883

The overall objective of the geochemical assessment was to geochemically characterise reverse circulation drill samples selected and collected by RTIO from their Robe Valley operations. Samples from seven deposits across RTIO's Robe Valley operations were selected by RTIO and delivered to OKC's laboratory in Osborne Park for a range of geochemical analyses. The laboratory analyses were completed over two stages with results from the first stage influencing the second stage of testing. This report includes results and interpretations of the geochemical characterisation program.

All samples showed low AMD risk.

Updated AMD Risk Assessment Summary for Inclusion into 2016 Robe Valley Closure Plan (Mesa H, Mesa J and Mesa K) **2016**

Internal reference: RTIO-PDE-0147826

A review of the AMD risk assessment has been completed to support the development of a Robe Valley closure plan focusing on the Mesa H, Mesa J and Mesa K mining and project areas. This update is based the latest (2015/2016) available drillhole data and proposed final pit shells.

The overall AMD risk for these areas remains low following an update to the assessment. However, it is recommended that the AMD risk assessment be reviewed for the Mesa H project area once 2015/2016 drillhole interpretation is finalised, and also upon completion of the Mesa J/K drillhole re-interpretation being undertaken to support Mesa H pre-feasibility studies.

Mesa H 2017 AMD Risk Assessment Update Summary (memorandum) **2017**

Internal reference: RTIO-PDE-0154172

A review of the acid and metalliferous drainage (AMD) risk associated with mining in the Mesa H project area has been completed to support the referral of the Mesa H Iron Ore Project Feasibility study. This review considers recently available (July 2017) drillhole data and mine planning data.

The overall AMD risk for the Mesa H area remains low following an update to the initial assessment.

Physical characterisation

Characterisation of Mesa J TSF1 Tailings and Vegetation **2009**

Internal reference: RTIO-HSE-0083225

The purpose of this study is to provide an understanding of the chemical, physical and biological properties present at the Mesa J Tailings Storage Facility (TSF1). The study investigates the spatial distribution of the coarse, transition and fine zone surface tails, as well as characterising the material properties for comparison with surrounding analogue soils.

Despite some differences in physical characteristics between the different tailings zones, in general, the tailings are considered suitable for plant growth. The fine tailings zone supports water dependent vegetation, the transition zone supports mixed low closed shrubland and also most alien species. The coarse tailings zone supports scattered tall Acacia shrubs and low trees. Root penetration into the TSF1 is expected to enhance cracking and the development of soil structure and also further drying of the soil beneath. Top soil stockpiles have been identified as a source of native seed.

Net solute load response to the installation of infiltration limiting dry cover systems over acid forming waste piles **2014**

Internal reference: RTIO-PDE-0128431

This work was conducted to verify the central design concept of store-and-release covers over sulfidic above water table waste dumps that is, whether limiting net percolation volume through the cover results in a lesser sulfate and acidity load being realised generated and passing through the dump.

The results from this thesis project confirm that the central aim of store-and-release covers to reduce net percolation volume is a valid measure for reducing the net loading of sulfate and acidity. The mechanism through which decreasing net percolation (applied water volume) results in a lesser sulfate and acidity load was identified, however further work in a site context is needed to assess how this relationship between percolation volume and loading persists in the real-world environment.

Mesa H Geological Modelling and Resource Estimation Report **2014**

Internal reference: GDSR 6103

Document information collected about local geology and extent of resource.

Mesa H is one of a group of oolitic to pisolitic goethite-hematite deposits of Tertiary age which have formed in ancestral drainage channels of the Robe River, in the western Pilbara region of WA. This group is known as the Lower Robe (or Deepdale) group and comprises fourteen mesas or cuestas (which are identified by the letters A to N, commencing from the mouth of the Robe River).

Modelling and Resource Report - Mesa J South **2016**

Internal reference: GDSR 6360

Document information collected about local geology and extent of resource.

Mesa J is one of a group of oolitic to pisolitic goethite-hematite deposits of Tertiary age which have formed in ancestral drainage channels of the Robe River, in the western Pilbara region of WA. This group is known as the Lower Robe (or Deepdale) group and comprises fourteen mesas or cuestas (which are identified by the letters A to N, commencing from the mouth of the Robe River).

Waste characterisation and erodibility assessment for landform design : Tertiary Pisolite Clay **2017**

Internal reference: RTIO-HSE-0304816

The objective of this report is to define appropriate landform batter characteristics for the Tertiary Pisolite Clay materials supplied from the Mesa H deposit.

The results indicate that for the TPC materials at Mesa H (using a climate sequence developed for Mesa J), a lift height of 10m is achievable. Minimum berm widths vary with lift height (and slope length). A 20 degree lift at Mesa J sheeted with TPC material would require a 15m wide, 5% backsloping berm in order to store runoff from a rain event with a 200 year return period, and sediment generated from the slope for a period of 200 years. Lift options other than a 20 degree linear slope are also provided. This includes a concave option that indicates that a single lift (without a berm) that is 35m high could be constructed.

Growth Media Characterisation **2018**

Internal reference: RTIO-HSE-0324326

This report provides an interpretation of material characterisation data for a total of 53 potential growth media samples made up of 34 samples for which data has been previously collected by Outback Ecology Services on behalf of Rio Tinto, 11 samples for which data has been previously collected by Landloch on behalf of Rio Tinto as part of previous erosion studies and 8 additional samples collected and analysed as part of this project. Based on this characterisation, each material was classified as either suitable or not suitable for use as a growth medium.

Properties tested for included pH1:5 (water), salinity (EC1:5, EC1:2), exchangeable cations (K+, Ca2+, Mg2+, Na+, Al3+), effective cation exchange capacity (ECEC), exchangeable sodium percentage (ESP), particle size distribution (fine fraction<2mm), coarse fraction (> 2mm), particle size distribution (all material), texture, emerson class, dispersion potential rating, rock particle density, rock water absorption and rock cover of rain-armoured surface. A classification scheme for key parameters was then developed to classify a material as suitable or unsuitable. Several materials have properties that were invariably suitable. In some cases, materials have some properties that are suitable and others unsuitable. In others, several of the properties are problematic. Suitable materials represent those that have base properties that are not likely to impede vegetation. Marginal materials are those that are likely to support vegetation but that have some properties that may limit establishment and growth. Unsuitable materials are those that have properties that are likely to significantly impact on vegetation growth either through being saline, prone to dispersion, and having pH values quite different to those typically observed. Of the 53 samples, 21 were recommended as suitable growth media, 25 were assessed as marginal growth media and 8 were not recommended as growth media. Samples which were recommended were sourced from Yandicoogina, Channar, Mesa J, Mesa K, Eastern Range, Paraburdoo and Parker Point. Marginal samples were sourced from Brockman 4, Brockman 2/Nammuldi, Mesa A, Mesa J, Channar, Eastern Range, Paraburdoo, Yandicoogina and Hope Downs 4. Samples which were not recommended were sourced from areas at Greater Paraburdoo (Paraburdoo and Eastern Range), West Angelas, Western Turner Syncline and Parker Point.

Groundwater

Mesa J Water Management Study - Groundwater Modelling **2007**

Internal reference: RTIO-PDE-0033605

This report details the modelling work undertaken during this study, but summarises also any relevant previous hydrogeological and modelling work done for the Mesa J site.

There are three major aquifer units in the Jimmawurrada – Bungaroo Creek valley: • Alluvial overburden: is a major unconfined aquifer, if saturated. In the Mesa J area, the alluvial overburden is relatively thin and rises above the water table such that it is largely unsaturated, except in the Robe River and along the Jimmawurrada Creek. • Robe Pisolite: forms the main regional aquifer. In the Mesa J area, the pisolite is unconfined. The Robe Pisolite is bounded to the east and west of Mesa J by basement highs. To the north, the aquifer is dissected by the Robe River and is in hydraulic continuity with the Robe River valley. • Yarraloola Conglomerate and weathered/fractured dolomite of the Wittenoom Formation: Aquifer potential in the Yarraloola Conglomerate is consistent with the findings of other recent work in the area (such as the water supply investigations undertaken at Warramboo). This aquifer is the target of the recently drilled water supply bores DWB11 to 20.

Pannawonica and Mesa J Groundwater Operating Strategy **2014**

Internal reference: RTIO-HSE-0017341

This document forms the Groundwater Operating Strategy for Pannawonica Town and Mesa J Borefields.

The Mesa J mine is situated in the Jimmawarruda-Bungaroo Creek Valley. There are several major aquifer units in region. The highly permeable alluvial is found in the river beds and flood plains of the local watercourses. The ore body itself forms an unconfined aquifer of highly variable permeability. Beneath the Robe Pisolite is the Yaraloola Conglomerate. In the mining area the basement units are from the Wittenoom and Marra Mamba Formation.

Mesa H 2016 Pre-Feasibility Study: Hydrogeological Drilling Program Completion Report **2016**

Internal reference: RTIO-PDE-0142386

This report presents drilling and construction details for works completed as part of the Mesa H Pre-Feasibility Study (PFS).

Drilling results helped define the extent of the Robe Pisolite (CID) underneath the Robe River alluvium, identify the Paraburdoo Member and the Bee Gorge Member of the Wittenoom Formation as local aquifers and at the same time classify the unmineralised BIF (whenever underlying the CID) as an aquitard.

Mesa H Conceptual Hydrogeology **2016**

Internal reference: RTIO-PDE-0147732

Dewatering is required with a max drawdown of ~20m (current water table). Permanent pools, riparian vegetation and 2 x Rights Reserve sites have to be protected during mining operations.

Permanent pools and riparian vegetation are sustained by the Robe River aquifer. Storage of the Rove River aquifer likely to be very high. Lowering the water table in the CID could cause localised drain of the Robe River aquifer. Lowering of the water table in the Wittenoom Aquifer unlikely to affect the Robe River Aquifer.

Mesa H Surface and Groundwater Chemistry Interpretation **2016**

Internal reference: RTIO-PDE-0144245

An interpretation of chemistry and isotope data has been conducted for Mesa H in an attempt to establish whether Robe River pools are groundwater fed and hydraulically connected to the CID and/or Wittenoom aquifers. This Technical Memorandum summarises the methodology and results of this assessment.

Available chemistry and isotope data indicate that the Robe River pools are likely connected to the alluvial aquifer, and that the CID and Wittenoom aquifers are mainly comprised of fresh recharge. However, the latter aquifers appear to be receiving unusually high saline recharge at different locations particularly along the topographically low part of the mesa located to the west of Mesa H and down-gradient of the tailings pond. It is unclear whether the high salinity recharge observed in outlier CID/Wittenoom bores results from diffuse recharge due to local topography or geology, seepage from the tailing pond or an unknown recharge mechanism.

Mesa H Conceptual Hydrogeology **2016**

Internal reference: RTIO-PDE-0147733

The main objectives of this conceptual hydrogeological study are to define aquifer types and hydraulic characteristics, define groundwater boundaries, define recharge and discharge systems and volumes, assess the Robe River permanent pools hydraulics and groundwater dependency, and identify the risk of groundwater abstraction to impact sensitive ecological and heritage receptors.

The main findings observed in this study were: • Three regional aquifers: Wittenoom Aquifer, CID Aquifer and Robe River Aquifer; • Three no-flow boundaries: Marra Mamba Iron Formation, Brockman Iron Formation and Boolgeeda Iron Formation; • One partially confining layer: Tertiary Basal Pisolite; • Robe River pools chemical signature are associated mostly with the Robe River Aquifer with lesser correlation to the other regional aquifers; • Dewatering of the CID has the potential to locally lower the water level in the Robe River Aquifer draining the alluvium depending on the duration and extent of the groundwater abstraction; • Impact to the Rights Reserve pool to the west of Mesa H (KM-RR16) is unlikely; and • Impact to the Rights Reserve to the northeast of Mesa H (KM-RR21) is possible.

Robe River catchment water strategy **2016**

Internal reference: RTIO-PDE-0147734

The Iron Ore Water Strategy 2016 aims to support business value by reducing water-related constraint in current operations and future developments, and strengthen our licence to operate through responsible water management.

The environmental and cultural values of the Robe River are considered to be of high significance to the Kuruma Marthudunera (K&M) people, government regulators and the broader community. Water-related activities required to enable the 5-year plan are achievable. The water-related challenges facing the development of the Bungaroo and Jimmawurrada deposits remain significant.

Review of Depth to Groundwater at Mesa K **2016**

Internal reference: RTIO-PDE-0023804

Geological Support hydrogeologists were asked to assess the depth to groundwater and to determine if mining would intersect the water table.

Indications are that the maximum extent of potential mining would intersect the water table at Mesa K.

Robe Valley Mesa H Pre-Feasibility Study – Dewatering, Water Supply and Impact Assessments **2017**

Internal reference: RTIO-PDE-0149724

RTIO is undertaking a PFS study to expand into Mesa H. As part of the PFS, dewatering estimation, assessment of potential drawdown impacts on the Robe River, assess potential water supply for the mine and groundwater recovery are required to support the Environmental Review.

During closure, the drawdown front is predicted to have moved further to the north, reaching Robe River and surface water polls along its path. The model predicts peak drawdown of ~0.5m in the Robe River area, north of the Mesa H – Pit 8 and Pit 9 in 2042. Full system/aquifer recovery associated with the groundwater levels is predicted to occur within 50 years after the end of dewatering.

Independent peer review of the Environmental Risk Assessment for "Mesa J Tailings Storage Facilities (TSF)" **2018**

Internal reference: RTIO-PDE-0161266

This report provides a simple, screening-level assessment of the potential for Contaminants of Potential Concern (COPC) to be transported from Mesa J TSFs to receptors along Robe River and associated tributaries. The overall approach was to use an existing numerical groundwater model to predict chloride transport as conservative proxy for all COPC, which include chloride, copper and nitrate. Predictions were made at the end of the model calibration period (Dec. 2016), at the end of Mesa H operations (Dec. 2037), and at 190 years after mine closure (Dec. 2227). Based on the model results, dilution factors were calculated and applied to TSF monitoring bore concentrations in order to estimate exposure concentrations.

Whilst this review finds the overall approach to be appropriate, it is recommended that further modelling and statistical treatment of the monitoring data is warranted to provide a range of possible exposure concentrations and thus a more defensible risk characterisation. Model structural uncertainty and parameter uncertainty should also be discussed and investigated if either/both are deemed to have a significant influence on results.

Surface water

Mesa K surface water management **2007**

Internal reference: RTIO-PDE-0032034

This memo outlines the catchment hydrology of the Mesa K deposit, and the current surface water management practices.

Prior to historical mining activities, this area would have originally drained directly into the Robe River. The Mesa proper has been heavily disturbed and as a result is now largely internally draining, intercepting 0.03% of the flow contribution to the Robe River.

Long Term Ecological Research on a Pilbara River System **2009**

Internal reference: RTIO-PDE-0147723

The Robe River alluvial aquifer has been identified as a potential water source in the Pilbara regional water plan and previous regional hydrogeological assessments. This document summarises the groundwater dependent values associated with the Robe River alluvial aquifer and describes the links between these ecosystems and the aquifer.

The Robe River, like most Pilbara rivers is ephemeral, with a highly variable flow regime reliant on summer cyclones and autumn thunderstorms. The alluvial aquifer is recharged from direct infiltration through the riverbed during these unpredictable river flow events. River pools, riparian vegetation and aquifer ecosystems are identified as being sustained, at least in part, by water from the alluvial aquifer, particularly during periods of no river flow. The river and riparian ecosystems are of conservation significance at the local scale and provide valuable habitat for several priority fauna species, two federally protected migratory birds and a potentially new fish species. The aquifer ecosystem with its distinct stygofauna species is expected to be of high conservation value.

Mesa J & K Surface Water Management **2011**

Internal reference: RTIO-PDE-0068650

This report describes the interaction between natural surface water runoff, the local environment and the Mesa J and Mesa K mine sites.

Mining operations in Mesa J have intercepted the local Western Creek. The termination of this ephemeral creek into Pit 11 South results in a catchment area reduction of over 60% for the local Western Creek. The Mesa J mine is protected by the railway embankment in addition to the Southern Levee which affords the Mesa J mine flood protection against a 50 year flood event. The Mesa J to K causeway crosses the Robe River immediately north of Mesa J mine operation. The causeway consists of a number of culverts and a spillway that will be overtopped during a 1 in 2 year ARI flood event. A section of the causeway, known as the Plug, will preferentially erode away once the causeway is overtopped.

Mesa J and K Mine Site Flood Risk Assessment **2014**

Internal reference: RTIO-HSE-0235234

The objectives of this assessment are to define the hydrological characteristics of the area and assess current flood risks in order to facilitate management of surface water runoff and minimise resulting production loss at the Mesa J. Mesa K remains inactive over this wet season.

The Mesa J causeway causes minor impoundment and ponding of surface water by intercepting surface water runoff from the upper Robe River catchment. A “plug” has been incorporated into the causeway bridge that should preferentially erode when windrows have been breached and the causeway is being overtopped. Two levee banks are in place to protect the south eastern portion of the Mesa J mine and borefield from local runoff and Jimmawurrada Creek flood waters.

Five Year Surface Water Management Strategy: Mesa J and K 2014 to 2019 **2014**

Internal reference: RTIO-PDE-0147726

This report summarises the known surface water management strategy, risks to plan and opportunities to the mine site and co-commitments required to implement the strategy for the next five years of mining (2014-2019)

At Mesa J and K, four key risks have been identified relating to surface water. The first risk focuses on pit inundation, particularly Pit 11. This pit is sacrificial and has storage for a ARI 50 year event. The second risk is around landform erosion, and is managed using landform design. The third is operational, when the river floods and removes access to the mine. The fourth is also operational, in how to manage discharge to the creek during floods. All risks have been assessed and the residual risk is Low or Moderate.

Aquatic Ecosystems Study: September 2015 **2015**

Internal reference: RTIO-HSE-0290103

The current program outlined in this report assesses impacts, if any, from mining activities on Robe River pools. This on- ground program incorporates an annual aquatic ecosystem survey of Robe River pools as part of an on-going commitment to assess any environmental impacts of mine development on the adjacent and downstream aquatic ecosystem.

In September 2015, there were no significant changes to the river pools from the long-term mean position. The long term database that exists from these Robe surveys allows informed analysis and interpretation of these changes. The current survey supports previous findings that difference in environmental characteristics of pools are primarily a result of overriding climatic influences determining pool permanence and local morphology. To date, there have been no detectable changes in the aquatic ecology of the Robe River that could be attributed to mining operations.

Mesa H Order of Magnitude Design Flood Estimation and Floodplain Mapping **2016**

Internal reference: RTIO-PDE-0139440

The objective of this investigation is to provide design flood estimates and floodplain mapping for the Mesa H deposit. The results of this investigation will inform the development of surface water management options for the proposed mine.

The results from the hydraulic modelling indicate that, for the most part, Mesa H lies beyond the 1% AEP floodplain and is not vulnerable to riverine flooding (Figure 12). The 1% AEP flood depths are predominantly shallower than 1 m and the corresponding velocities are generally lower than 2 m/s.

Mesa J Life of Mine Pit UF14.18 Design Hydrology Review **2016**

Internal reference: RTIO-PDE-0147721

This memo details the current understanding flood management practices and risks at Mesa J in preparation for the update to the mine plan.

The existing southern levee and the levee southeast of the mine prevent rising floodwater from Jimmawurrada Creek entering the mine. Local runoff is trapped behind the levees and left to dissipate naturally via infiltration and evaporation. The southern cutback pits, including Pit 11, Pit 12, Pit 14, Pit 7 and Pit 6, are exposed to surface water flows from the southern catchments and moderate to high surface water risks have been identified. The flood water is either managed in pit by sump pump measure or defended by the local dumps and flood protection bunds. At Pit 11, two options for flood protection bunds have been assessed to divert the southern creek into the existing diversion drain (an upgrade of the drain has also been investigated) which flows into a natural creek at its northwest extent.

Flora

Baseline Flora and Vegetation Assessment of Robe Valley Mesas (Mesas B, C, D, E, F, H and I) **2011**

Internal reference: RTIO-HSE-0111431

This report documents the methods, results and key findings of the baseline flora and vegetation survey within the study area. It provides an assessment of the vegetation communities and flora species recorded.

Biota Environmental Sciences (Biota) was commissioned in August 2010 to conduct a biological survey of various mesas in the vicinity of Pannawonica. Fifty vegetation units, including three mosaic units, were identified and mapped within the study area. None of the vegetation units within the study area comprise TECs. A total of 221 species were recorded within the study area. Three species of Priority flora (Triodia sp. Robe River (M.E. Trudgen et al. MET 12367), Ptilotus mollis and Rhynchosia bungarensis) were recorded from the study area. Fifteen species of introduced flora were recorded in the study area.

Statement Addressing the 10 Clearing Principles: Mesa J Southern Cutback Flood Protection Bund **2013**

Internal reference: RTIO-HSE-0187908

This desktop report has been prepared from a review of existing biological information, including available databases and various studies in the Mesa J locality. It is intended that this report will be used as supporting documentation for Rio Tinto's NVCP application.

The landforms, vegetation, flora and fauna habitats are well represented within the Mesa J locality and the broader Pilbara region. The study area does not contain any TECs pursuant to the EPBC Act 1999, ESAs pursuant to the EP Act 1986, or PECs listed by the DEC.

Mesa J Road Reconstruction Flora and Fauna Assessment **2013**

Internal reference: RTIO-HSE-0192503

The study area extends from Pannawonica to Mesa J (Figure 1.1) and comprises approximately 12 km of established road covering a total area of 69 ha. The purpose of this assessment was to undertake adequate surveys to provide the necessary information required to support a NVCP Application, and undertake a rare flora assessment of area prior to ground disturbance works commence.

Rio Tinto Iron Ore commissioned ecologia Environment to undertake a single-phase Level 1 flora and vegetation and a Level 1 vertebrate fauna survey prior to the reconstruction of the Mesa J Access Road. A total of 154 plant taxa were recorded and fully identified. No plant taxa listed under the EPBC Act or the WC Act have been recorded in the study area. Twelve weed species were recorded within the study area, seven of which have been assessed within the DEC (now DPaW) environmental threat assessment of weeds for the Pilbara bioregion. Thirty-one fauna species (three mammals, 29 birds and two reptile species) were opportunistically recorded during the survey, including the conservation significant Rainbow Bee-eater (EPBC Act Migratory, WC Act S3).

Mesa K Gravel Pit South Rehabilitation Record **2013**

Internal reference: RTIO-HSE-0246225

This report summarises the rehabilitation of the gravel pit south area at Mesa K Operations, completed in 2013 by the RTIO Rehabilitation team, with the assistance of Mesa J/K Operations team.

The 4.5ha gravel pit south rehabilitation area consisted of two separate elevations joined together via a gentle slope (batter). A track along the bottom edge of the higher elevation was left in situ to service the area. Windrows were installed around the outer edges of all rehabilitated areas to stop water flowing off the top berms and down the outer slopes. No topsoil was imported as the area had very good natural regrowth prior to commencement of rehabilitation; the land was scalped and re-spread as part of the rehabilitation process.

Mesa J, Pit 10 Rehabilitation Record 2014 **2014**

Internal reference: RTIO-HSE-0300385

This report summarises the rehabilitation of part of the Pit 10 area at Mesa J Operations that was completed in 2014 by the RTIO Rehabilitation team, with the assistance of Mesa J Operations team. Threshed and non threshed spinifex seeds were trialled.

Two sections of Pit 10, totalling ~11.5 hectares, were rehabilitated. Rehabilitation earthworks involved areas with unconsolidated waste, such as minor ramps and small piles of dirt near pit walls, to be re-profiled and blended in with the surrounding terrain to ensure appropriate drainage. The area was re-profiled to level out material on the pit floor, and topsoil was applied and spread to ~2.86 ha in the northern section of the pit. The northern section of the pit had been fallow for 8 years and little vegetation growth had occurred during that time. Both areas were ripped along the contours and seeded with native seed of local provenance. The pit walls were not treated. On two 1 hectare blocks, threshed *Triodia wiseana* seeds were spread to measure germination success against non threshed (control) seeds. No topsoil was applied to these areas to ensure seeds stored in the seed bank did not impact the germination results.

Flora, Vegetation and Fauna Habitat Assessment at Jimmawurrada **2014**

Internal reference: RTIO-HSE-0220213

This report is intended as a supporting document for an NVCP application by Rio Tinto, as required by Section 51A of the Environmental Protection Act 1986 (EP Act). The report has been prepared on the basis of a review of existing information for the project area, combined with two site visits. This report describes the methodology employed for the flora, vegetation and fauna habitat assessment of the study area, and documents the results of the survey. In particular, this report identifies vegetation, flora and fauna habitats of conservation significance relevant to the study area.

Six broad fauna habitats were recorded within the study area; low hills and hill slopes, plains, floodplain, mosaic, major drainage lines, and soak. A total of 284 native taxa from 135 genera belonging to 51 families were recorded by Biota. An additional 18 taxa were recorded during the current study. Five conservation significant species were recorded within the study area.

Desktop Flora, Vegetation and Fauna Habitat Assessment at Robe Valley **2015**

Internal reference: RTIO-HSE-0257758

Approval for clearing of native vegetation associated with the proposal is required via a Native Vegetation Clearing Permit (NVCP) under Section 51A of the Environmental Protection Act 1986 (EP Act). Vegetation, flora and fauna assessments at Robe Valley (the study area) were required to address the 10 Clearing Principles as part of the NVCP application process.

One Priority 3 flora taxon has been previously recorded in the study area, Triodia sp. Robe River (M.E. Trudgen et al. MET 12367). Four weed species were previously recorded within the study area. Six vegetation associations were described from Hills and Slopes, eight units from Plains and one unit from Flowlines. Four conservation listed terrestrial fauna species have been previously recorded from the study area.

Mesa H Project – Level 2 Vegetation, Flora and Fauna Assessment – Phase 1 Summary **2015**

Internal reference: RTIO-HSE-0243872

The objective of the assessment was to complete Phase 1 of a two-phase biological survey of vegetation, flora and fauna of the Mesa H survey area and provide a brief summary presenting the key findings of the survey.

Astron was engaged to undertake a Level 2 vegetation, flora and fauna assessment for the Mesa H Project. Siz broad fauna habitat types were recorded in the survey area: Riverine, Gorge, Drainage, Breakaway, Rocky Hills, Low Hills/Slopes, Loamy/Stony Plain. One hundred and forty-three vertebrate fauna species were recorded within the survey area during the survey, of which eight were conservation significant. Two hundred and thirty-seven vascular flora species from 48 families and 125 genera were recorded in the survey area.

Mesa J Mine Extension – Level 2 Vegetation and Flora Assessment **2015**

Internal reference: RTIO-HSE-0280041

The objective of the assessment was to provide a single season Level 2 assessment of vegetation and flora values through a desktop assessment and field survey. The resultant data will be utilised to produce a report to support and inform the environmental assessment process for the Mesa J Mine Extension project.

Astron was engaged to undertake a Level 2 flora and vegetation assessment for the Mesa J Mine Extension. One hundred and thirty-six flora species, Representing 78 genera from 35 families were recorded in the survey area. No Threatened flora was recorded during the survey. Two State-listed Priority flora were identified in the survey area. Seven introduced flora species (weeds) were recorded in the survey area, none of which are listed as a declared pest.

Middle Robe and Eastern Deepdale Level 2 Vegetation and Flora Assessment **2015**

Internal reference: RTIO-HSE-0279582

Astron was engaged to undertake a Level 2 flora and vegetation assessment for the Middle Robe and East Deepdale Iron Ore Mine and Infrastructure Project the results of the assessment are presented in this report.

Vegetation condition ranged from ‘very poor’ to ‘excellent’. Fourteen of the 23 mesas within the survey area have been at least partially mined previously. Areas with clay soils typical of the Robe River floodplains were generally degraded from cattle grazing and weed proliferation, while vegetation associated with undisturbed mesas, hilltops and slopes was generally intact with very low weed abundance and little to no other signs of disturbance. Many of the permanent and semi-permanent pools and drainage channels of the Robe River area are relatively undisturbed. Six state-listed Priority flora were identified in the survey area. Twenty-five introduced flora species (weeds) were recorded in the survey area, none of which are listed as a declared pest for the Shire of Ashburton nor are they Weeds of National Significance. *Cenchrus ciliaris (Buffel Grass) and *C. setiger (Birdwood Grass) were the dominant weed species recorded, often characterising the understory of alluvial plains and drainage lines.

Desktop Flora, Vegetation and Fauna Habitat Assessment at Robe Valley **2016**

Internal reference: RTIO-HSE-0282048

Approval for clearing of native vegetation associated with the proposal is required via a Native Vegetation Clearing Permit (NVCP) under Section 51A of the Environmental Protection Act 1986 (EP Act). Vegetation, flora and fauna assessments at Robe Valley (the study area) were required to address the 10 Clearing Principles as part of the NVCP application process.

None of the three Threatened flora species known from the Pilbara region have been recorded from the study area. No conservation listed flora species have been previously recorded within the study area. One broad habitat type was described from the study area Plains. This broad habitat has been split into two categories; Stony Plain and Acacia on Stony Plain. Evidence of one conservation listed fauna species has been recorded in the study area, inactive mounds of the Western Pebble-mound Mouse.

Mesa H Level 2 Vegetation and Flora Assessment **2016**

Internal reference: RTIO-HSE-0300719

The objective of the assessment was to undertake a two-phase Level 2 assessment of vegetation and flora values through a desktop assessment and field survey. The resultant data will be utilised to produce a report to support and inform the environmental assessment process for the Mesa H project.

Astron Environmental Services has been commissioned to undertake a two-phase Level 2 vegetation and flora assessment in the Mesa H survey area which is approximately 4,930 hectares in size. There were 310 vascular flora species from 53 families and 150 genera recorded in the survey area. Three State-listed Priority flora were identified: Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301) P3, Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3 and Rhynchosia bungarensis P4.

Mesa H Riparian Vegetation – Baseline Monitoring **2016**

Internal reference: RTIO-HSE-0298821

Rio Tinto engaged Astron to establish and survey permanent transects downstream and upstream of proposed discharge locations within the Robe River and relevant tributaries, to record baseline riparian vegetation data. This data will provide a baseline with which ongoing monitoring data can be compared in subsequent years to identify any potential impacts to riparian vegetation from discharge.

In anticipation of potential impact to riparian vegetation due to increased stream flow, Rio Tinto has engaged Astron to establish a monitoring program to compile baseline data on the existing riparian vegetation and its condition. Data were also compiled for riparian vegetation upstream of the discharge point which acts as a reference area. There were 118 plant species from 36 families and 82 genera recorded from the 126 quadrats. No Threatened or Priority taxa were recorded within the transects, however one Priority flora species, Rhynchosia bungarensis P4, was recorded opportunistically within adjacent areas of the Robe River. Sixteen weed species were recorded within the transects.

Fauna

Middle Robe and East Deepdale - Mesa Façade Assessment **2015**

Internal reference: RTIO-HSE-0275944

Astron was engaged to undertake a mesa façade ecological value assessment for the Middle Robe East Deepdale Iron Ore Mine and Infrastructure Project. The purpose of the mesa facade assessment was to assist in determining which mesa facades should be retained if the Proposal proceeds.

The assessment concluded that 7% of the total length of the mesa facade within the survey were rated as high priority for retention. Mesa facades on four mesas were rated as high priority for retention; 37% of Mesa L, 10% of Mesa M, and 100% of Mesas 2400A and 2400C (both Mesas 2400A and 2400C are undisturbed by mining). Mesa that have impacted/disturbed facades were found to have low priority for retention and low ecological value based on the assessment parameters.
Mesa L and Mesa M are previously impacted mesas, however, they still retained breakaway habitat with ecological features important to fauna species of conservation significance. In addition the Priority 3 Ecological Community 'Triodia sp. Robe River assemblages of mesas of the West Pilbara' potentially occurs over the mesa and Triodia sp. Robe River (Priority 3) was present.
Mesa 2400A was rated as a high priority for retention due to the presence of a confirmed Pilbara Olive Python den and high suitability of habitat for the Northern Quoll. Mesa 2400C was rated as a high priority for retention due to multiple records of Northern Quolls indicating denning and shelter habitat. Both mesas were intact and provide important refuge and shelter opportunities for Matters of National Environmental Significance fauna species.

Middle Robe and East Deepdale Level 2 Fauna Assessment, August 2015 **2015**

Internal reference: RTIO-HSE-0280204

Astron was engaged to undertake a two-phase Level 2 vertebrate and short range endemic invertebrate fauna assessment for the Middle Robe and East Deepdale Iron Ore Mine and Infrastructure Project.

Six broad fauna habitat types were recorded in the survey area: Riverine, Drainage, Mesa, Breakaway, Stony Hills and Slopes, and Grassland Plains. Areas of disturbed habitat were also present within the survey area, particularly previously mined mesas. The Riverine and Breakaway habitats in the survey area are considered significant for fauna due to the microhabitats they provide such as caves and water pools. The Breakaway in particular contains a high diversity of microhabitats; it is an important site of refuge due to its location within isolated mesas and as habitat for conservation listed fauna. Nine conservation listed fauna species were recorded. The three targeted Matters of National Environmental Significance species, Pilbara Olive Python, Northern Quoll and Pilbara Leaf-nosed Bat were recorded frequently within the survey area. The two most prospective habitat types for short range endemic fauna, Breakaway and Stony Hills and Slopes, supported a moderately diverse short range endemic community of both specialist and relict short range endemic fauna species. The six potential short range endemic species were recorded.

Mesa J Mine Extension – Level 2 Fauna Assessment **2015**

Internal reference: RTIO-HSE-0279183

The objective of the assessment was to provide a single phase biological survey of vertebrate and SRE invertebrate fauna values through a desktop assessment and field survey. The resultant data will be utilised to produce a report to support and inform the environmental assessment process for the the Mesa J Mine Extension Proposal.

Rio Tinto engaged Astron to undertake a Level 2 vertebrate fauna and Short Range Endemic (SRE) invertebrate fauna assessment for a proposed extension to the Mesa J Mine. Three broad fauna habitat types were recorded in the survey area: Low Hills and Slopes, Loamy/Stony Plain and Drainage Line. Seventy-eight vertebrate fauna species comprising 20 reptiles, 48 birds and 10 mammals were recorded during the survey. Three conservation significant species were recorded during the survey.

Mesa H Level 2 Fauna Assessment **2016**

Internal reference: RTIO-HSE-0300720

The objective of the assessment was to undertake a two-phase Level 2 vertebrate fauna assessment and targeted SRE invertebrate fauna assessment, and to incorporate data from previous biological surveys to provide a report that meets Environmental Protection Authority (EPA) requirements.

Astron Environmental Services has been commissioned to undertake a two-phase Level 2 vertebrate and Short Range Endemic invertebrate fauna assessment in the Mesa H survey area.Seven broad fauna habitat types were recorded in the survey area: Riverine, Drainage Line, Gorge, Breakaway, Rocky Hills, Low Hills and Slopes, and Loamy/Stony Plain. There were 169 vertebrate fauna species recorded within the survey area. Seven conservation listed fauna species were recorded.

Mesa H – Riparian Community Assessment **2016**

Internal reference: RTIO-HSE-0298820

In anticipation of potential impact due to increased stream flow, Astron Environmental Services has been commissioned to undertake a Level 2 flora and vegetation assessment and Level 1 vertebrate fauna and aquatic fauna assessment in the Riparian Community survey area which is 2,105 hectares in size.

In anticipation of potential impact due to increased stream flow, Astron Environmental Services has been commissioned to undertake a Level 2 flora and vegetation assessment and Level 1 vertebrate fauna and aquatic fauna assessment in the Riparian Community survey area which is 2,105 hectares in size. There were 124 plant species from 37 families and 82 genera recorded from sampling sites and opportunistically throughout the survey area. No Threatened taxa were recorded, however three Priority flora species were recorded within the Robe River and its tributaries.

Biodiversity improvement studies

Evaluation of mine waste materials as alternative rehabilitation growth medium **2010**

Internal reference: RTIO-HSE-0109961

This study reviewed the physical and chemical properties of soil, tailing and mineral waste from select Pilbara mining operations, to identify waste material and material combinations for use as a topsoil substitute or supplement.

The study showed plant-available nutrients held within the waste materials, although variable, was characteristically low and comparable to natural soils in the region. The majority of the waste materials had macro and micro nutrient concentrations within the range or above the levels measured in benchmark Pilbara topsoil and rehabilitated soils. The pH and phosphorus buffering index of most waste materials were also comparable to that of the benchmark topsoil materials. However, some of the waste types and tailings may need to be mixed with rocky material due to poor physical / erodibility characteristics.

Genetic diversity in Eucalyptus leucophloia across the Pilbara: Provenance zone implications **2011**

Internal reference: RTIO-HSE-0108843

This study was undertaken to define the provenance seed collection zones for a common species of the Pilbara, Eucalyptus leucophloia (Snappy Gum). This report details information on genetic analysis conducted on E. leucophloia. Collections of E. leucophloia were made from 20 populations across the Pilbara bioregion and genetic analysis was conducted using microsatellite markers.

Genetic diversity in E. leucophloia was high and was typical of that found in other eucalypt species with wide spread distributions. Across the species the level of population differentiation was low and the majority of the diversity was maintained within populations with only 6% of variation partitioned between populations. Genetic variation in E. leucophloia showed little structure across the Pilbara with no clustering of populations based on any geographical proximity or in association with obvious topographical, physiogeographical or geological features such as the Hamersley or Chichester Ranges. Populations towards the edges of the species distribution within the Pilbara showed greater levels of differentiation from populations within the species main range. The high levels of genetic diversity and low levels of differentiation within E. leucophloia implies that seed resources for rehabilitation can be selected from a wide range within the Pilbara.

Genetic diversity in Acacia ancistrocarpa across the Pilbara: Provenance zone implications **2011**

Internal reference: RTIO-HSE-0119260

This study was undertaken to define the provenance seed collection zones for Acacia ancistrocarpa (Fitzroy Wattle). This report details information on genetic analysis conducted on Acacia ancistrocarpa. Collections were made from 24 populations across the Pilbara bioregion and genetic analysis was conducted on 16 populations using microsatellite markers.

Genetic diversity in A. ancistrocarpa was high but lower than that in E. leucophloia, another widespread species in the Pilbara. Across the species Pilbara range the level of population differentiation was low and the majority of the diversity was maintained within populations with only 3% of variation partitioned between populations. Genetic variation in A. ancistrocarpa showed little structure across the Pilbara with no clustering of populations based on geographical proximity or in association with obvious topographical, physiogeographical or geological features. Populations towards the edges of the species distribution within the Pilbara showed greater levels of differentiation from populations within the species main range. The high levels of genetic diversity and low levels of differentiation within A. ancistrocarpa implies that seed resources for land rehabilitation and mine-site revegetation programs can be selected from a wide range within the Pilbara

Root hydraulic conductance and aquaporin abundance respond rapidly to partial root-zone drying events in a riparian Melaleuca species **2011**

Internal reference: RTIO-HSE-0252171

This study examined partial root zone drying (PRD) responses of Melaleuca argentea.

The results demonstrate that PRD can induce rapid changes in root hydraulic conductance and aquaporin expression in roots, which may play a role in short-term water uptake adjustments, particularly in species adapted to heterogeneous water availability.

Baseline Terrestrial Fauna Assessment of Pilbara Rehabilitation Areas **2012**

Internal reference: RTIO-HSE-0134168

In 2011 a fauna survey was conducted within established rehabilitation areas at Brockman 2 and Tom Price mine sites, with the aim of identifying whether fauna is recolonising rehabilitation sites in assemblages comparable to reference sites.

The study found that at least 85 species of native vertebrate fauna, as well as representatives from each of six major groups of invertebrate fauna, are using rehabilitation areas at Brockman 2 and Tom Price, with species compositions that were broadly similar to reference sites. Ant collections were typical of the Pilbara bioregion, with an absence of invasive ant species. The study found greater data correlation between monitoring sites at a particular mine site (Tom Price or Brockman 2) than between rehabilitation and reference sites, indicating the importance of selecting local reference sites. The study concluded that the best candidates for bio-indicators are ants and reptiles.

Hay Project – Native Seed Orchard **2012**

Internal reference: RTIO-HSE-0141263

Commencing in 2011 (and still ongoing), a trial irrigated seed orchard was established at the Hamersley Agriculture Project (Marandoo). The purpose of the trial was to identify an alternate method of addressing seed deficits. If successful, the project may be implemented at other Rio Tinto operations, such as the Nammuldi agriculture project.

Genetic diversity in Aluta quadrata:Implication for management and provenance zone **2012**

Internal reference: RTIO-HSE-0156732

This study was undertaken to define the provenance seed collection zones for Aluta quadrata. This report details information on genetic analysis conducted on Aluta quadrata. Collections were made from 8 populations across the Pilbara bioregion and genetic analysis was conducted using microsatellite markers.

Genetic diversity in A. quadrata was moderate and lower than in the other two more widespread Pilbara species, E. leucophloia and A. ancistrocarpa. The findings suggest that its populations may have fluctuated significantly in size over time with genetic drift and possibly inbreeding resulting in a reduction in genetic variability, particularly in rare alleles. Despite the narrow geographic range, the level of population differentiation in A.quadrata was relatively high with 25% of the genetic variation maintained between populations and 19% due to differences between the three different locations. This significant genetic structure indicates that A. quadrata consists of three conservation or management units, Western Ranges, Pirraburdoo and Howie's Hole.

Genetic diversity in Acacia atkinsiana across the Pilbara: Provenance zone implications **2012**

Internal reference: RTIO-HSE-0187256

This study was undertaken to define the provenance seed collection zones for Acacia atkinsiana (Atkins wattle). This report details information on genetic analysis conducted on Aluta quadrata. Collections were made from 16 populations across the Pilbara bioregion and genetic analysis was conducted using microsatellite markers.

Genetic diversity in A. atkinsiana was low and lower than that observed in its congener Acacia ancistrocarpa, a widespread species across northern Australia. The level of population differentiation was high and 30% of the diversity was partitioned between populations across the range of A. atkinsiana. Genetic variation in A. atkinsiana showed some structure across the Pilbara with clustering of populations in the western part of the distribution and from the Hamersley Range, along with other populations that were divergent from these groups. The low levels of genetic diversity and high levels of differentiation within A. atkinsiana implies that seed for land rehabilitation and mine-site revegetation programs should be restricted to specific zones. For rehabilitation of sites within the Hamersley Range we recommend seed collections be restricted to that region. Similarly, for rehabilitation in the part of the distribution west of Pannawonica, seed collections should be restricted to that area.

Rehabilitation Quality Metric (RQM) Project **2012**

Internal reference: RTIO-HSE-0164020

Western Australia has no formal process to measure habitat quality and as such RTIO has needed to design its own customised metrics. Vegetation condition scoring has previously been developed by RTIO through a Biodiversity Net Positive Impact Assessment, but a more precise metric was needed. The Rehabilitation Quality Metric (RQM) project was developed to provide a repeatable method to assess rehabilitation quality against pre-determined reference sites, on a site by site basis, to predict rehabilitation ecosystem quality at the time of relinquishment.

The RQM methodology employs seventeen parameters to characterise the landscape, including vegetation, fauna habitat, fauna presence, erosion, and ecosystem function. Parameters are tailored to be an applicable measure for both rehabilitation and native vegetation (reference sites). Parameters are scored, based on measured or observed characteristics, with a value between 0 and 1, with 1 being functional (terrestrial ecosystem is functioning for the maintenance of biodiversity values at a local or property scale) and 0 being dysfunctional (terrestrial ecosystem is failing; indicators of ecosystem function have scored below acceptable levels). Both rehabilitation areas and reference sites are scored. Scores are subsequently determined for the entire mine lease, based on the condition of the land before mining (extrapolated from the reference sites, area weighted) and the likely post-mining conditions (extrapolated from the rehabilitation areas and expected closure domain distribution, area weighted, ie pits with no rehabilitation score 0). The difference between the pre-mining and post-mining scores represents the residual impact of mining.

Propagation of Pilbara spinifex (Triodia sp.) **2012**

Internal reference: RTIO-HSE-0169744

Triodia has often been observed to have very poor establishment from broadcast seed. This project investigated alternatives to growing Triodia (spinifex) from seed, focussing on ways to propagate seedlings from wild harvested material.

The project found the most successful propagating material was stolons. Greatest propagation success was achieved when Triodia were collected when semi to fully dormant (mid Winter-Spring). The 'Moist Root Induction Method' recommended by previous researchers was less successful than the standard propagation techniques employed in this project. Success varied notably between populations. Consequently, any future collections of propagating material should target multiple populations to maximise potential for success.

Pilbara Seed Science Project, Part 2 Final Report Jan 2012 **2013**

Internal reference: RTIO-HSE-0174944

Undertaken between 2009-2012, this seed research investigated germination, biology, dormancy classification and treatments for dormancy alleviation for a range of species from the Pilbara.

The *Acacia atkinsiana, Indigofera monophylla and Sida echinocarpa* seed lots have physical dormancy. Heat treatments and mechanical scarification improved germination on dormant seeds, however, heat treatments killed non-dormant seeds. The treatments used for *Goodenia stobbsiana* seeds failed to overcome dormancy, suggesting deep physiological dormancy. The *Hakea lorea/ chordophylla* seed lots were found to be non-dormant, with very high germination results in the controls. As such, they will not require any pre-treatments prior to direct seeding. The florets surrounding the *Triodia pungens* and *T. wiseana* seeds were found to restrict germination, however, many of the freshly extracted seeds out of the florets were found to be physiologically dormant. Treatments for dormancy include mechanical scarifier to rupture seed coat, hot water (noting potential damage to immature or non-dormant seeds) and increases to germination through wet / dry cycling and / or temperature cycling.

Morphological variation in the western rainbowfish (Melanotaenia australis) among habitats of the Pilbara region of northwest Australia. **2013**

Internal reference: RTIO-HSE-0252169

The aim of this honours thesis was to determine and quantify the extent of morphological variation present in M. australis and relate this to environmental variables, which will provide the first step to understanding how the species copes with environmental change.

This results of this thesis found that there was limited evidence that fish morphology correlated with environmental variables

Patterns of water use by the riparian tree Melaleuca argentea in semi-arid northwest Australia **2013**

Internal reference: RTIO-HSE-0249538

This thesis examines the water use physiology of the riparian tree Melaleuca argentea, and the ways in which this species may respond to anthropogenic disturbances to hydrologic processes.

M. argentea displays highly plastic root-level responses to heterogeneous water availability and to waterlogging, facilitating high rates of water use and growth in the riparian wetland habitats of the Pilbara. Mature M.argentea trees appear to tolerate groundwater drawdown of at least several metres, most likely by employing the same plastic root strategies to access deeper water. M.argentea can also withstand short periods of severe drought, by adopting a 'waiting' strategy of ceasing growth and shedding leaves to avoid moisture loss, a state from which they can then recover. M. argentea populations are unlikely to thrive under large and prolonged reductions in water availability.

Priority Species Seed Quality and Germination Final Report **2013**

Internal reference: RTIO-HSE-0207487

This study investigated the quality and germination biology of a range of priority and keystone (Triodia) plant species from the Pilbara.

Eremophila magnifica subsp. Magnifica has physical & physiological dormancy. Propagation methods other than seed may be more successful. Geijera salicifolia and Olearia mucronata has physiological dormancy. Temperature cycling may be required to stimulate germination. Indigofera ixiocarpa and Indigofera sp. Bungaroo Creek has physical dormancy or is non-dormant. Mechanical scarification may be required. Ptilotus subspinescens is non-dormant and will germinate easily without removal from the perianth sheath. However, seed is likely to lose viability with a few years. Sida echinocarpa and Sida sp. Barlee Range has physical dormancy. Seeds should be removed from the mericarp and then scarified in order to germinate. Triodia pungens has T. wiseana non-deeep or deep physiological dormancy. Germination of de-husked seeds can be improved by applying gibberellic acid or 1% smoke water and wet/dry cycling.

Early physiological flood-tolerance and extensive morphological changes are followed by slow post-flooding root recovery in the dryland tree Eucalyptus camaldulensis subsp. Refulgens **2014**

Internal reference: RTIO-HSE-0252170

This study investigated physiological and morphological response to flooding and recovery in Eucalyptus camaldulensis subsp. Refulgens, a riparian tree species from a dryland region prone to intense episodic flood events.

E. camaldulensis subsp. Refulgens underwent considerable morphological changes during flooding, including extensive adventitious root production, increased root porosity and stem hypertrophy. Physiologically, net photosynthesis and stomatal conductance were maintained for at least 2 weeks of flooding before declining gradually. Despite moderate flood-tolerance during flooding and presumably high environmental selection pressure, recovery of reduced root mass after flooding was poor.

Priority Species Project Progress Report 2013 **2014**

Internal reference: RTIO-HSE-0207486

The Priority Species Project, initiated in 2012, aims to improve knowledge of priority plant species and develop methods to successfully germinate and establish priority species, to enable priority plant species to be integrated into Rio Tinto rehabilitation programmes. This work is being undertaken in conjunction with the Department of Parks and Wildlife.

13 plant species were selected as being potentially suitable for establishment in rehabilitation: Eremophila magnifica subsp. magnifica, Indigofera sp. Bungaroo Creek, Indigofera sp. gilesii, Acacia bromilowiana, Sida sp. Barlee Range, Ptilotus subspinescens, Ptilotus mollis, Acacia subtiliformis, Isotropis parviflora, Grevillea sp. Turee, Hibiscus sp. Canga, Themeda sp. Hamersley Station, and Aluta quadrata. Indigofera sp. Bungaroo Creek and Ptilotus subspinescens were found to readily germinate in laboratory conditions, and a field trial was established at Brockman 4 late in 2013.

Regional Variation in Metal Concentrations of Pilbara Fish in Relation to Concentrations in Water and Sediments **2014**

Internal reference: RTIO-HSE-0216967

This study aimed to characterise and document natural, background metal concentrations in freshwater fishes from different locations across the Pilbara in order to understand how local geology may affect baseline metal levels in fish tissues and surface waters. Metal concentrations were analysed from water, sediment and muscle and liver tissues from fish collected from up to 13 sites as yet unimpacted by mining across the Pilbara during October (dry season) of 2012.

Levels of dissolved metals from water samples were generally low. However, some elevated concentrations of Boron, Copper and Zinc were recorded. Concentrations of heavy metals in sediments were variable across the Pilbara. Generally, sediment concentrations were well below the Interim Sediment Quality Guidelines (ISQG). However, metal concentrations in excess of ISQG TVs were recorded for Chromium and Copper at some sites. There was no relationship between metal concentrations in sediment and those in water. Metal concentrations in fish tissue (muscle and liver) varied between species with some significantly higher in some particular species. The study concluded that variation in metal concentrations in water, sediment and fish across pools in the Pilbara was likely to be mainly dictated by the local geological setting in which the pool occurs.

Progress Report 2014, Ecological responses of native fishes to dynamic water flows in northwest arid Australia **2014**

Internal reference: RTIO-HSE-0246021

This three year Australian Research Council linkage Project commenced in 2013 and aims to increase understanding of the effects of altered stream flows on the Pilbara freshwater aquatic environment. Project aims: 1. Quantifying fish biodiversity and population structure in relation to hydrological and environmental parameters to identify thresholds of ecological concern for water management; 2. Determine the fundamental physiological, morphological and behavioural adaptations of fishes to variations in water quality using experimental manipulations; and 3. Examine spatial scales of gene flow to determine if increased flows increase genetic connectivity relative to natural-flow sites.

To date work has focuses on characterisation of baseline physicochemical parameters across aquatic habitats within the Fortescue River catchment (Aim 1), analysis of variation in rainbow fish morphometrics and mechanosensory lateral line systems in response to geographic region and water management regime (Aim 2), and extraction of DNA samples from 17 populations across the Fortescue River catchment (Aim 3). The project will culminate in the development of a predictive model for stream restoration relevant to future closure scenarios for above and below-groundwater mines. Results from an honours thesis indicate that rainbow fish body shape varies according to geographic region but fish from a dewatered site (WW Ck) were more streamlined than other populations from the upper Fortescue catchment. This statement of results has been superseded by the results of the actual thesis report RTIO-HSE-0252169.

Progressive rehabilitation

Ecosystem Function Analysis of Robe Valley rehabilitated areas **2014**

Internal reference: RTIO-HSE-0280240

Five rehabilitation areas were monitored in 2013 - S Dump and T dump at Mesa J, and the Pit Floor, West Waste Dump and Haul Road at Mesa K. Six reference transects were monitored for comparison to the rehabilitation. Mesa J Hub uses the EFA monitoring technique.

S and T dump have established well, with increasing cover and density since rehabilitation. T Dump has stopped increasing in 2010, indicating full establishment. T Dump has lower density than S Dump, potentially due to the topsoil differences. All areas at Mesa K are well established, reflecting the maturity of the rehabilitation.

Mesa J Tailings Storage Facility 1 (TSF1) Rehabilitation Record **2014**

Internal reference: RTIO-HSE-0246219

This report summarises the rehabilitation of 45Ha of TSF1 at the Mesa J Operations, completed in 2014 by the RTIO Rehabilitation team, with the assistance of a rehabilitation contractor and the Mesa J/K Operations team.

The project totalling 45 hectares (Ha) involved the removal and stockpiling of 15kt (6,000m3) of high grade ore, the removal and stockpiling of 160kt (64,000m3) of course material to be used as stemming and the import of 85kt (38,500m3) of capping material, prior to shaping, ripping and seeding of the entire rehabilitated surface.

2014 Robe Valley EFA Monitoring **2014**

Internal reference: RTIO-HSE-0266718

Three rehabilitation areas were monitored in 2014 - Pit 10 and TSF1 at Mesa J, and the Gravel Pit at Mesa K. Five reference transects were monitored for comparison to the rehabilitation. Mesa J Hub uses the EFA monitoring technique.

The vegetation communities on all rehabilitation sites were in the initial stages of ecosystem development. Cover and density was lower than reference sites, as would be expected from newer rehabilitation.

2015 Robe Valley EFA Monitoring **2015**

Internal reference: RTIO-HSE-0273809

Six rehabilitation areas were monitored in 2015 - S Dump, T dump, Pit 10, TSF1 and the Rail Upgrade construction areas at Mesa J, and the Gravel Pit at Mesa K. Five reference transects were monitored for comparison to the rehabilitation. Mesa J Hub uses the EFA monitoring technique.

S and T dump have established well, with increasing cover and density since rehabilitation until 2010 and 2015, when T Dump and S dump stopped increasing respectively, indicating full establishment. T Dump has lower density than S Dump, potentially due to the topsoil differences. Pit 10 North has good vegetation establishment with a range of native vegetation species. Pit 10 South has limited native perennial vegetation establishment, due to both the young age of the rehabilitation and the lack of topsoil. Vegetation establishment has been variable across TSF1, with the better establishement occurring on coarser tailings or rocky edges. Vegetation establishment along in the construction areas is beginning to occur, however vegetation parameters are low, reflecting the young age of the rehabilitation. Better establishment is shown where the surrounding area is not disturbed or used regularly. Vegetation atthe Gravel Pit is establishing well, with vegetation parameters comparable to the reference sites.

Landform design

Results of flume investigations of the stability of rock mulches **1998**

Internal reference: RTIO-HSE-0109221

This study assessed the potential for rock mulches to be stripped from the soil surface by overland flows.

Although 150-300mm diameter BIF was not removed by simulated overland flows, even for 100mm/hr simulated runoff on 55% gradients, considerable scour of the spoil between the rocks was observed, indicating potential for long-term development of rills or gullies if the level of rock cover was less than 100%. Large reductions in sediment concentrations were observed when finer rocks were mixed with BIF. The data indicate that it is crucial for any rock mulch to cover a wide range of particle diameters, including a component of finer rocks. The resulting mixed rock created a framework of large rocks that resist movement by flows, while the smaller rocks reduce erosion being anchored within the larger (framework) rock. For rock mulches with a mixture of rock diameters, 80% cover produced acceptable erosion rates. Sediment loads were slightly higher for 40% cover by rock of mixed diameters, and it was speculated that this may also achieve acceptable erosion rates with the addition of vegetation.

Final Landform Design Criteria for Use During Mine Planning **2012**

Internal reference: RTIO-PDE-0159989

Rio Tinto Iron Ore WA have historically designed closure landforms for waste materials with berms ~10 m, lifts ~20 m and ad hoc alterations to batter gradients where erosion rates have been perceived to be unacceptably high. This report integrates recent advances in characterisation and modelling of materials, climate and erosion processes to provide appropriate final landform batter characteristics for key Pilbara mineral wastes and soils.

Material properties of mineral wastes were assessed and classified for the range of mineral wastes found across Rio Tinto Pilbara sites. Climate sequences were used to model and test potential erosion rates for a range of batter configurations (shapes (linear, concave), heights, gradients, berm capacity) and validated against existing slopes for which material and climate data were available. This information was used to develop a searchable waste dump batter database for all major mineral wastes and soils, intended for use during mine planning design.

Mesa J TSF Concept Closure Study **2016**

Internal reference: RTIO-HSE-0300384

The purpose of this report was to develop a concept design for the future closure of the TSF's at Mesa J based upon the Robe Valley 2014 Life of Mine plan. The report considers which pits will be used for waste backfill and which for future Tailings dams. Designs for future facilities are conceptual and will be updated over time.

The report considers which pits will be used for waste backfill and which for future Tailings dams. Designs for future facilities are conceptual and will be updated over time. The information is incorporated into the Life of Mine plan and utilised by the closure plan. Generic requiremenrts for 2m of capping has been used.

Contamination

Pannawonica Preliminary Site Investigation & Sampling & Analysis Plan **2007**

Internal reference: RTIO-HSE-0057556

This preliminary site investigation was undertaken to determine areas of potential contamination associated with current and historical activities at the site.

Analysis of the site concluded that the highest ranked activities in terms of risk are: fuel storage/handling at Pannawonica Service Station, fire training activities, storage and handling of fuels and oils at the Mine Services Building and the Eastern Deepdale fuel storage/transfer area. Many sites have not undergone environmental investigation for their potential negative impacts. In all cases visual and/or anecdotal evidence suggest that potential adverse impacts exist to soil, groundwater or surface water, be it fuel spills, leaking tanks, ongoing run-off/infiltration or burning, had historically occurred at these locations. For each issue of concern, a soil and groundwater sampling and analysis plan has been developed.

Phase 2 Environmental Site Assessment Pannawonica Service Station **2007**

Internal reference: RTIO-HSE-0042275

The objective of this investigation was to identify the location of the underground storage tanks and associated fuel lines and assess whether the reported loss of integrity in the underground storage tanks system has resulted in any sub-surface impacts to soil or groundwater.

The results of the Environmental Site Assessment indicate that no impacts to the environment have resulted from the observed loss of integrity in the fuel storage system. Of the twelve (12) soil samples submitted, no samples reported detectable concentrations of total petroleum hydrocarbons, benzene, toluene, ethylbenzene or xylenes or polycyclic aromatic hydrocarbons above the laboratory limits of detection. Detectable concentrations of lead were reported in all samples however none exceeded guideline values. No visual or olfactory evidence of hydrocarbon contamination was noted in the samples.

Impact of Nitrogen from Explosives on Mine Site Water Quality **2008**

Internal reference: RTIO-PDE-0054638

The likely issues associated with the use of nitrogen based explosives on mineral waste and any leachate water are explored in this report. The amounts of explosives used on site are described, along with nitrogen chemistry and toxicity. Nitrogen concentrations for various mine sites and specific lithologies are presented which includes concentration in rock assays and liquid extracts.

It was concluded that the largest risk of nitrogen contamination is likely to arise from the discharge of surface waters that have been in contact with blasted materials and are discharged off site into creeks or waterways. This becomes a more significant issue if the water is also acidic. Algae (ie cyanobacteria) plumes have been identified in acidic water at Tom Price

Control Measures for Potentially Acid Forming Pit Wall Rocks **2010**

Internal reference: RTIO-PDE-0079541

Desktop study of potential strategies to manage exposed sulfidic materials and find viable options for management was conducted with a focus on the Hope Downs 1 and Tom Price sites.

Chemical treatments have the potential to be effective only in the short-term and only for minor water quality issues. Grouting of the pit walls is expected to have limited applicability, although grout curtains behind the wall may have success (untested). Cover technologies have the greatest potential to be effective over the long term, but would need to be resistant to puncture by underlying rocks, resistant to weathering and UV damage ie shotcrete, geomembranes. For long term performance the exposed surface need to be as stable and free of loose material as possible. Treatment effectiveness will also depend on the site conditions, eg chemical less effective at Tom Price.

Workshop Summary and Desktop Review: Dewatering and Sulfate Accumulation **2012**

Internal reference: RTIO-PDE-0101903

This is a summary of a workshop held to determine the risks of dewatering sulphides within the pit wall. The outcomes from this workshop will be used to develop models to estimate the mass of sulfate produced as a consequence of dewatering activities.

There are many processes that contribute to poor pit water quality. Most of these processes are known and accounted for in existing models. However, the science of fluid flow in fractured rock is not well developed and this lack of knowledge restricts the outcomes of studies on pit water quality. There is a general lack of empirical data for estimating parameters used in models, creating a large degree of uncertainty in predictive models. Sensitivity analysis can be used to overcome some of these challenges.

Updated Preliminary Site Investigation and Sampling Analysis Plan for Mesa J Final **2012**

Internal reference: RTIO-HSE-0148155

The objectives of the project were to update existing information relating to known or suspected contamination at Mesa J and surround areas and to subsequently develop a Sampling Analysis Plan in order to present an approach for future intrusive investigations designed to further characterise identified areas of interest.

The review of the Preliminary Site Investigation found that, in general, the existing findings are accurate and have been carried out and presented consistent with the Department of Conservation's Contaminated Sites Management Series. Results of the Sampling Analysis Plan conclude that potential areas of interest are: 1) Pannawonica Town - Substation, sewage treatment plant, service station, former minor and main landfill, Pannawonica MSB; 2) Middle Robe - Former power station, load out and laydown/park up areas, decommissioned 2E workshops, decommissioned vehicle refuelling areas, former ammonium nitrate shed, former Yaleen homestead, 2E former landfill; 3) Eastern Deepdale - Former workshops and refuelling areas, former sewage treatment plant, former landfill; 4) Mesa J - Workshop area, Mesa J tank farm, bulk lube storage area, light vehicle refuelling area; and 5) Mesa K - Groundwater.

Development of a conceptual model: Sulfate accumulation as a consequence of pit dewatering activities, memo **2012**

Internal reference: RTIO-PDE-0101903

Mine dewatering and the consequent lowering of the water table may result in desaturation of sulfide bearing lithologies. The objective of this work was to develop a conceptual model of the associated processes: where sulphide bearing rock intersects the pit walls, and where the sulphide bearing rock is located behind the pit walls but not directly exposed on the pit wall face.

The conceptual model developed estimates the mass of sulfate produced as a consequence of dewatering activities, considering processes during operations and after operations cease, and using sensitivity analysis where parameter inputs are uncertain. The model output provides the basis for an assessment of potential impacts on water quality for general risk assessment applications. Further work was identified to improve parameterisation of the model, including the collection of additional empirical data for pit wall fracturing, saturation of pit wall fractures and sulfide oxidation rates in talus and on pit walls.

Ethnographic or archaeological values

Water and Indigenous People in the Pilbara: A Preliminary Study, CSIRO: Water for a Healthy Country **2011**

Internal reference: RTIO-HSE-0218222

Water resources are vital to Indigenous identities, beliefs, environmental philosophies and livelihoods. This report provides a broad-scale scoping study of Indigenous relationships to water in the Pilbara and considers the potential impacts of Indigenous water values.

Indigenous belief systems perceive water as an elemental part of the broader cultural landscape, held and managed under customary systems of law. Water sources were derived during the Dreaming and are the most important features in the Pilbara cultural landscape. Interviews raised issues of long term drying, obstruction of water flow, over-extraction, inappropriate discharge from de-watering and access restrictions.

Ethnobotanical Survey for the RV region **2011**

Internal reference: RTIO-HSE-0122187

This survey outlines provenance species which Traditional Owners identified as important to include in rehabilitation work for the Robe Valley.

22 species were considered to have ethnobotanical significance, including species of Acacia, Aristida, Cleome, Corymbia, Cymbopogon, Enchylaena, Eucalyptus, Petalostylis, Ptilotus, Rhynchosia, Senna, Solanum, Trichodesma, Triodia and Typha. Traditional owner use these plant species for specific purposes, such as bush tucker, ornamental, medical or as a tool.

Appendix D – Closure risk assessment

Ref.				Risk Description					Risk Management C	
Risk Type (T=Th	Category	Subcategory	Item	Evaluated 20 of 20 risks (0 Remaining) Threat Title	Potential causes (Triggers / Indicators)	Impacts (Consequences)	Existing Controls and Commitments	Evaluation Rationale (Maximum reasonable consequence)		Detailed Action Descriptions
T	**A**			**Planning and knowledge**						
T	**A**	**01**		**Contaminated sites**						
T	A	01	1	Contaminated sites (Non AMD) lead to an ongoing environmental or financial impact	• Use of chemicals and hydrocarbons during operations • Housekeeping practice and maintenance of work areas and equipment	CAPEX / OPEX Environment	• Regular maintenance / inspection / audit of work place procedures • Spill management kits readily available • Contaminated sites register maintained across life of operation	Contamination is missed during closure phase and identified post-closure. Teams are required to mobilise to clean up the contamination.	II	
T	A	01	02	Under-estimated acid and / or metalliferous drainage management requirements during operations (pre-closure) & decommissioning phase	• Potential for acid / alkaline / metalliferous / neutral / saline drainage generation during operation of mine • Water management, storage and monitoring practices • Water quality prior to return to environment e.g. via infiltration or discharge Elevated salts observed around the tailings facilities	CAPEX Environment OPEX	• Geochemical characterisation of mineral waste material routinely undertaken during drill programs. • Mine does not intend to excavate any PAF materials • Discharge water quality monitored. Includes sampling and trigger / response requirements • Wet season management plans used to control run off. • Groundwater operating management plan to monitor groundwater quality	Highly saline water generated as part of waste fines management results in neutral mine drainage i/ groundwater salination ssues during operations and continues throughout closure (including impacts to permanent Robe River pools).	II	
T	A	01	03	Acid and / or metalliferous drainage generation (after closure) creates a contaminated site	• Interaction of water and mineral waste or tailings could generate acid / alkaline levels that leach metals / salts from the mineral waste or local environment • Presence of temporary or permanent open water bodies, enabling evapoconcentration to occur with creation of alkaline / hypersaline water quality • Ability of metals / salts to move through environment to impact a sensitive receptor, to meet definitions in Contaminated Sites Act 2003	CAPEX Environment OPEX	• Mine does not intend to excavate any PAF materials	Pit wall erodes and collapses post-mining revealing PAF materials that impact water quality (including impacts to permanent Robe River pools).	II	
T	A	01	04	Human health impacts from in situ fibrous material exposures	• Hazardous fibres exposed in situ by mining, mined and moved to encapsulated areas or naturally present in soils disturbed by mining / rehabilitation activities • Erosion of materials containing hazardous fibres post-closure	Health	• Physical materials characterisation for fibres routinely undertaken as part of drilling campaign (part of Fibrous materials management program) • Physical materials characterisation complete, no fibres present in mineral waste or mineralised materials.	Pit wall erodes and collapses post-mining revealing fibrous materials.	II	
T	**A**	**02**		**Void management**						
T	A	02	01	Pit lakes or Tailings have undesirable impacts on local ecosystem function	• Open water bodies in Pilbara naturally attract fauna (feral and native species) for food/ water/ refuge, safe access to water required • Concentration of natural groundwater or mineral waste derived salts through evapoconcentration in open water bodies • Release of metals from natural geology or mineral waste into water (infiltration or groundwater flow) • Water provides opportunity for plant /weed growth, good and bad (toxic algal blooms, noxious weeds) • Certain plant / animal species bio-accumulate / magnify toxic metals • Instability associated with saturated, unconsolidated ground, can be increased by high trafficability	Safety Environment Community Reputation Compliance CAPEX OPEX	• Void closure management guidance • Geochemical waste characterisation, good understanding of water chemistry / reaction chemistry • Physical waste characterisation • Rehabilitation handbook • Landform design guidance • Aquatic fauna research underway to understand natural levels of toxic metal accumulation / impact on native species	Cattle regularly access pit lakes for water. The lake fringe suffers severe erosion, becoming boggy, such that cattle regularly become stuck in pit area, die and contaminate water source.	II	RV03: Confirm the assumption that pit lakes will not be formed above WFSF at closure by conducting a water balance analysis for Mesa J waste fines storage facilities. RV04: Undertake a review of predicted water quality for the Mesa J reservoir to assess viability of leaving this areas as pit lakes. RV64: Develop detailed closure designs for existing WFSF's at Mesa J
T	A	02	03	Pit lakes or tailings have undesirable impacts on downstream ecosystem function	• Concentration of natural groundwater or mineral waste derived salts through evapoconcentration in open water bodies • Groundwater flow through pit lake / Tailings or mineral waste with connection to regional aquifer • Density driven saline groundwater flow from groundwater sink-style pit lakes • Downstream groundwater users (people, plants or animals) Alternate ecosystem may develop at discharge points leading to stakeholder concern when discharge ceases, However changes may not have been explained at commencement of project	Health Environment Community Reputation Compliance	• Any proposed pit lakes would be assessed in accordance with Void closure management guidance • Environmental surveys include regional groundwater dependent ecosystem • Geochemical waste characterisation, no PAF excavation planned	Higher saline groundwater from the former mining areas seeps into the Robe River pools, impacts local pool water quality / flora / fauna	III	RV10:Review environmental reports on potential impacts of mining activities on Robe River permanent pools and compare waters level and water quality. Determine key environmental receptors and potential ecological impacts. Determine if effects / impacts are masked by other impacts, such as discharge to Jimmawurrada Creek. RV15: Document and distribute conceptual understanding of pool supplement water supply post closure to mitigate drawdown impacts on Robe River pools.

Ref.				Risk Description					Risk Management C	
Risk Type (T=Th	Category	Subcategory	Item	Evaluated 20 of 20 risks (0 Remaining) Threat Title	Potential causes (Triggers / Indicators)	Impacts (Consequences)	Existing Controls and Commitments	Evaluation Rationale (Maximum reasonable consequence)		Detailed Action Descriptions
T	A	02	06	Pit wall stability compromises closure outcomes	• Influence of erosion, subsidence, seismicity, wall slip • Influence of groundwater recovery and surface water flow on stability. • Creek system neighbouring or within zone of instability, potential stream capture • Ecosystem downstream of void dependent on surface water flows • Poor communication of zone of instability to facilitate identification of important features • Clay zones not previously identified in the footwall compromise pit wall stability	Safety Environment Community Reputation Compliance CAPEX OPEX	• Geotechnical assessments for wall stability and zone of collapse part of mine design reviews • Mesa A façade / MEZ preservation required.	An area of the pit wall facade collapses, and some troglofauna habitat, heritage sites and caves are lost.	II	RV67: Incorporate any Troglofauna pit boundary changes into closure plan at Mesa K.
T	**A**	**03**		**Heritage**						
T	A	03	01	Heritage site condition / cultural value is degraded as a result of implementing the closure plan	• New (previously unidentified) heritage sites, not considered in existing assessment, discussions, agreements or with authority to disturb • Changes to landforms on closure have potential to alter conditions at downstream sites, e.g. consider drainage, landform footprint, erosion implications • Cessation of maintenance of / to heritage site Cultural values not considered in rehabilitation strategies Presence of heritage sites in close proximity to mining areas Downstream area of significant value to traditional owners	Community Reputation Compliance	• Internal ground disturbance approval request system • GIS system includes results from heritage surveys • Heritage sites within mine area, S18 application etc. prior to disturbance • Ongoing consultation with Traditional Owners • Geotechnical assessments • Exclusion area for homestead outstation Heritage management plan Environmental groundwater and pools monitoring regime in place during operations	Failure to stabilise the Homestead outstation landform leads to significant erosion of the remaining in situ topography and eventual loss of the site.	III	
T	A	3		**Closure Landforms**						
T	A	3	01	Built landforms (excluding mine void areas) erode and / or collapse	• Physical material properties considered in design • Drainage and erosion management • Construction of landforms / waste dumps to design requirements • Sensitive receptors identified downstreamadily modelled Design does not consider PMP/PMF events Wbo surface water model not completed	Environment OPEX	• RTIO Rehabilitation handbook used for general rehabilitation activities Landform design guidelines Rehabilitation designs approved by multiple disciplines including geology, geo-tech and hydrology Rehabilitation designed to be stable without vegetation	Waste dump erodes due to poor surface water management practice, causing rehabilitation to fail and necessitating post-closure repair.	III	RV24: Identification, segregation and stockpiling of competent materials to allow for armouring of erosive final landform surfaces to be encountered at Mesa H. RV61: Confirm material types contained in the Mesa K waste dumps. Closure plan assumes all hydrated waste RV63: Complete a rehabilitation design incorporating hydrological considerations for the Mesa K Northern waste dump, including the River and landform location RV66: Complete a surface water closure design for Mesa H, J and K
T	A	3	02	Vegetation does not meet completion criteria	• Vegetation established, but does not re-seed in same abundance • Weed competition • Species selection / insufficient species diversity • Animal interference i.e. feral animals eating new growth • Changes to soil water conditions e.g. salinity, water logging etc. Potential shortfall of topsoil and subsoil for use in rehabilitation Potential shortfall in seed procurement to meet closure schedule	Environment Community OPEX	• Rehabilitation handbook provides guidance on seed selection for appropriate diversity • Top soil stockpiles provide seed bank • Wetland rehabilitation trial established to assist in appropriate species selection for post-closure soil water conditions • Invasive species management plan will be developed as part of decommissioning activities • Geochemical materials characterisation complete. Material is inert and general expected to be acceptable growth media. • Rehabilitation handbook provides direction on surface treatment options • Annual stockpile reconciliation of top soil and sub soil stockpiles, return of 200mm to create quality surface growth media • Wetland rehabilitation trial established at Yandi will provide feedback on general waste erosion performance, will look at value of adding mulch	Vegetation establishment is below expectations leading to rework and additional seeding or more intensive and costly revegetation techniques	III	

Ref.				Risk Description					Risk Management C	
Risk Type (T=Th	Category	Subcategory	Item	Evaluated 20 of 20 risks (0 Remaining) Threat Title	Potential causes (Triggers / Indicators)	Impacts (Consequences)	Existing Controls and Commitments	Evaluation Rationale (Maximum reasonable consequence)		Detailed Action Descriptions
T	**A**	**04**		**Other regional considerations**						
T	A	04	01	Environmental outcomes outside of disturbance areas do not align with approved environmental impacts	• New (previously unidentified) environmental sites, not considered in existing environmental impact assessment • Changes to environmental conditions due to cessation of artificial support / mitigation activities, e.g. water supplementation • Change to drainage patterns on closure e.g. removal of temporary diversions, drains etc.	Environment Community Reputation Compliance	• Internal ground disturbance approval request system to prevent inadvertent disturbance • Baseline biological / ecosystem health surveys and existing monitoring to define post-mining status • GIS system includes results from all flora, fauna, vegetation surveys • Operational management plan for discharge includes actions relating to water quality and discharge extent targets, to ensure environmental issues are managed during operations • Significant species management plan implemented during operation to minimise impact to select species • Vegetation management plan implemented during operations to monitor and manage impacts to vegetation (riparian, understorey and weeds)	Waste dump failure causes downstream silting of water cause and impacts riparian ecosystem health	**II**	
T	A	04	02	Adverse impact to flora or fauna with conservation status or wider regional impact to high value environment	• Scheduled, listed or declared rare and / or threatened species of flora or fauna present in/adjacent to site • Downstream regional area of high value • Environmental conditions post-closure differ significantly from pre-mining conditions • Post-mining land use differs from pre-mining land use	Environment Community Reputation Compliance CAPEX	• Internal ground disturbance approval request system to prevent inadvertent disturbance • Baseline biological / ecosystem health surveys and existing monitoring to define post-mining status • GIS system includes results from all flora, fauna, vegetation surveys e.g. Mesa A MEZ exclusion zone • Operational management plan for discharge includes actions relating to water quality and discharge extent targets (proximity to Fortescue Marsh), to ensure environmental issues are managed during operations • Significant species management plan implemented during operation to minimise impact to select species • Vegetation management plan implemented during operations to monitor and manage impacts to vegetation (riparian, understorey and weeds)	Weeds florish in the rehabilitation areas and spread, increasing the weed growth in the surrounding undisturbed landscape.	**II**	
T	**B**			**Stakeholders**						
T	**B**	**01**		**Consultation**						
T	B	01	01	Consultation fails to identify stakeholder concerns	• Large number of stakeholders in the project • Clarity of explanation / prediction of closure outcomes, communication styles, long term engagement of agreed outcomes through generational change. • Stakeholder expectations change over time, due to changing global benchmarks for mine rehabilitation success, intergenerational change, regulatory changes etc. • Stakeholders do not endorse site closure as their issues / concerns were not addressed	CAPEX OPEX Reputation	• RTIO stakeholder engagement practice with key stakeholders i.e. Traditional Owner M&L, etc. • Ad hoc consultation with key stakeholders • Detailed engagement planned during decommissioning study • Stakeholder engagement register	A stakeholder comes forward during the decomissioning phase and requires different closure outcomes than planned.	I	
T	**B**	**02**		**Key stakeholder expectations**						
T	B	02	01	Closure outcomes do not meet stakeholder(s) / community expectations	• Absence of rehabilitation trial or data to support predicted outcomes, closure activities fail to achieve completion criteria • Communication of anticipated closure outcomes and post-closure land use needs i.e. wrong plant species established • Unrealistic expectations for economic potential opportunities / post-closure land use capability i.e. aquiculture in pit lakes Visual ammenity not considered in landform design	CAPEX OPEX Reputation Community	• RTIO stakeholder engagement practice with key stakeholders • Monitoring established for water, rehabilitation trials started • Numerical completion criteria established for some aspects	Historic rehabilitation outcomes are no longer acceptable to key stakeholder and re-work is required.	**III**	RV36: Review Mesa J proposed waste dumps to ensure in-pit backfill is maximised where practical and impacts to visual amenity are minimised. This may mean an increase to waste fines storage facility capping thickness
T	B	02	02	A stakeholder's expectations conflict with that of another stakeholder, causing delays to plan approval and / or closure	• Conflicting stakeholder expectations or areas of authority e.g. different regulators for environment, heritage, health, economic, tourism • Conflicting legal obligations e.g. State Agreement and EPA • Interactions between catchment land uses, including mining developments, at different points in time	Community Reputation	• RTIO stakeholder engagement practice with key stakeholders	Stakeholder disagree on decommissioning strategy, requiring extensive re-negotiation and delaying closure.	**II**	
T	B	2	3	Inability to achieve closure objectives and criteria due to cumulative impacts from third parties	Regional approach not taken No forum currently available for sharing information with other mining companies	Cost Reputation Compliance	Development of a business policy is underway to allow Rio Tinto to discuss rehabilitation and closure with third parties	This is not currently viewed as a serious credible threat for the Robe Valley		

Mesa J Hub Closure Risk Assessment

Ref.				Risk Description					Risk Management C	
Risk Type (T=Th	Category	Subcategory	Item	Evaluated 20 of 20 risks (0 Remaining) Threat Title	Potential causes (Triggers / Indicators)	Impacts (Consequences)	Existing Controls and Commitments	Evaluation Rationale (Maximum reasonable consequence)		Detailed Action Descriptions
T	B	2	04	Closure strategy prevents or limits future exploitation of resources	• Backfill sterilises ore reserves • Lakes or habitat restoration prevent / limit future access to adjacent resources	Community	• RTIO stakeholder engagement practice with key stakeholders • Integration of potential Billiards North expansion deposits into current closure plan options	Closure of the Mesa J site is compromised by future approvals to mine adjacenrt deposits	I	
T	**B**	**03**		**Other expectations**						
T	B	03	01	Mine closure has a significant, long-term detrimental impact on local communities	• Local communities receive direct support from operation for basic community services e.g. doctor • Significant proportion of community are directly or indirectly employed by operation	Reputation	• Pannawonica township is owned by Rio Tinto, houses Mesa J personel • Mesa A is FIFO site, with independent workers camp	Closure of the Robe Valley mines result in loss of tourism	I	
T	**C**			**Obligations**						
T	**C**	**01**		**Agreements and commitments**						
T	C	01	01	Closure is not implemented in accordance with the approved closure plan	• Mine development changes prevent closure plan from being implemented as planned • Implementation results in a different outcome than anticipated	CAPEX OPEX Community	• Integration of closure plan with LoM plan • Mesa A Troglofauna Management Plan Ministerial statement Stakeholder input and review of closure plans	Closure commitment to re-establish troglofauna habitat is mis-interpreted and does not meet approved closure plan requirements	**III**	

Appendix E – Task, Research and Trial Activities Schedule

Ref	Task	Indicative timeframe
RV03	Confirm the assumption that pit lakes will not be formed above WFSF at closure by conducting a water balance analysis for Mesa J waste fines storage facilities.	Next Closure Plan
RV04	Undertake a review of predicted water quality for the Mesa J reservoir to assess viability of leaving this areas as pit lakes.	Next Closure Plan
RV10	Review environmental reports on potential impacts of mining activities on Robe River permanent pools and compare waters level and water quality. Determine key environmental receptors and potential ecological impacts. Determine if effects / impacts are masked by other impacts, such as discharge to Jimmawurrada Creek.	Next Closure Plan
RV15	Document and distribute conceptual understanding of pool supplement water supply post closure to mitigate drawdown impacts on Robe River pools.	Before OoM
RV24	Identification, segregation and stockpiling of competent materials to allow for armouring of erosive final landform surfaces to be encountered at Mesa H.	During operations
RV36	Review Mesa J proposed waste dumps to ensure in-pit backfill is maximised where practical and impacts to visual amenity are minimised. This may mean an increase to waste fines storage facility capping thickness	Next LOM Plan
RV50	Review post-closure access road and road designs with key stakeholders to establish long-term liability and ownership for road maintenance at Mesa J hub	OoM
RV51	Review access to open faces, placement of abandonment bunds or reshape landform as appropriate (Mesa J hub)	Next LOM Plan
RV61	Confirm material types contained in the Mesa K waste dumps. Closure plan assumes all hydrated waste.	Next Closure Plan
RV62	Complete landform designs for any backfilled waste materials in the Mesa J pits to meet Landform Design Guidelines.	Next Closure Plan
RV63	Complete a rehabilitation design incorporating hydrological considerations for the Mesa K Northern waste dump, including the River and landform location	Next Closure Plan
RV64	Develop detailed closure designs for existing WFSF's at Mesa J	Next Closure Plan
RV66	Complete a surface water closure design for Mesa H, J and K	Before OoM
RV67	Incorporate any Troglofauna pit boundary changes into closure plan at Mesa K.	Next Closure Plan
RV68	Pit 11 backfill – refine location where the backfill volume is likely to come from and the respective rehabilitation design for this area	Next LOM Plan

Appendix F – Landform design criteria

The following tables provide summaries of the key design criteria (where available) of the waste landforms associated with Mesa J Hub.

Please note that these are interim rehabilitation designs and will be refined as the dump approaches rehabilitation.

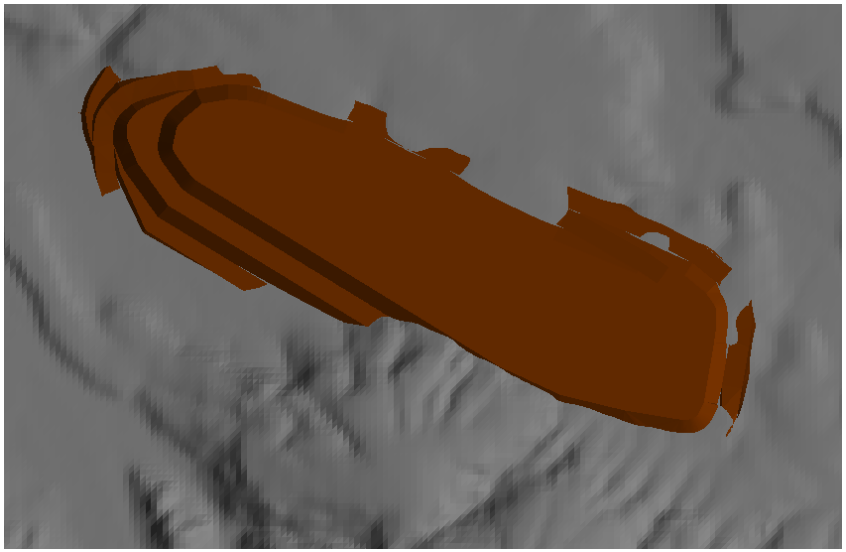
Mesa H SW Dump (Dump 2)

Waste volume		
Erodibility ranking	Moderate - High	
Classification	Inert ☒	Capping required at closure:
	PAF ☐	-
	Fibrous minerals ☐	-
	WFSF ☐	-
Overall height (m)	30	
Topsoil required (Mm^3)	95,074 m^3	

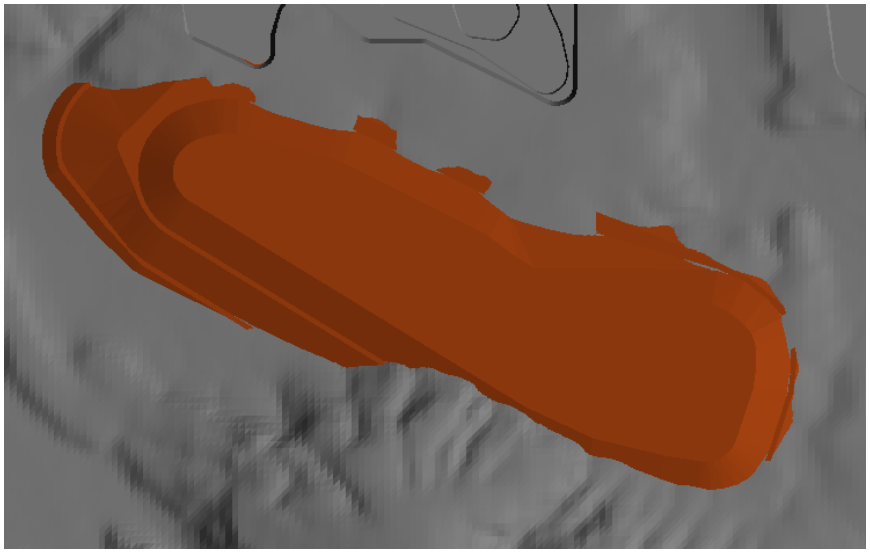
	Construction Specifications	**Rehabilitation Specifications**
Slope angle (deg)	37°	20°
Lift height (m)	20, 10	20, 10
Berm width (m)	NA	NA
Berm slope (deg)	NA	NA
Footprint (ha)		39.2

Comments:
Capped with hydrated waste for erosion mitigation

Construction Design



Rehabilitation Design



Mesa H SE Dump (Dump 3)

Waste volume		
Erodibility ranking	Moderate - High	
Classification	Inert ☒	Capping required at closure:
	PAF ☐	-
	Fibrous minerals ☐	-
	WFSF ☐	-
Overall height (m)	20	
Topsoil required (Mm^3)	362,663 m^3	

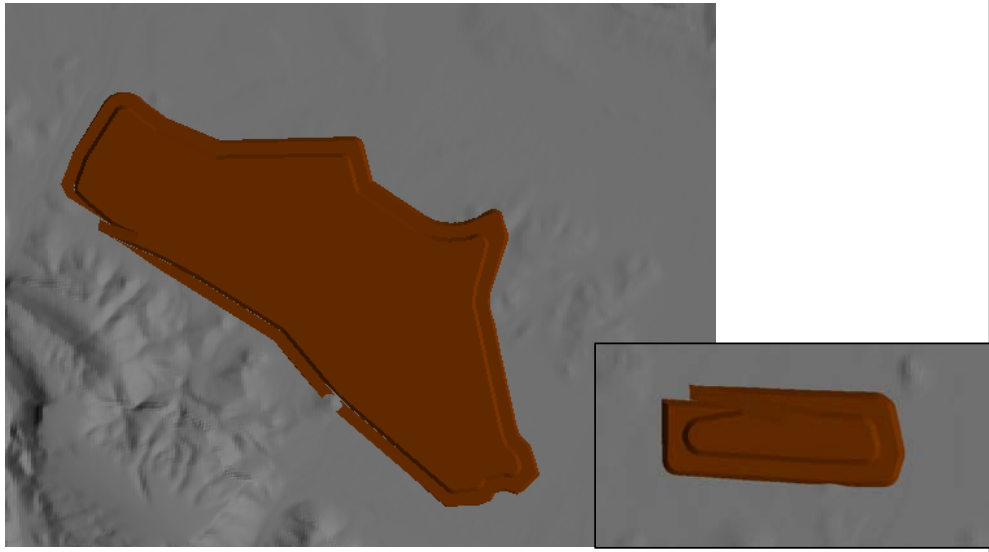
	Construction Specifications	**Rehabilitation Specifications**
Slope angle (deg)	37°	20°
Lift height (m)	10	10
Berm width (m)	NA	NA
Berm slope (deg)	NA	NA
Footprint (ha)		124

Comments:

Capped with hydrated waste for erosion mitigation

Rehabilitation design for the extension (inset image) will be completed prior to the next closure plan submission

Construction Design



Rehabilitation Design

Mesa H NE Dump (Dump 4)

Waste volume		
Erodibility ranking	Moderate - High	
Classification	Inert ☒	Capping required at closure:
	PAF ☐	-
	Fibrous minerals ☐	-
	WFSF ☐	-
Overall height (m)	30	
Topsoil required (Mm^3)	185,169 m^3	

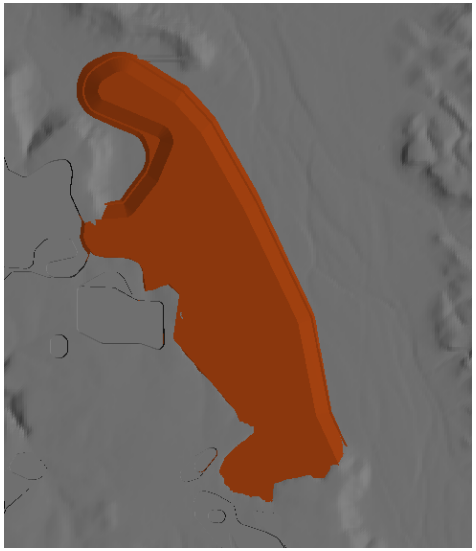
	Construction Specifications	**Rehabilitation Specifications**
Slope angle (deg)	37°	20°
Lift height (m)	20, 10	20, 10
Berm width (m)	NA	NA
Berm slope (deg)	NA	NA
Footprint (ha)		90.81

Comments:

Capped with hydrated waste for erosion mitigation

Construction Design

Rehabilitation Design



Mesa H Pit 1/3/4 backfill

Waste volume		
Erodibility ranking	NA	
Classification	Inert ☒	Capping required at closure:
	PAF ☐	-
	Fibrous minerals ☐	-
	WFSF ☐	-
Overall height (m)	NA	
Topsoil required (Mm^3)	TBC m^3	

	Construction Specifications	**Rehabilitation Specifications**
Slope angle (deg)	NA	NA
Lift height (m)	NA	NA
Berm width (m)	NA	NA
Berm slope (deg)	NA	NA
Footprint (ha)	TBC	TBC

Comments:

No rehabilitation design required as surface is flat

Construction Design

Rehabilitation Design

Mesa H Pit 6/8 backfill

Waste volume		
Erodibility ranking	NA	
Classification	Inert ☒	Capping required at closure:
	PAF ☐	-
	Fibrous minerals ☐	-
	WFSF ☐	-
Overall height (m)	NA	
Topsoil required (Mm^3)	TBC m^3	

	Construction Specifications	**Rehabilitation Specifications**
Slope angle (deg)	NA	NA
Lift height (m)	NA	NA
Berm width (m)	NA	NA
Berm slope (deg)	NA	NA
Footprint (ha)	TBC	TBC

Comments:

No rehabilitation design required as surface is flat

Construction Design

Rehabilitation Design

Mesa H Pit 9 backfill

Waste volume		
Erodibility ranking	NA	
Classification	Inert ☒	Capping required at closure:
	PAF ☐	-
	Fibrous minerals ☐	-
	WFSF ☐	-
Overall height (m)	NA	
Topsoil required (Mm^3)	TBC m^3	

	Construction Specifications	**Rehabilitation Specifications**
Slope angle (deg)	NA	NA
Lift height (m)	NA	NA
Berm width (m)	NA	NA
Berm slope (deg)	NA	NA
Footprint (ha)	TBC	TBC

Comments:

No rehabilitation design required as surface is flat

Construction Design

Rehabilitation Design

Mesa J Boondock

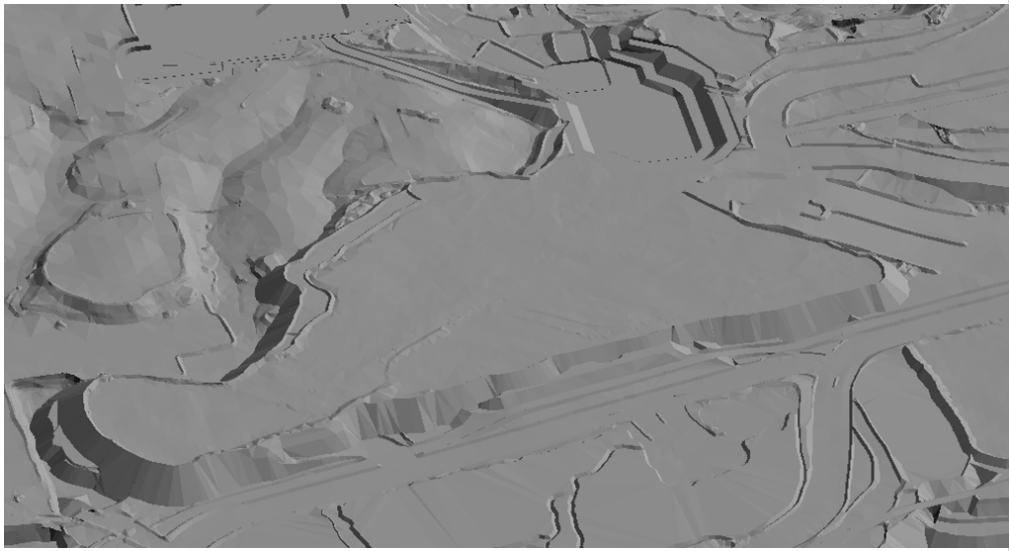
Waste volume		
Erodibility ranking	Low - Moderate	
Classification	Inert ☒	Capping required at closure:
	PAF ☐	-
	Fibrous minerals ☐	-
	WFSF ☐	-
Overall height (m)	20	
Topsoil required (Mm^3)	190, 000 m^3	

	Construction Specifications	**Rehabilitation Specifications**
Slope angle (deg)	37°	20°
Lift height (m)	20	20
Berm width (m)	NA	NA
Berm slope (deg)	NA	NA
Footprint (ha)	51.6	54.8

Comments:

Rehab design pending a construction design extension, based on sterilisation drilling of the area.

Construction Design



Rehabilitation Design

Mesa J Pit 11 in-pit dump

Waste volume		
Erodibility ranking	Low - Moderate	
Classification	Inert ☒	Capping required at closure:
	PAF ☐	-
	Fibrous minerals ☐	-
	WFSF ☐	-
Overall height (m)	25	
Topsoil required (Mm^3)	382, 000 m^3	

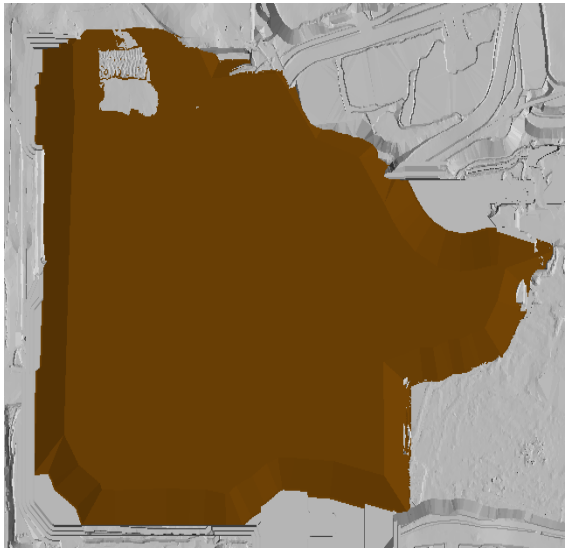
	Construction Specifications	**Rehabilitation Specifications**
Slope angle (deg)	37°	20°
Lift height (m)	25	25
Berm width (m)	NA	NA
Berm slope (deg)	NA	NA
Footprint (ha)	201.8	190.9

Comments:

Design will require review as adjacent WFSF designs are developed

A berm may need to be added if lift height does not meet erodibility requirements

Construction Design



Rehabilitation Design

Mesa J Pit 6 in-pit dump

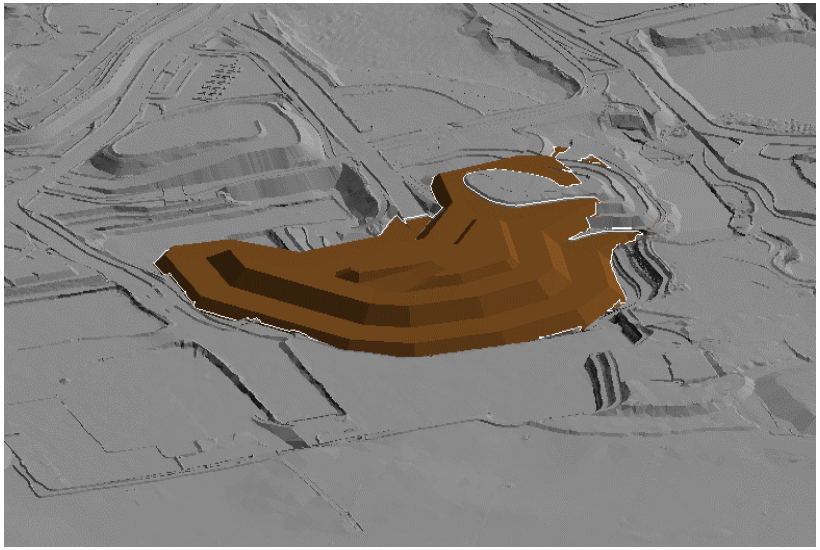
Waste volume		
Erodibility ranking	Low - Moderate	
Classification	Inert ☒	Capping required at closure:
	PAF ☐	-
	Fibrous minerals ☐	-
	WFSF ☐	-
Overall height (m)	54	
Topsoil required (Mm^3)	78, 000 m^3	

	Construction Specifications	**Rehabilitation Specifications**
Slope angle (deg)	37°	20°
Lift height (m)	20, 10	20,10
Berm width (m)	50	25
Berm slope (deg)	0	0
Footprint (ha)	24.3	24.3

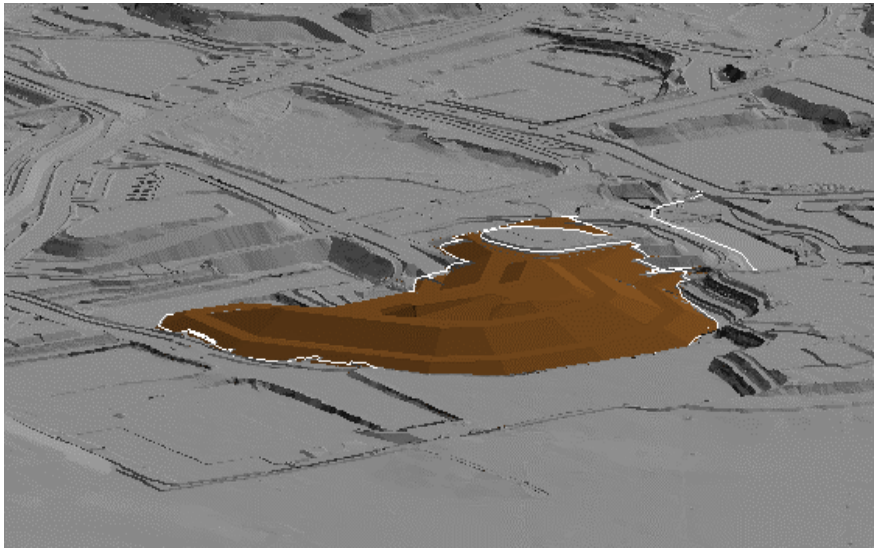
Comments:

Design will require review as adjacent WFSF designs are developed

Construction Design



Rehabilitation Design



Mesa K Northern Dump

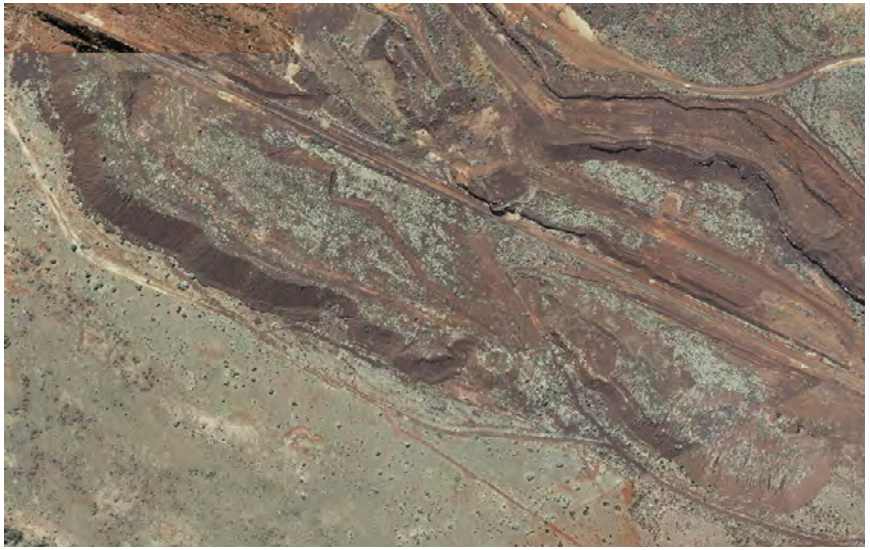
Waste volume		
Erodibility ranking	Low	
Classification	Inert ☒	Capping required at closure:
	PAF ☐	-
	Fibrous minerals ☐	-
	WFSF ☐	-
Overall height (m)	< 35	
Topsoil required (Mm^3)	27, 600 m^3	

	Construction Specifications	**Rehabilitation Specifications**
Slope angle (deg)	37°	15-20° (North), 20° (South)
Lift height (m)	35	10 (North), 20 (South)
Berm width (m)	NA	Concave (North), 25 (South)
Berm slope (deg)	NA	NA (North), 3° (South)
Footprint (ha)		21.1

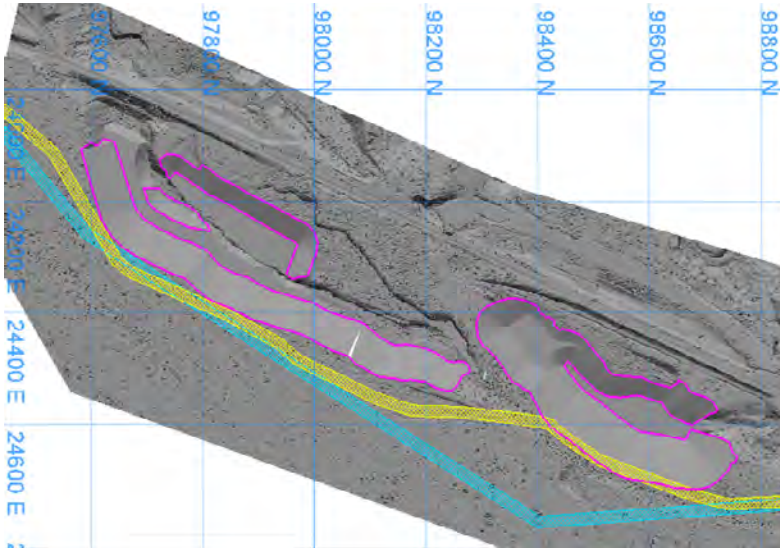
Comments:

Design under review due to significant constraints

Construction Design



Rehabilitation Design



PEER REVIEW: MESA H: H3 HYDROGEOLOGICAL ASSESSMENT

INTRODUCTION

The Robe River Joint Venture (the Proponent) is undertaking studies to support additional mining operations that will sustain production from the Robe Valley. A number of channel iron deposits (CID) resources in the Robe Valley have been considered.

Mesa H is proposed as the next development to sustain the Mesa J hub production and is scheduled to commence Q1 2020 utilising existing Mesa J infrastructure including existing wet processing facilities.

Mining at Mesa H is scheduled to extend over a period of about 18 years. Water levels in much of the Mesa H mine area have been lowered significantly by dewatering activities at the adjacent Mesa J but further dewatering will be required as approximately 13% of the resource lies below the current water-table (BWT). Water supply augmentation for the expanded mining and processing requirements is also planned.

Pre-Feasibility Studies (PFS) have been completed and it is currently anticipated that the works will progress to a Feasibility Study (FS) in 2017/2018 with planned Implementation in 2019. The Proponent is currently planning to submit API/PER approval documents to in Q4 2017 seeking to obtain a Part IV approval by Q4 2018 / Q1 2019.

PROJECT OVERVIEW

Mesa H is located immediately west and adjacent to the existing Mesa J mine, downstream from the confluence of the Robe River and Jimmawurrada Creek.

The deposit is bounded in the north and northwest by the Robe River where riparian vegetation is extensive and a series of pools exist. One of these pools - Yeera Bluff - is a Rights Reserve site of high significance to the traditional owners.

Dewatering at Mesa H, combined with operations at Mesa J, has potential to lower water levels along the drainage courses.

A significant data base and dewatering/water supply experience has been gained over many years at the adjacent Mesa J site, where similar geological conditions exist, but there have been limited investigations at Mesa H prior to 2015.

A detailed PFS investigation was undertaken through 2015-2016 to address hydrogeological risks identified during an earlier Order of Magnitude (OoM) study – specifically, identifying dewatering requirements and assessing potential associated impacts to the Robe River. The 2016 programme comprised drilling, construction and testing of four (4) water bores with 32 associated monitoring bores the results from which were used (in conjunction with Mesa J data) to develop a conceptual hydrogeological model and subsequent groundwater numerical model.

PEER REVIEW

Provisions were made in August 2016 for an independent peer review of the hydrogeological assessments of the Robe Valley projects.

The key objectives of the review were identified as:

- Review and verify the quantity and quality of hydrogeological information considered as part of the assessment is sufficient to satisfy PFS level understanding and to support API/PER approval submissions
- Review and verify the current conceptual hydrogeological models including an assessment of technical robustness, rigour and level of confidence in the interpretations and analyses;
- Review and verify the numerical groundwater model inputs, design, calibrations and outputs and assess in terms of National Water Commission's Australian Groundwater Modelling Guidelines (2012);
- Provide recommendation to address gaps in the conceptualisation and numerical models.

Independent Groundwater Consultants Pty Ltd was commissioned to undertake the review which has been undertaken by Graham Smith, a professional hydrogeologist with 40 years of local and international experience specializing in arid zone hydrogeology with familiarity of the Pilbara and Robe River through site visits, a number of mine development projects and previous Rio Tinto commissions (e.g. member of Expert Panel; 2015 Pre-Feasibility Study for the Bungaroo mine; Peer Reviewer hydrogeological assessments for Warramboo, Mesa C and West Angelas C&D).

The review has involved review of project technical documentation, a site visit and several discussions with technical personnel as the studies have progressed.

This report presents comment on the H3 Assessment Report for Mesa H with primary attention given to data availability, hydrogeological conceptualisation, analysis and assessment methods, groundwater modelling, impact assessments, mitigation measures if/as appropriate, water management planning and proposed future work programmes. The review of the hydrogeological conceptualisations and groundwater models draws on the Australian Groundwater Modelling Guidelines (Barnett et al, 2012).

Key Documents

The primary reference document provided for review was:

- Mesa H: H3 Hydrogeological Level Assessment v4.0 (RTIO, October, 2017).

Supporting documentation included:

- Mesa H: 2016 Pre-Feasibility Study Hydrogeological Drilling Program Completion Report (RTIO, May 2016).
- Mesa H: Groundwater Modelling rev.E (RPS, October, 2017).

Report Overview

The primary report has been well-prepared and is well supported by figures, tables and Appendices providing detail on the bore completions, the numerical model and an assessment of surplus water discharge extent. It includes the following Sections:

Introduction – provides an overview of the deposit (local aquifers, nearby water courses and environmental setting) and the adjacent Mesa J mine where dewatering occurs to facilitate BWT mining and provide process supplies.

Climate and Rainfall – describes climatic conditions, provides annual rainfall data, outlines contributing catchments and provides Robe River annual streamflow data (from upstream Ngalooin Pool and downstream Yarraloola).

Hydrogeology – describes local geology, aquifer occurrence (CID, Wittenoom and Robe River alluvium) well illustrated with cross-sections, hydrographs illustrating water level drawdown resulting from Mesa J dewatering and responses to rainfall, predicted pre-mining and current water level contours, recharge/discharge processes, water balance, an extended section on Robe River hydraulics where an estimate of mean annual flow (50GL/year) is given and contributing factors associated with the occurrence and status of permanent and semi-permanent pools occurring along the drainage are discussed, with supporting hydrographs. This is followed by an overview of flooding within Jimmawurrada Creek and connectivity with upstream Bungaroo palaeochannels.

Four (4) hydrogeological conceptualisations are presented in recognition of stated uncertainties around the characteristics of the Brockman Iron Fm and continuity of the Wittenoom Fm. Constraints associated with the heterogeneity of the local Robe River alluvial aquifer and the paucity of drilling information north of Mesa H and in Jimmawurrada Creek are also identified.

Existing Groundwater Use – describes dewatering (sumps/trenches), abstraction from an external borefield (Southern Cutback Borefield – SCB – that provides process and potable water supplies) and re-cycling at Mesa J, the Pannawonica town supply borefield drawing ~0.7GL/yr since 1981 from the Robe River alluvium (~10km northwest of Mesa H) and the Bungaroo Coastal Water Supply borefield (permitted to supply up to 10GL/yr for the West Pilbara Water Scheme) located upstream ~20km southeast of Mesa H.

Groundwater Investigation – summarises the extensive hydrogeological investigations to support water supply and dewatering at Mesa J since 1987, establishment of 14 monitor bores at Mesa H in 2015 and the 2016 works comprising installation of four (4) test production bores and 18 monitor bores (with reference to bore completion reports given as Appendix A). A summary of pumping tests and results (3 bores in Mesa H and 18 in Mesa J) is provided. Reference is made to RTIO-PDE-0143871 (not sighted) in presentation of Robe Rive alluvial aquifer characteristics as determined from analysis of long-term abstraction from the Pannowonica town supply borefield.

Groundwater Chemistry – presents detail on extensive programme of groundwater (43 bores) and surface water (7 pools) sampling and analysis (since 1993 at Mesa J) with discussion of

major ions, minor ions and isotopic composition to characterise the three main aquifers at the site and assess their potential contribution to the Robe River alluvial aquifer.

Groundwater Flow Model – summarises previous modelling works to predict inflows to Mesa J (initiated in 2002 and subsequently updated in 2003, 2004 and 2006), describes development of a new groundwater model in 2016 that combines both Mesa H and Mesa J (Modflow_Surfact v4.0 with Groundwater Vistas graphical user interface). Reference made to details provided in supporting Appendix B – Groundwater Numerical Model.

Difficulties associated with steady-state calibration and need for a dynamic calibration process are described with resultant good agreement between conceptual and model inflows and outflows.

Transient calibration, using annual time steps, compared predicted and observed groundwater levels through period 1990-2017 (using 37 bores with long-term records and 33 recently installed bores). Calibrated aquifer parameters are tabulated and a water balance presented. Zone budget analyses are described for the confluence of the Robe River and Jimmawurrada Creek and sites of inflow/outflow from the Robe River alluvium.

Model predictions are provided for dewatering of Mesa J and Mesa H and drawdown along the Robe River; these include augmentation of the SCB with an additional 3-5 water supply bores to meet the increased demand of the wet plant (8.7GL/yr) and continued discharge of surplus water along Jimmawurrada Creek the footprint of which as determined from a separate model. Reference made to details provided in supporting Appendix C –Surplus Water Discharge Extent Assessment.

Prediction uncertainty is discussed and eleven (11) additional model runs described for uncertainty analysis.

Assessment of Potential Impacts – using predicted 2037 water level drawdown resulting from dewatering and water supply discusses potential impacts (on water levels, the Robe river and Jimmawurrada Creek environments and the aquifer including predictions on post-mining water level recovery).

Site Water Balance – presents a detailed site water balance for each year through 2019-2037 identifying supply sources to meet demand for wet plant processing, infrastructure and dust-suppression.

Groundwater Monitoring – provides information on current (and planned) monitoring schedule from the approved site Groundwater Operating Strategy. Ongoing monitoring of flora, fauna and pools will continue in accordance with the Mesa J Environmental Management Plan. Risk to the environment with development of Mesa H is cited as high with acknowledgement that formal triggers (biological and water levels) will need definition prior to commencement of dewatering at Mesa H in 2024.

Management Approach/Conclusions – outlines defined Water Strategy, discharge system, maintenance and monitoring.

Key Findings

The key findings reported may be summarized as follows:

Aquifers

Groundwater occurs in three (3) main aquifers – the Robe River alluvials, the CID and the weathered basement (Marra Mamba Iron and Wittenoom Formations). Connectivity between the CID (to be dewatered during mining) and the underlying basement is constrained by the basal pisolites. Regional groundwater throughflow (CID and weathered basement) is estimated to be ~1.6GL/year.

Depth to water along the Robe River channel is shallow (2-5mbgl) and may fluctuate up to 3m annually in response to high rates of recharge and evapotranspiration. Natural groundwater throughflow is estimated to be ~0.8GL/year.

Conceptualisation

Groundwater flow in the CID and basement is from SE to NW following the trend of the CID palaeochannel deposits from upstream Bungaroo valley. The CID and Wittenoom aquifers are bounded by bedrock aquicludes (in the east by fresh Marra Mamba Iron Formation and by the Brockman Iron Formation in the west). Natural recharge is limited to direct inputs from rainfall but this has been locally augmented by leakage from Mesa J reservoirs.

Groundwater throughflow in the streambed alluvials of the Robe River and Jimmawurrada Creek naturally follows the drainage courses and are primarily recharged by infiltration of surface water flows that are generated by major rainfall events (supplemented locally by discharge of surplus water). The two principal drainages coalesce just upstream of Mesa H.

The pools that occur along the Robe River appear to be related to the alluvial aquifer and are groundwater dependent in drought periods.

A number of key uncertainties have been identified all of which may have significant impact on groundwater flow processes and responses to dewatering; these include aquifer characteristics of the Robe River and Jimmawurrada Creek alluvial systems. Four (4) different concepts are presented to accommodate primary uncertainties related to (a) whether the Brockman Iron Formation underlying Yeera Bluff is impermeable and (b) whether flow in the Wittenoom Formation discharges into the overlying Robe River alluvium or continues to the north.

Dewatering

Dewatering at Mesa H will commence 2024/2025 and, for all years, can be affected by in-pit sump pumping. Peak abstraction of 6.5ML/day will occur in 2033; total abstraction during LoM will be 11.3GL. Total abstraction 2019-2037 from the combined Mesa H and Mesa J operations, including water supply, will be 170GL with a peak of 9.5GL/year.

Water Disposal

Surplus water will be discharged to Jimmawurrada Creek at average rate of 2.1GL/year (peak 4.5GL). With potential discharge rates in range 5-30ML/day, the distance travelled by the surface water flow is predicted to be between 3.5km to 11.8km.

Water Demand and Supply

Water demand is dominated by the requirements of the Wet Plant which will require between 8.8 GL/year to 14.2 GL/year (average 11.9GL/year). Total water demand (including evaporative losses from on-site reservoirs) will range from 9.5GL/year to 15.6GL/year (average 13.3GL/year).

Dewatering product, seepage and decant recovery will make a significant contribution to supply but an external source will continue to be required; expansion of the SCB is planned to meet a maximum requirement of 8.5GL/year.

Impacts

Discharge of surplus water from Mesa J operations to Jimmawurrada Creek has likely contributed to maintaining water levels in the alluvial aquifer where no evidence of any impact on the aquatic environment has been found.

Combined dewatering operations at Mesa H and Mesa J will have minimal (<1m) impact on water levels along the Robe River north of the mines.

It is not expected that there will be significant impact to permanent pools in the Robe River (e.g. Yeera Bluff) but shallow semi-permanent and seasonal pools may dry out at a faster rate during prolonged periods when no surface water flows occur. Significant water level drawdowns will occur along a 9km reach of Jimmawurrada Creek as a result of the cumulative, combined impacts of Mesa J dewatering, abstraction from the SCB and the upstream Coastal Water Supply (CWS) borefield operation.

It is not anticipated that there will be any significant impact to riparian vegetation along the Robe River but there will likely be impact on phreatophytic vegetation along a 4-9km reach of Jimmawurrada Creek. Reductions in stygofauna habitats may also occur with lowering of water levels there but this is expected to be localised and minor.

Natural water levels will recover to pre-mining levels after 60 years.

Uncertainties

Inherent uncertainties exist with the parameters adopted to describe the hydrogeological system. Uncertainty analysis has been undertaken to evaluate conceptual model, climate change and numerical model uncertainties; results tend to confirm conceptualization and model behaviour.

Mitigation

The requirement for a mitigation strategy to supplement water to the permanent and semi-permanent pools in Robe River from 2030 (given uncertainties, values and ecosystem sensitivity) is identified. It is envisaged that monitoring of water levels in the Robe River pools and the area predicted to be impacted along Jimmawurrada Creek will be used to develop and trigger mitigation actions Options for mitigation have been identified (eg supplemental discharge, modification of abstraction regime, aquifer reinjection, etc.).

Planned Future Works

Planned works, cited in Scope of Work Mesa H FS Hydrogeology Drilling June 2017 v2.2, seek to address the hydrogeological risks identified in the PFS and include:

- Installation of up to six (6) test bores, eleven (11) monitor bores and two (2) VwP.
- Aquifer testing of all installed bores.
- Discharge trial (up to 30 days) in the Robe River (to support design of an impact mitigation strategy for local pools).
- Investigation of water supply sources for construction camp.

Review Comments

Field Investigations

The PFS investigations have been conducted to a high standard. Drilling, monitor and test production bore construction methods and aquifer testing conform to best-practice, are well documented and provide a sound data set for the Mesa H mine area.

Data Availability

Available rainfall and Robe River streamflow records have been included in the assessment; these demonstrate frequency of major rainfall and flood events. Groundwater levels and quality are well established with an extensive monitor bore network. Whilst there is limited discrete aquifer data, the adopted parameters conform to experience in similar environments and appear reasonable. No test data is provided to support the assumption that the basal pisolites constrain flow between the CID and underlying bedrock aquifers; based on the recorded lithology and thickness, however, this is considered a reasonable assumption. Data to characterize the alluvial aquifers associated with the Robe River near Mesa H and Jimmawurrada Creek near Mesa J are similarly absent. Aquifer parameters deduced from operation of the Pannawonica borefield appear reasonable and provide support for the parameters adopted for the Robe River alluvial aquifer. Uncertainties remain with regard to the alluvial system associated with, and surface water flows within, Jimmawurrada Creek. Notwithstanding the above, the cumulative data set is considered to provide an adequate technical foundation for the conceptualisations and detailed numerical modelling process.

Hydrogeological Conceptualisation

The geological model and characteristics of the primary hydro-stratigraphic units are well-established and provide a sound foundation for hydrogeological assessment. The conceptual model is based on the integration of all available information including background information from previous investigations, extensive experience in water management gained over many years at Mesa J where similar hydrogeological conditions exist, ongoing monitoring at Mesa J and information generated by specific investigations.

The concepts re: pools and alluvial aquifer processes is based on detailed assessment of available water level and water quality data and appear sound.

Uncertainties in conceptualisation have been clearly identified and adequately addressed in the modelling process.

Modelling

The objectives of the modelling are clearly stated and the model set-up honours the documented hydrogeological conceptualisation. Standard modelling packages and techniques have been deployed and what appear to be appropriate boundary conditions established.

Calibrated aquifer parameters are in general conformity with field-derived values; adopted low fresh bedrock values are considered appropriate. Inherent uncertainty exists with storage parameters.

Model predictions accommodate a number of assumptions related to many operational processes. These appear well-considered and further demonstrate a sound site water management plan. The assignment of surface water flows in Jimmawurrada Creek as a proportion of Robe River flows (based on contributing catchment areas) is supported.

Uncertainty analysis has usefully assessed conceptualisation and climate variables. Summary results indicate that drawdowns in the Robe River alluvials in excess of 1m are predicted to only occur in the sustained absence, or large-scale reduction, of flood flows. It is noted, however, that drawdowns of similar magnitude are predicted with modification of the general head inflow boundary associated with the Robe River which warrants further assessment.

The documentation for the modelling effort is of high standard and well-presented. The claimed model confidence level classification – Class 2 – is supported.

Dewatering

The predicted rates/volumes appear reasonable and gain support from the longer-term experience gained in the adjacent Mesa J pits where similar conditions prevail.

Impacts

Potential impacts have been identified and assessed. The dominance of surface water flows in the water balance (or indirect recharge derived therefrom) has, as would be expected, been clearly demonstrated.

The prediction that impacts along the Robe River north of Mesa H and Mesa J will be minor appear sound. Under average annual streamflow conditions and assumption of vertical flow constraints imposed by the basal pisolites underlying the CID aquifer, such impacts are less than natural seasonal variations and consequently considered unlikely to be of such a magnitude to pose any threat to local environmental values. Any water level drawdowns in the alluvials that do result from dewatering operations will, however, be naturally augmented in the absence of flood events. The contention that there will be natural mitigation of minor drawdown impacts along the Robe River by infiltration of surface water flows is supported by hydrographs from monitor bores showing water level responses associated with significant rainfall events (and assumed floods) along the Robe River (at Pannawonica) and Jimmawurrada Creek (near Mesa J) and appears reasonable.

The predicted significant drawdown impacts along a section of Jimmawurrada Creek are as would be anticipated given location near the SCB and predicted groundwater flow reversal resulting from continued operation of the upstream CWS borefield.

Uncertainties

A number of uncertainties have been identified that primarily relate to the aquifer characteristics of various formations, groundwater flow paths and hydraulic connectivity between formations. These should be adequately addressed in the planned, follow-on work programmes with further insight provided by continued monitoring.

Summary

The quantity and quality of hydrogeological information presented is considered sufficient to satisfy PFS-level understanding and to support API/PER approval submissions.

The current conceptual hydrogeological models have been developed on an extensive data set taking due account of local geology, hydrology, hydrogeology and historic site water management and are supported; uncertainties have been identified and will be addressed in follow-on programmes.

The numerical groundwater model honours the hydrogeological conceptualization and is considered fit for purpose meeting key objectives of quantifying required dewatering rates and potential impacts. Design conforms with standard practices and is based on a sound geological model; calibrated parameters are in accordance with field-derived or acceptable values. Information on calibration, predictions and uncertainty runs is well documented. In terms of the National Water Commission's Australian Groundwater Modelling Guidelines (2012), the reported Class 2 level of confidence is supported.

Model predictions indicate that:

- dewatering drawdown impacts along the Robe River will be minor and less than natural water fluctuations. Evidence exists to support contention of natural mitigation through infiltration of surface water flows.

- significant water level drawdowns will occur along a reach of the Jimmawurrada Creek as a result of abstraction from the nearby SCB and upstream CWS.

A requirement for mitigation measures has been identified; options exist and are to be further assessed.

Recommendations

Whilst the proposed work to advance hydrogeological understanding to Feasibility Level and continued monitoring should address the key uncertainties that have been identified, consideration should also be given to:

- Augmentation of the monitoring network with facilities to record flood events along both the Robe River and Jimmawurrada Creek and water levels/quality in any pools therein.

- Further examination of the available data sets with a view to confirming the areal extent, thickness and hydraulic properties of the basal pisolite layer.

- Obtaining discrete hydraulic properties of the key formations.

In addition, as a prelude to future modelling work, a re-assessment of boundary conditions would be prudent and further analysis of zonal water balances to confirm, and improve definition of, expected fluxes between the key formations.

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Memo

From	Darryn Knoesen
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To	File
CC	Mark Pearcey; Jeremy English
Reference	RTIO-PDE-0149961
Date	12 March 2017
Number of pages	12

Surplus water discharge extent assessment: Mesa H

Overview

The Mesa H deposit is located approximately 11 km southwest of Pannawonica and adjacent to the Robe JV Mesa J mine, downstream of the confluence of the Robe River and Jimmawurrada Creek (Figure 1). Approximately 40% of the resource is below the current water table (which has been lowered by dewatering at Mesa J). Consequently, approval will be sought to commence mining below water table, which will require dewatering.

Management of water on Rio Tinto sites follows strict environmental and water use standards (refer to Rio Tinto Environmental Standards). These standards align with the "Pilbara Water in Mining Guideline" (DoW, 2009) which identifies options for use and/or release of dewatering discharge:

- Efficient on-site use, including mitigation of any impacts.
- Used for fit for purpose activities (such as processing and dust suppression). The proponent needs to demonstrate that the water is of suitable quality for the end use.
- Transferred to meet other demand including other proponents in the area and public water supply, as approved by the Department. Where it is proposed to use the water for public supply, a drinking water source protection plan should be developed and approved by the Department of Water and the Department of Health.
- Injection back into the aquifer at designated sites determined by the proponent and agreed by the Department.
- Controlled release to the environment where the dewater release is allowed to flow (either through a pipe or overland) into a designated water course or wetland and determined by the proponent and agreed by the Department.

Management of surplus water at Mesa H may include the controlled discharge of surplus water at existing discharge locations at Mesa J, namely Discharge point 5 (Jimmawurrada Creek) or Discharge Point B (Robe River tributary immediately west of Mesa J). Therefore, the objective of this study was to estimate the extent of impact of surplus water discharge along the respective watercourses. The methodology to achieve this objective is outlined below:

- Develop a 2D hydraulic model of the river system downstream of the proposed discharge location.
- Determine the hydraulic characteristics that are not inherently accounted for by the 2D hydraulic model, i.e. saturated hydraulic conductivity of the soils.
- Estimate the maximum possible extent that surplus water discharge will flow under steady-state conditions.
- Investigate multiple steady-state scenarios, namely a continuous discharge rate of 5, 10, 15, 20, 25 and 30 ML/day.

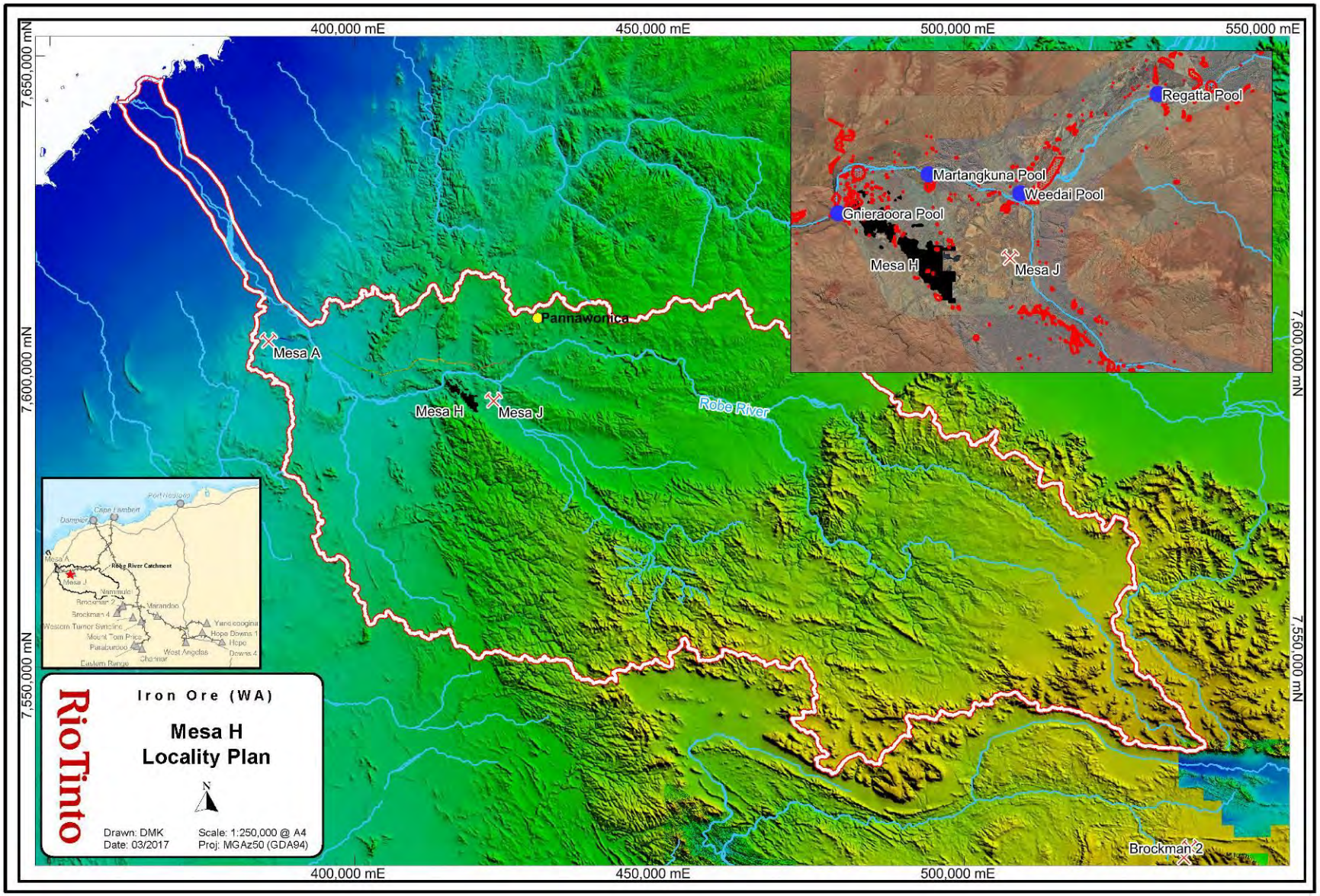

Figure 1: **Mesa H surplus water discharge study location plan**

Modelling Approach

Water flowing in a watercourse is removed from the surface via two mechanisms, namely: evaporation and infiltration. However, these hydrologic processes are inextricably intertwined with the flow characteristics, and hence the hydraulics, of the river system. The braided nature of typical Pilbara watercourses creates a complex hydrodynamic environment where the flow behaviour is essentially 2D in nature, which may be poorly represented using a 1D model.

Recent developments to the **T**wo-dimensional **U**nsteady **Flow** (TUFLOW) model have effectively transformed TUFLOW into a 2D coupled hydrologic-hydraulic modelling system, with the ability to model soil infiltration in both unsaturated and saturated conditions. This makes the TUFLOW model a useful tool for the estimation of surplus water discharge extent.

This section documents the process and assumptions made in developing the 2D hydraulic model for the Mesa H surplus water discharge.

TUFLOW hydraulic model

For this study, TUFLOW's GPU Module was adopted. This is a powerful new solver built into the TUFLOW software, which utilises the substantial parallel computing ability of modern Graphics Processor Units, or GPUs (TUFLOW, 2014). TUFLOW GPU is an explicit solver for the full 2D Shallow Water Equations, including a sub-grid scale eddy viscosity model. The scheme is both volume and momentum conserving. Owing to the power of modern GPUs very large models (>100 million cells) with fine grids can now be run within a sensible timeframe (TUFLOW, 2014). This allowed for a high resolution 1 m DEM, derived from LiDAR, to be used to describe the topography of the river system. This represents a major advantage of this approach. The model configurations are shown in Figure 2.

Manning's roughness coefficient *n*

Surface roughness is defined using the Manning's *n* roughness coefficient. The roughness coefficients adopted for this study were determined according to Chow (1959), which takes into consideration channel irregularities, variation in cross section, obstructions, vegetation density and meandering of the reach. These factors were assessed using aerial photography and confirmed during a site visit. The adopted Manning's *n* roughness coefficient for the Robe River and Jimmawurrada Creek was 0.045, while the Robe River tributary immediately west of Mesa J was assigned a Manning's *n* roughness coefficient of 0.035. These values were applied to all applicable active cells in the model, which was limited to the river/creek channels, as can been seen in Figure 2.

Model inflows

Multiple steady-state scenarios were assessed, namely a continuous discharge of 5, 10, 15, 20, 25 and 30 ML/day.

Model outflows

The maximum discharge extent is achieved when equilibrium is reached between the inflows to and the outflows from the system. Water flowing in a watercourse is removed from the surface through evaporation and/or infiltration.

Evaporation

Annual and monthly potential evaporation rates (A-pan) are available from the Bureau of Meteorology (BoM) website. However, evaporation from open water bodies can be significantly less than A-pan estimates owing to a variety of climatic factors. As such, correction factors are often required to relate A-pan evaporation to evaporation from open water bodies. From Figure 3 it can be seen that evaporation from open water bodies for most of the Pilbara region of Western Australia is between 60-70% of the A-pan evaporation rates.

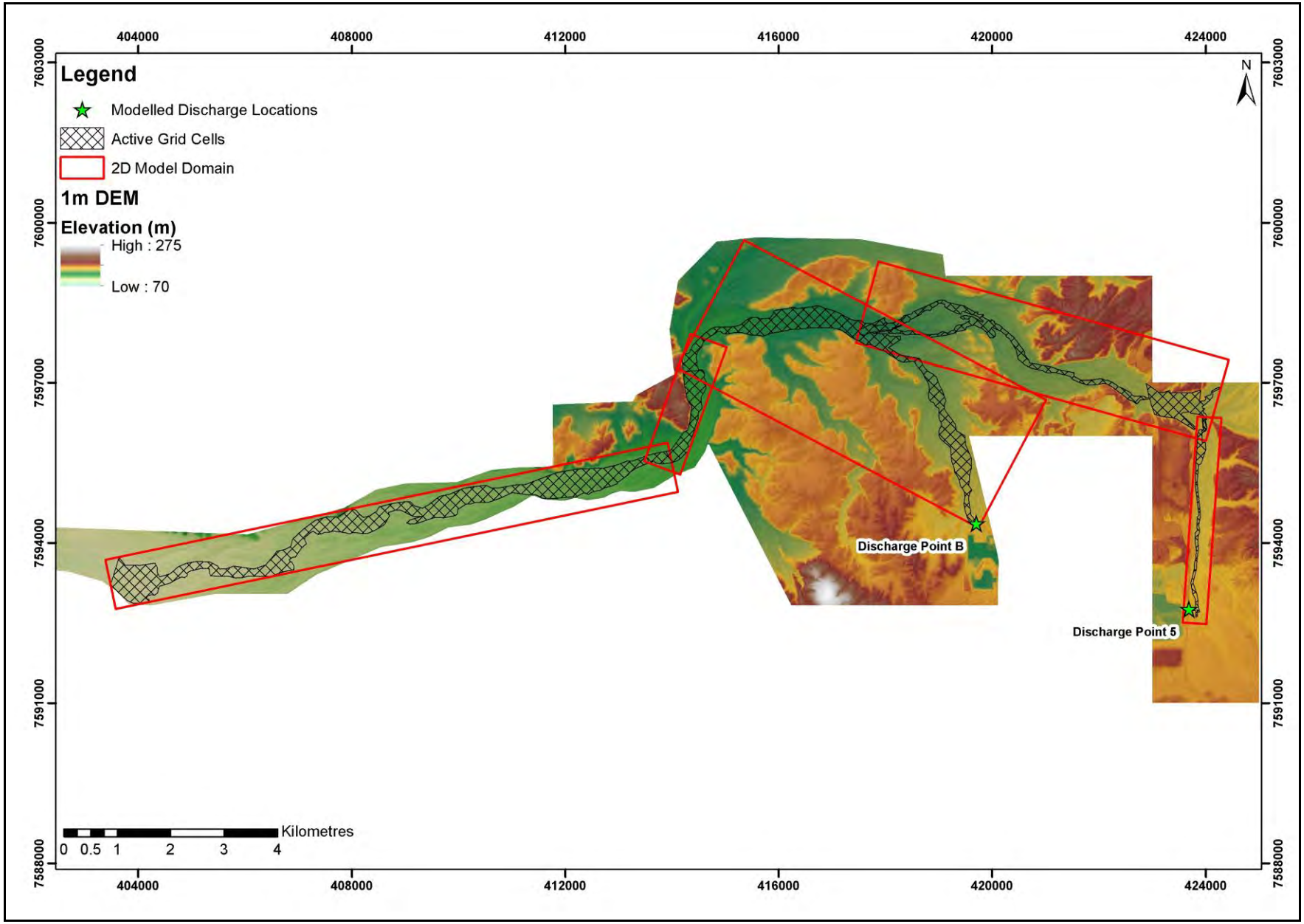

Figure 2: TUFLOW model configuration

From Figure 3, the A-pan evaporation rate for Mesa H was determined to be 3400 mm per year. However, the lowest monthly A-pan evaporation occurs in June (157 mm). This was multiplied by 0.65 (Luke et al., 1987) to relate A-pan to open water body evaporation. Consequently the adopted evaporation rate was 102 mm per month, which translates to an average rate of 0.14 mm/h.

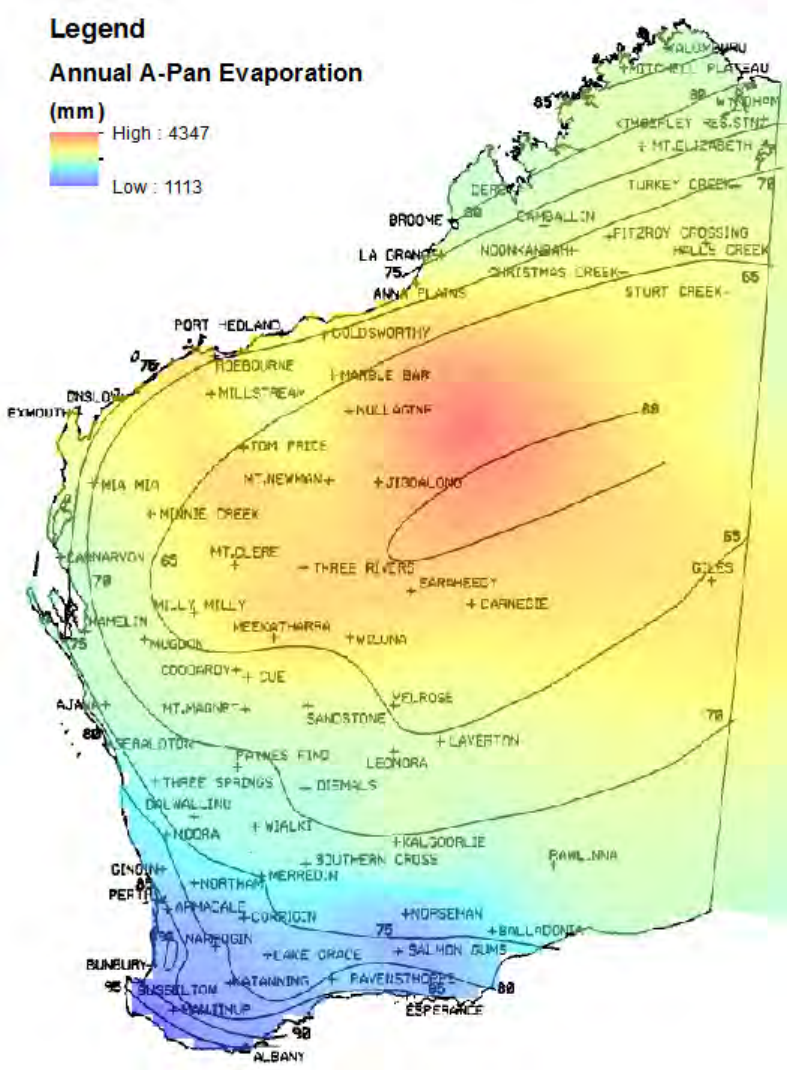

Figure 3: **Gridded annual A-pan evaporation and A-pan correction factors (contours) for Western Australia (from BoM and Luke et al., 1987)**

Infiltration

The maximum discharge extent is achieved when equilibrium is reached between the inflows to and the outflows from the system. As the soil moisture content increases so the infiltration rate of the soil decreases until the saturated hydraulic conductivity (K_{sat}) of the soil is reached. Consequently, equilibrium between the inflows and outflows, and hence the maximum discharge extent, can only be achieved once the soils have reached saturation. As such, when the aim of the discharge extent modelling is to determine the maximum discharge extent for long-term discharge there is no need to simulate losses in unsaturated conditions, and a continuing loss equal to K_{sat} may be adopted.

Although the Soil Hydrological Properties for Australia (Western and McKenzie, 2006) provides K_{sat} values for the whole of Australia, experience has shown that these values can be up to three orders of magnitude too high, thereby overestimating losses from the system and drastically under estimating the maximum discharge extent. As a result, a texture based approach to estimate K_{sat} in the absence of measured data has been applied. This approach derives a weighted clay content for each Map Unit in the Atlas of Australian Soils (Northcote

et al., 1960-1968), which places the Map Unit into one of six Texture Groups documented by McKenzie et al. (2000), shown in Table 1.

Table 1: Texture groups according to clay content - adapted from McKenzie et al. (2000)

Weighted Clay Content (%)	Texture Group	Texture Grade
0 – 8	Sands	Sand Clayey Sand Loamy Sand
8 – 17.5	Sandy Loams	Sandy Loam Fine Sandy Loam Light Sandy Loam
17.5 – 25	Loams	Loam Loam, Fine Sandy Silt Loam Sandy Clay Loam
25 – 35	Clay Loams	Clay Loam Silty Clay Loam Fine Sandy Clay Loam
35 – 47.5	Light Clays	Sandy Clay Silty Clay Light Clay Light Medium Clay
47.5 – 100	Clays	Medium Clay Heavy Clay

The least permeable texture grade is adopted as the representative texture for each Texture Group, and is therefore considered to be a conservative estimate. The adopted K_{sat} values for each Texture Group are presented in Table 2.

Table 2: Saturated hydraulic conductivities for different texture groups – adapted from Clapp and Hornberger (1978), Cosby et al. (1984) and van Gool et al., (2005)

Texture Group	Adopted K_{sat} (mm/h)
Sands	50.6
Sandy Loams	18.8
Loams	10.1
Clay Loams	6.1
Light Clays	3.7
Clays	3.0

Figure 4 shows that the creeks and rivers downstream of the discharge locations cross four different soil Map Units, namely, B27, Fa13, My1 and Oc66. Using the approach outlined above the Texture Group and K_{sat} for each Map Unit was derived, and is presented in Table 3.

Table 3: Soil Map Units in study area and adopted saturated hydraulic conductivities

Soil Map Unit	Weighted Clay Content of Limiting Soil Horizon (%)	Texture Group	Adopted K_{sat} (mm/h)
B27	30.0	Clay Loams	6.1
Fa13	27.5	Clay Loams	6.1
My1	36.5	Light Clays	3.7
Oc66	44.0	Light Clays	3.7

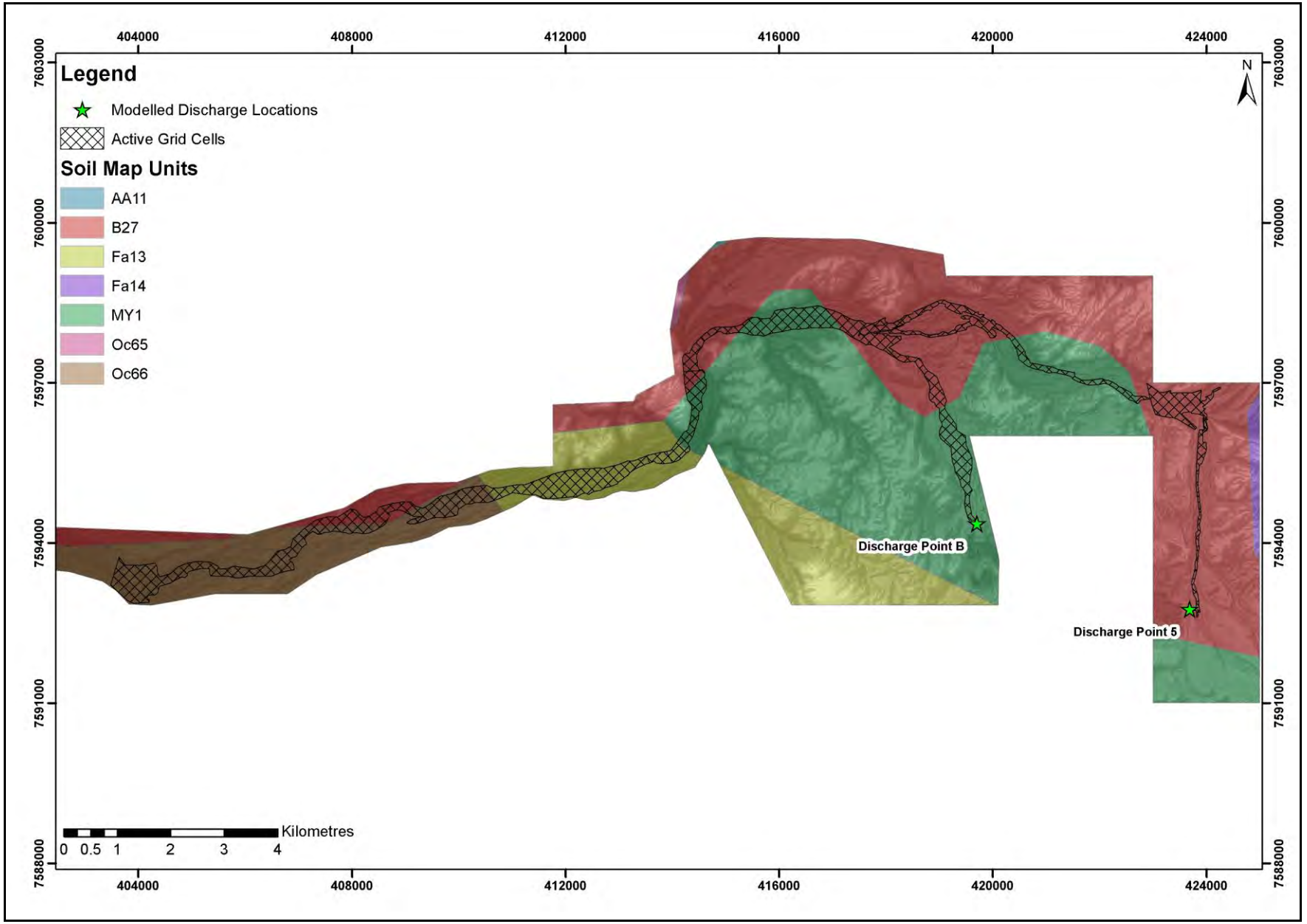

Figure 4: **Soil Map Units intersected by the watercourses downstream of the proposed surplus water discharge locations**

Results

Results for the various discharge modelling scenarios are presented in Table 4 and Figure 5. It is estimated that the surplus water discharge extent will range from 3.5 km to 20 km down gradient of the assumed discharge point depending on the discharge rate and discharge location, before completely infiltrating/evaporating.

Table 4: Estimated discharge extent from discharge location for various discharge rates

Scenario	Distance Travelled (km)	
	Discharge Point 5	Discharge Point B
5 ML/d	3.5	4.7
10 ML/d	5.2	8.8
15 ML/d	5.2	11.8
20 ML/d	5.9	14.4
25 ML/d	9.3	17.2
30 ML/d	11.8	19.9

The braided nature of typical Pilbara watercourses creates a complex hydrodynamic environment where the flow behaviour is essentially 2D in nature. Often braided flows are thought of as a consequence of flooding where flows break out onto poorly defined floodplains. Figure 6 clearly demonstrates that complex bifurcations can also be a characteristic of the low flow regime, and was found in this assessment to be typical in the Robe River, thereby justifying the selection of a 2D hydraulic model.

The surplus water discharge volume would be significantly smaller than the volume generated by the catchment during flood events. Based on model results, discharged water would be contained within the low flow channel/s, hence overtopping of the creek banks in dry conditions is not anticipated.

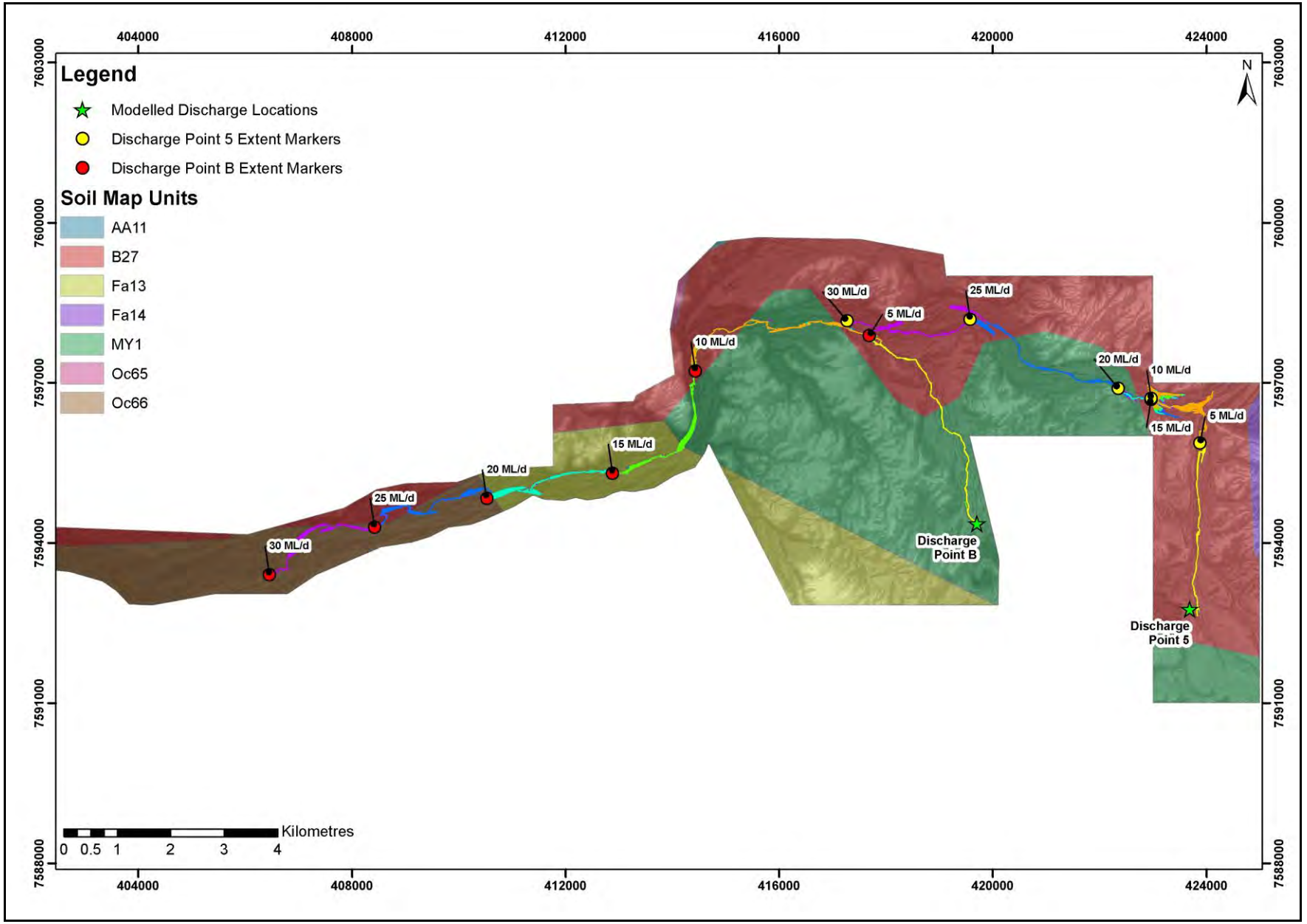

Figure 5: **Modelled maximum discharge extents for various discharge rates**

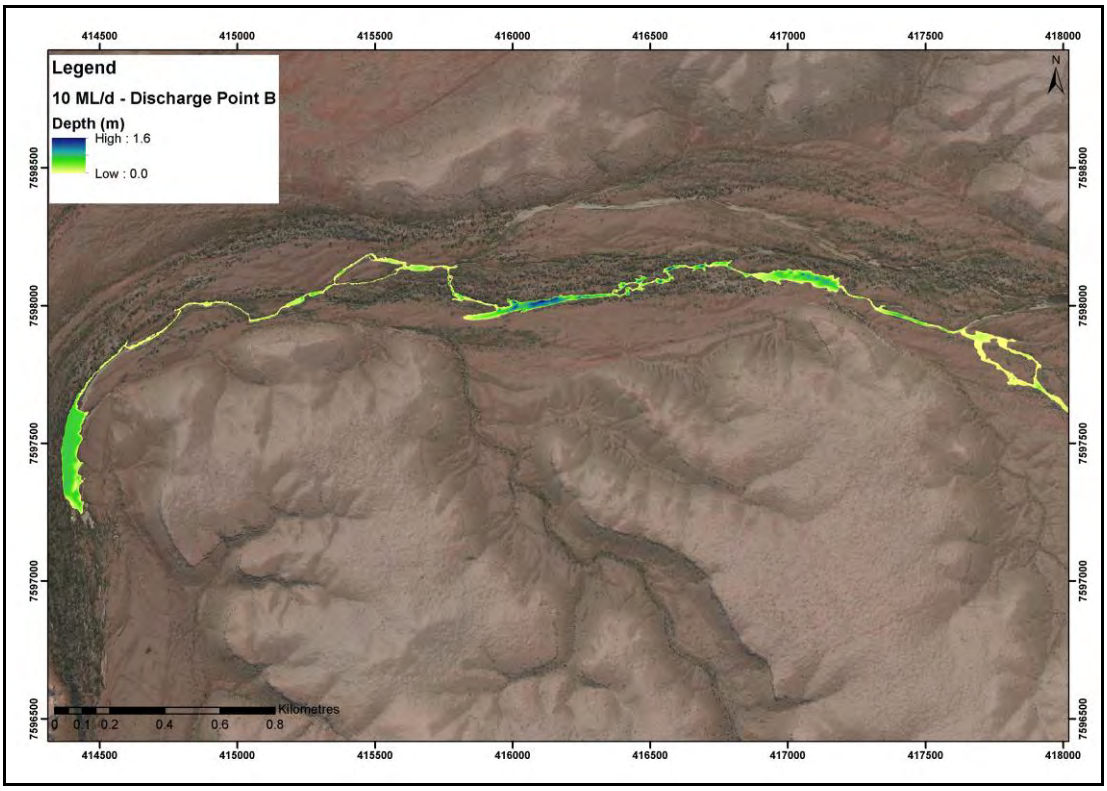

Figure 6: **Complex flow regime of the Robe River modelled in TUFLOW**

Conclusion

A 2D hydraulic model of the Robe River and relevant tributaries has been developed to estimate the extent of future potential surplus water discharge from the proposed Mesa H operations. The key advantage of the approach was the ability to hydraulically simulate the complex hydrodynamic environment while simultaneously accounting for hydrologic processes such as infiltration and evaporation.

The maximum surface water extents from five discharge scenarios were modelled: namely a continuous rate of 5, 10, 15, 20, 25 and 30 ML/day. It is estimated that the surplus water discharge extent will range from 3.5 km to 20 km down gradient of the assumed discharge point depending on the discharge rate and discharge location, before completely infiltrating/evaporating.

The surplus water discharge volume would be significantly smaller than the volume generated by the catchment during flood events. Based on model results, discharged water would be contained within the low flow channel/s, hence overtopping of the creek banks in dry conditions is not anticipated.

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Internal Memo

From	Lisa Terrusi
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To	Melinda Brand
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Date	13 September 2017
Number of pages	12

Mesa H 2017 AMD Risk Assessment Update Summary

Introduction

A review of the acid and metalliferous drainage (AMD) risk associated with mining in the Mesa H project area has been completed to support the referral of the Mesa H Iron Ore Project Proposal under Section 38 of the *Environmental Protection Act 1986*. This review considers recently available (July 2017) drillhole data and mine planning data.

The overall AMD risk for the Mesa H area remains low following an update to the initial assessment [RTIO, 2016]. This memorandum presents a summary of information as documented in the *AMD Risk Assessment for the Robe Valley* [RTIO, 2017].

Background Information

Rio Tinto has undertaken an extensive program of geochemical testing over several years to understand the potential for acidification and/or metalliferous drainage to occur as a result of exposing various waste rock types common to mining operations in the Pilbara. The geochemical characterisation process aims to assess sulfur content as an indicator of acid generation potential, and to undertake static (acid base accounting) and, if appropriate, kinetic testing of materials. This information is applied to the geological and mining models to ensure materials posing potential geochemical risks are identified prior to mining and managed appropriately. This work is in accordance with the *Rio Tinto Iron Ore (WA) Mineral Waste Management Plan for Undeveloped Resources and Studies* and the *Spontaneous Combustion and Acid Rock Drainage (SCARD) Management Plan*.

The most significant geochemical risk posed by mining iron ore deposits in the Pilbara is associated with the sulfide mineral pyrite (FeS_2), which can form sulfuric acid when exposed to oxygen and water. The unoxidised Mount McRae Shale, most commonly associated with pyrite and AMD, will not be exposed during mining at Mesa H. However, pyrite may also occur in Banded Iron Formation (BIF) of the Marra Mamba Iron Formation (MM), as well as within the Wittenoom Formation (WD), which are known to underlie the channel iron deposit (CID) in the Mesa H area. Other sulfate minerals, such as alunite and jarosite, may also pose a geochemical risk, albeit the risk is usually lower due to self-limiting chemical processes.

Total Sulfur Analysis of Mesa H Drillhole Samples

A sulfur cut-off value of 0.3% is generally relevant to rock types associated with the Robe Valley area (e.g., BIF and detritals). However, for rock types containing black shale, where sulfur is likely to be in the form of pyrite and containing minimal acid neutralising capacity, a sulfur cut-off of 0.1% is applicable. In addition, material associated with elevated-sulfate (where sulfur values may range from 0.1% to greater than 1%) is also considered to be potentially acid forming in a low capacity. Sulfur cut-off values of both 0.1% and 0.3% are considered in this assessment.

The analysis of total sulfur content in drillhole data (covering historical drilling to 2017) was undertaken to identify the rock types which require further investigation relating to AMD risk. The risk is assessed by comparing the occurrence of total sulfur content greater than 0.1% and 0.3% in drillhole samples against the total number of samples which have been assayed for sulfur. This task was completed for all Mesa H project area drillhole samples, as well as those drillhole samples located within the proposed final pit shell. These results are summarised in Table 1, and documented in *Robe Valley AMD Risk Assessment* [RTIO, 2017]. **The risk of acid drainage being generated during operations and upon closure is low for Mesa H.**

In the Mesa H project area, 0.5% of approximately 81,650 drillhole samples have a sulfur content greater than 0.1%. Less than 1% of *waste* drillhole samples have sulfur values greater than 0.1%. If exposed during mining in this area, Wittenoom Formation located below the water table (BWT), which may include black shale, is considered to pose an AMD risk. This is based on the association of pyrite and relatively high sulfur content. However, based on the current final pit shell for the BWT pit, it is unlikely that this rock type will be exposed in significant (if any) volumes.

Table 1: Acid-forming potential risk based on sulfur values of drillhole samples.

Project Area	All waste drillholes		In-pit waste drillholes*		AMD Risk	Comments
	Rel.% with S>0.1%	Rel.% with S>0.3%	Rel.% with S>0.1%	Rel.% with S>0.3%		
Mesa H	0.7%	0.3%	0.3%	0.1%	Low	WD located BWT poses an AMD risk if exposed.

* *mesah_kn_ult_cf01* final pit shell considered (July 2017).

Geochemical Analysis of Mesa H (Robe Valley) Drillhole Samples

Drillhole data from various Robe Valley mining and project areas were combined to assess the geochemical characteristics of rock types that may be exposed in the greater Robe Valley area. When compared to the *average crustal abundance* [Bowen, 1979], most rock types are enriched or elevated in iron, correlating with the iron mineralisation. As with many Hamersley Group deposits, arsenic is enriched in all rock types, while tin is enriched or elevated.

Drillhole data were also contrasted with Ecological Investigation Levels (EILs) and Health Investigation Levels (HILs) provided in the *Contaminated Sites Management Series Assessment Levels for Soil, Sediment and Water* [DEC, 2010], as well as *US EPA Ecological Soil Screening Levels* (Eco-SSLs) [US EPA 2005, 2010]. In general, all Mesa H rock types (CID ore and waste, and basement lithologies) are considered to have higher

levels of Co, Cr, Mn, Pb and V compared to these guideline values. However, it should be noted that these guideline values may not be the most appropriate for Pilbara-specific receptors. Furthermore, material from RTIO mine sites is mostly rock, and not soil, and therefore whilst the EILs, HILs and Eco-SSLs discussed above are useful for screening purposes, they may not be appropriate to use as management triggers.

In summary, the elements **Fe, As, Co, Cr, Cu, Mn, Pb, Se and Zn** have been identified as being enriched in some Robe Valley rock types and should be considered in any source-path-receptor modelling related to potential AMD impacts. However, it should be noted that whilst some elements of potential environmental concern are considered enriched, these elements will not necessarily mobilise into groundwater. For instance, iron oxy-hydroxides such as hematite and magnetite have high sorption capacities for arsenic, and the release of manganese may be limited by solubility controls.

As part of a recent characterisation programme with a focus on elevated-sulfur samples and certain elemental enrichments, 191 samples collected from the greater Robe Valley area have been submitted for acid base accounting (ABA) and geochemical test work. Samples were collected from Mesa J, Mesa A/Warramboo, Mesa B, Mesa F, Mesa H and the Middle Robe areas and represent a range of rock types considered to be analogous across the greater Robe Valley.

A total of 96 (of 191) samples were collected from the Mesa H project area and the adjacent Mesa J mining area. Results are provided in *Robe Valley Geochemical Assessment* [O'Kane, 2016] and sample collar locations relative to drillhole locations at Mesa H are shown in Figure 1.

The 96 Mesa H/Mesa J samples submitted for ABA and geochemical test work comprise a variety of rock types including alluvium/detritals (ALL) waste rock (19 samples), pisolite/CID ore and waste rock (42 samples), Wittenoom Formation (WD) waste rock (32 samples) and Marra Mamba Iron Formation (MM) waste rock (3 samples). The CID samples have been further sub-divided based on ore-type/position within the orebody (i.e., hardcap (HTP), hard pisolite (TPH), mixed pisolite (TPM), clayey pisolite (TPC) and basal pisolite (TPB)).

Sulfur content for the 96 Mesa H/Mesa J samples range from 0.001% to 5.4%, where 23 of those samples have sulfur content greater than 0.1%. Eleven (11) of the 23 elevated-sulfur samples are classified as potentially acid forming (PAF) and represent the WD rock type (10 samples) and MM rock type (one sample). A summary of the total sulfur analysis compiled for all 191 geochemical samples is shown in Figure 2. Relatively higher *average* sulfur values for certain rock types (i.e., WD and MM) are indicative of sampling bias towards elevated-sulfur samples; the average total sulfur content for each rock type based on all Mesa H drillhole data is also shown and is more representative of the calculated *median* values (median values have been considered in this assessment).

A summary of the rock types tested relative to the tonnes of waste material expected during mining at Mesa H is shown in Table 2. The majority of Mesa H waste is expected to represent the TPC, TPM, ALL and HTP rock types, and basement lithologies including WD and MM are not expected to be exposed in significant quantities. **Waste material associated with elevated-sulfur is not expected to be mined in bulk at Mesa H.**

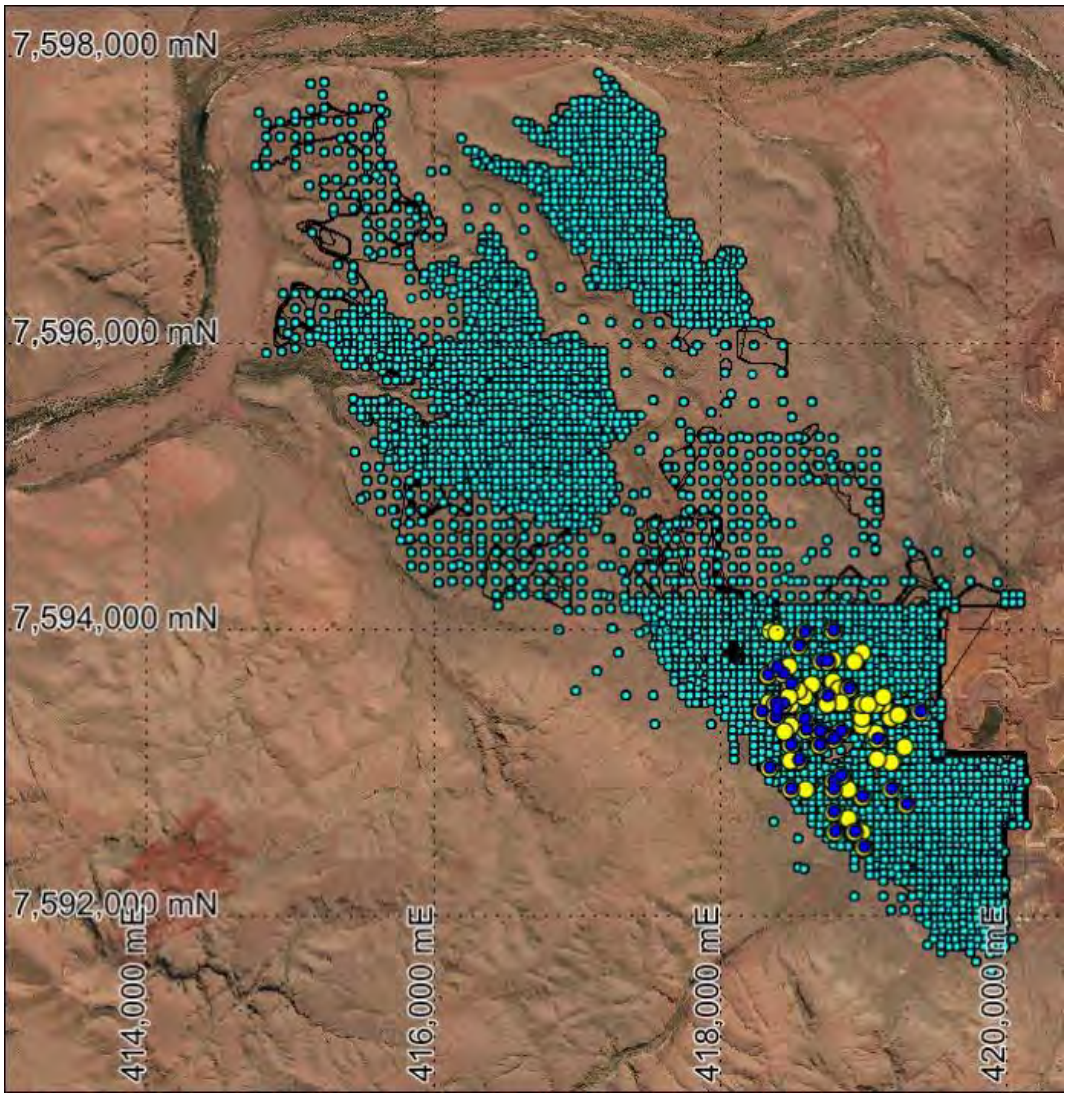

Figure 1: Plan view of Mesa H project area showing proposed final pit shell outline, drillhole locations (blue dots), collar locations of ABA/geochemical samples (yellow dots) and collar locations of samples associated with static leach tests (dark blue dots).

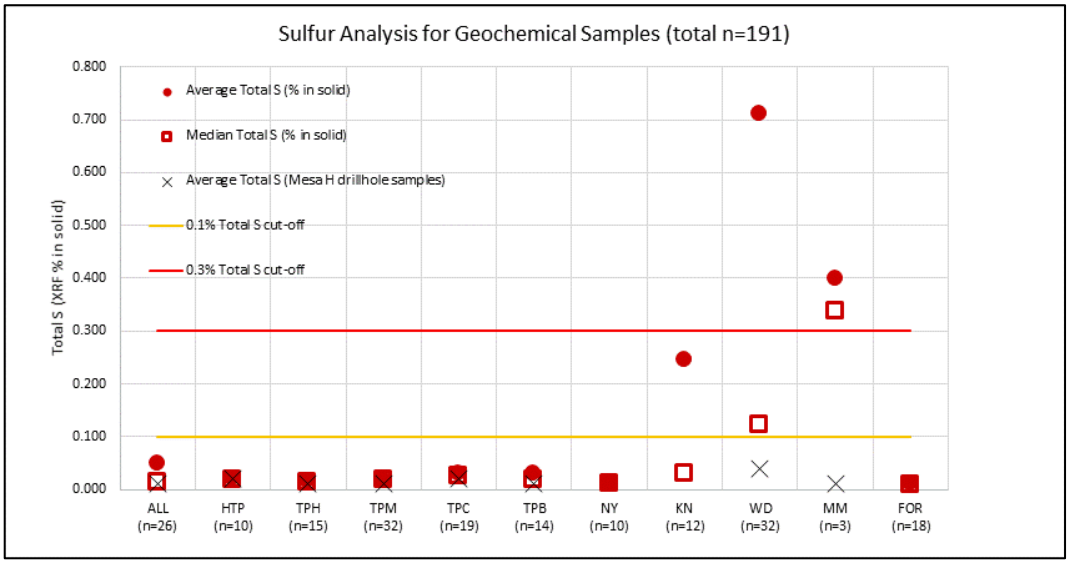

Figure 2: Total sulfur analysis compiled for all 191 geochemical samples, relative to total sulfur analysis of Mesa H drillhole data.

Table 2: Mesa H waste rock types relative to total waste expected to be mined, and number of ABA/geochemical characterisation samples collected from greater Robe Valley area.

Waste Rock Type[1]	Rel.% of total waste[2]	# ABA/geochemical test work samples[3]	Comments
TPC	49%	19	13 samples specific to Mesa H
TPM	24%	32	11 samples specific to Mesa H
ALL	13%	26	19 samples specific to Mesa H
HTP	11%	10	2 samples specific to Mesa H
TPH	2%	15	8 samples specific to Mesa H
TPB	1%	14	8 samples specific to Mesa H
MM	0.1%	3	3 samples specific to Mesa H
WD	0.01%	32	32 samples specific to Mesa H
NY		10	NY not represented at Mesa H
KN		12	KN not represented at Mesa H
FOR		18	FOR not represented at Mesa H
Total waste:	**100%**	**191**	

[1] waste rock types include material flagged with mp_dest = w or ltlg

[2] source rbvipr3pf_mesah_20170707_001

[3] samples from *Robe Valley Geochemical Assessment* [O'Kane, 2016]

Static Leach Test Analysis of Mesa H (Robe Valley) Samples

In addition to the ABA test work described above, static leach tests using deionised water were also carried out on 100 selected samples from the greater Robe Valley area [O'Kane, 2016]. Considering the finding that Fe, As, Co, Cr, Cu, Mn, Pb, Se and Zn may be enriched in Robe Valley rock types, the leach data has been analysed to focus on those parameters in addition to sulfate, nitrate, Al, B, Hg, Mo, Ni and U which also correspond to ANZECC/ARMCANZ [2000] and NHMRC/ARMCANZ [2011] assessment criteria. Results are summarised in Table 3, where the calculated *median* values are considered. As noted previously, sampling was biased toward elevated-sulfur and certain elemental enrichments, and the outlier data influencing higher calculated average values (e.g., for NO_3, Mn and Se) are currently being investigated further.

Table 3: Summary of static leach data relative to ANZECC/ARMCANZ [2000] and NHMRC/ARMCANZ [2011] assessment criteria.*

parameter (mg/L)	SO_4	$N\text{-}NO_3$	Al	As	B	Cd**	Co	Cr**	Cu**	Fe	Hg	Mn	Mo	Ni**	Pb**	Se	U	Zn**
95% aquatic ecosystem	*N/A*	*0.16*	*0.055*	*0.013*	*0.37*	*0.0002*	*N/A*	*0.001*	*0.0014*	*N/A*	*0.00006*	*1.9*	*N/A*	*0.011*	*0.0034*	*0.011*	*N/A*	*0.008*
Drinking water	*250*	*11*	*0.2*	*0.01*	*4*	*0.002*	*N/A*	*0.05*	*1*	*0.3*	*0.001*	*0.1*	*0.05*	*0.02*	*0.01*	*0.01*	*0.017*	*3*
Stock water	*1000*	*90*	*5*	*0.5*	*5*	*0.01*	*1*	*1*	*0.4*	*N/A*	*0.002*	*N/A*	*0.15*	*1*	*0.1*	*0.02*	*0.2*	*20*
ALL (14 samples)	17	0.05	0.05	0.00021	0.08	0.00001	0.00009	0.001	0.001	0.05	0.00005	0.01	0.00069	0.01	0.0002	0.0009	0.000106	0.001
HTP (4 samples)	15	0.05	0.05	0.00027	0.11	0.00001	0.00022	0.001	0.001	0.03	0.00005	0.02	0.00003	0.01	0.0003	0.0002	0.000004	0.001
TPH (5 samples)	21	0.05	0.81	0.00032	0.09	0.00001	0.00007	0.001	0.001	1.38	0.00005	0.01	0.00047	0.01	0.0001	0.0001	0.000027	0.001
TPM (13 samples)	22	0.05	0.16	0.00013	0.1	0.00001	0.00028	0.001	0.001	0.18	0.00005	0.01	0.00036	0.01	0.0002	0.0001	0.000033	0.001
TPC (5 samples)	100	0.05	0.05	0.00015	0.3	0.00001	0.0001	0.001	0.001	0.08	0.00005	0.01	0.00043	0.01	0.0001	0.0001	0.000017	0.001
TPB (11 samples)	26	0.05	0.05	0.0002	0.08	0.00001	0.00029	0.001	0.001	0.02	0.00005	0.03	0.00011	0.01	0.0002	0.0002	0.000006	0.001
NY (5 samples)	21	0.1	0.06	0.00039	0.1	0.00001	0.00021	0.001	0.001	0.03	0.00005	0.01	0.01232	0.01	0.0008	0.0001	0.00001	0.001
KN (10 samples)	507	0.1	0.49	0.00088	0.11	0.00081	0.46208	0.007	0.003	0.24	0.00005	3.03	0.00027	0.51	0.0003	0.0112	0.000125	0.024
WD (21 samples)	691	0.1	0.39	0.00034	0.05	0.00032	0.1268	0.002	0.003	0.86	0.00005	8.91	0.00005	0.37	0.0008	0.0119	0.00011	0.012
MM (3 samples)	926	0.8	0.04	0.00024	0.03	0.00046	0.01062	0.001	0.001	0.03	0.00005	10.82	0.00003	0.02	0.001	0.0129	0.000064	0.002
FOR (9 samples)	35	0.05	0.06	0.00043	0.15	0.00001	0.00039	0.001	0.001	0.02	0.00005	0.01	0.00139	0.01	0.0005	0.0003	0.000019	0.001

* the generally more conservative aquatic ecosystem criteria are considered (highlighted in orange), and exceedances (calculated median values) are highlighted in red.

** guideline values have not been adjusted for hardness.

It is important to note that since the physical and chemical conditions of the leach test will not be the same as those expected in the 'as placed' environment (e.g., due to solubility constraints, liquid to solid ratios, etc.), the leachate composition from these tests is not expected to be representative of that which may develop in the field. As such, the results should not be directly extrapolated to predict the actual water quality expected to seep from a waste rock dump, but are useful in providing an indication of the readily leachable elements that may be present. Furthermore, the characterisation programme had a focus on elevated-sulfur samples and certain elemental enrichments, therefore, the observation that several parameters show a greater leach potential is expected under acidic conditions.

The majority of Mesa H waste is expected to represent the TPC, TPM, ALL and HTP rock types, while basement rock including WD and MM are expected to be exposed in minimal quantities. Considering the calculated median values compiled for each rock type, the concentration of most parameters does not exceed the more conservative assessment criteria (typically the ANZECC/ARMCANZ [2000] trigger values applying to 95% protection level for slightly-moderately disturbed ecosystems). Exceptions are for concentrations of aluminum and iron; while the release of aluminum is likely to be limited by solubility controls [SRK, 2017], further work is ongoing to investigate the release of iron, as well as the release of other parameters under different conditions (e.g., multi-step leaching, saline leach solutions, and low-contact liquid to solid ratios [SRK, 2017]).

The analysis of static leach test results are provided in Appendix A.

Geochemical Analysis of Mesa J Tailings Samples

Geochemical test work was also carried out on five Mesa J tailings samples [EGi, 2014]. The samples are classified as non-acid forming and considered enriched in As, Fe and Se, and elevated in Bi, Co, Mn and Sb when compared to the average crustal abundance.

The analysis of tailings liquor show the majority of metals and metalloids are either at low concentrations or below the detection limit. Supplemental static leach tests were also undertaken using deionised water and saline solution, where results indicate relatively higher concentrations of copper and zinc in the saline extractions, which is likely due to a combination of cation exchange which increases their solubility [EGi, 2014]. Relatively lower concentrations of iron are associated with the saline extracts.

In general, the results indicate tailings, as represented by the samples provided, are unlikely to result in low pH conditions or metals leaching under oxidising conditions [EGi, 2014].

Fibrous Minerals

Fibrous minerals present a health hazard if fibres of a (defined) respirable size become airborne and are inhaled. The most common mineral associated with fibrous minerals encountered within the iron formations present in the Robe Valley area is riebeckite. Riebeckite is usually found in fresh (unweathered) BIF. The asbestiform variety of riebeckite is crocidolite, or blue asbestos. The presence of riebeckite does not necessarily pose a fibrous mineral risk but it is a precursor mineral to crocidolite, therefore, there exists a likelihood of encountering crocidolite.

If present, crocidolite seams would primarily occur within the unmineralised Marra Mamba Iron Formation that underlies the CID at Mesa H. In addition, crocidolite may also occur in BIF clasts found within overlying alluvium cover or within the basal pisolite horizon (i.e., TPB).

Crocidolite has not been intersected to-date in any drillholes within the Mesa H project area. However, the underlying Marra Mamba Iron Formation, as well as the TPB horizon in the Mesa H area, are considered to pose a potential fibre risk if exposed.

The *Rio Tinto Iron Ore (WA) Fibrous Minerals Management Plan* describes guidelines for the management of fibrous minerals encountered during mine production, however, based on current drilling and mine planning information, which indicates that basal or basement lithologies can generally be avoided during operations, *potentially hazardous* or *designated hazardous* areas are not expected within the life of mine or upon closure in these areas.

Lisa Terrusi
Specialist Geologist, Mineral Waste Management

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RTIO (2016b) *Rio Tinto Iron Ore (WA) Mineral Waste Management Plan for Undeveloped Resources and Studies* (RTIO-HSE-0040347)

RTIO (2016c) *Rio Tinto Ire Ore (WA) Spontaneous Combustion and ARD (SCARD) Management Plan for Operations (formerly known as the Black Shale Management Plan)* (RTIO-HSE-0010872)

RTIO (2016d*) Rio Tinto Iron Ore (WA) Fibrous Minerals Management Plan* (RTIO-PDE-0062061)

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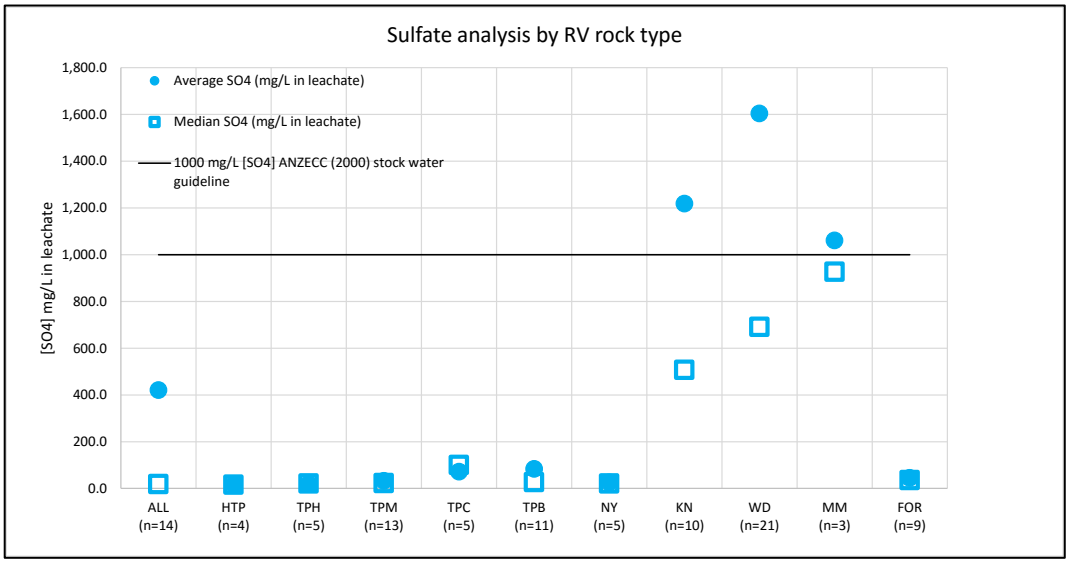
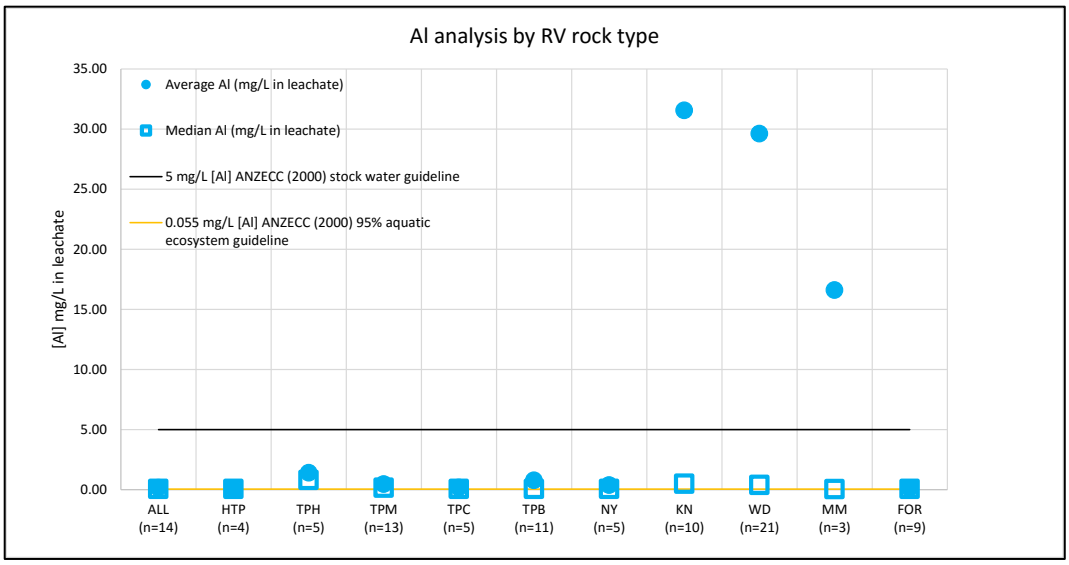
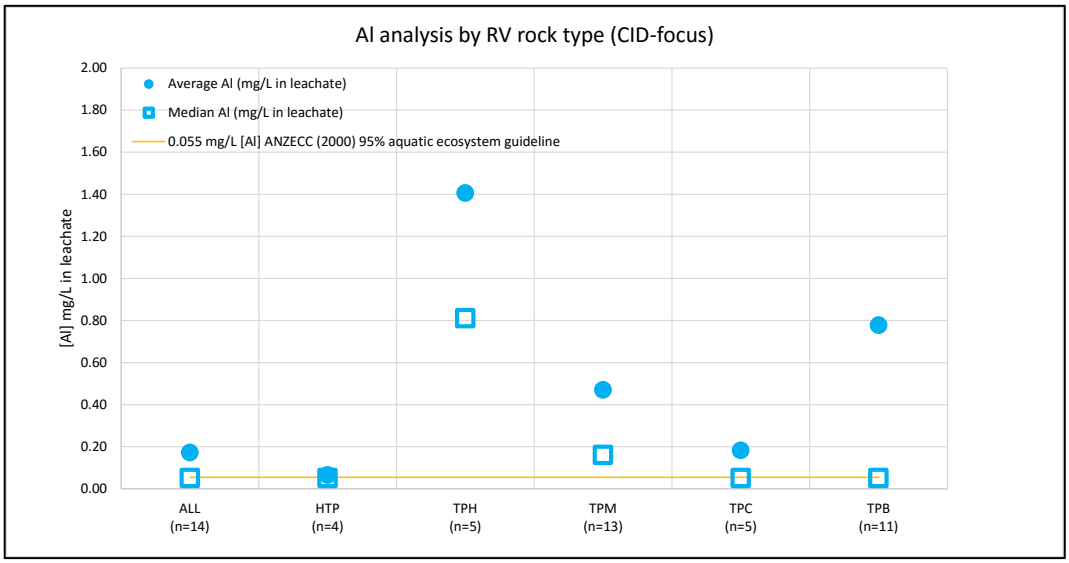
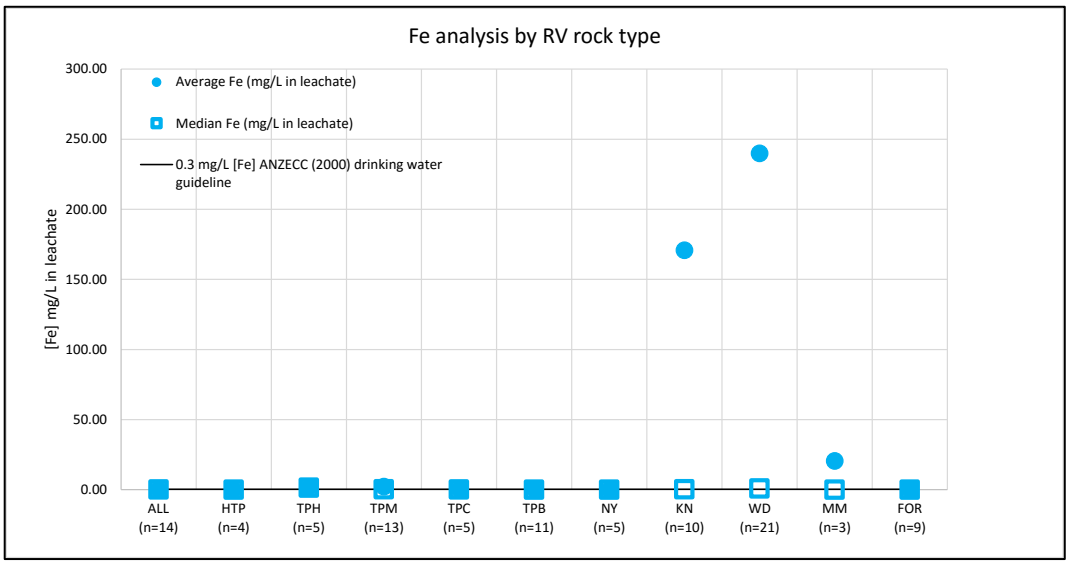
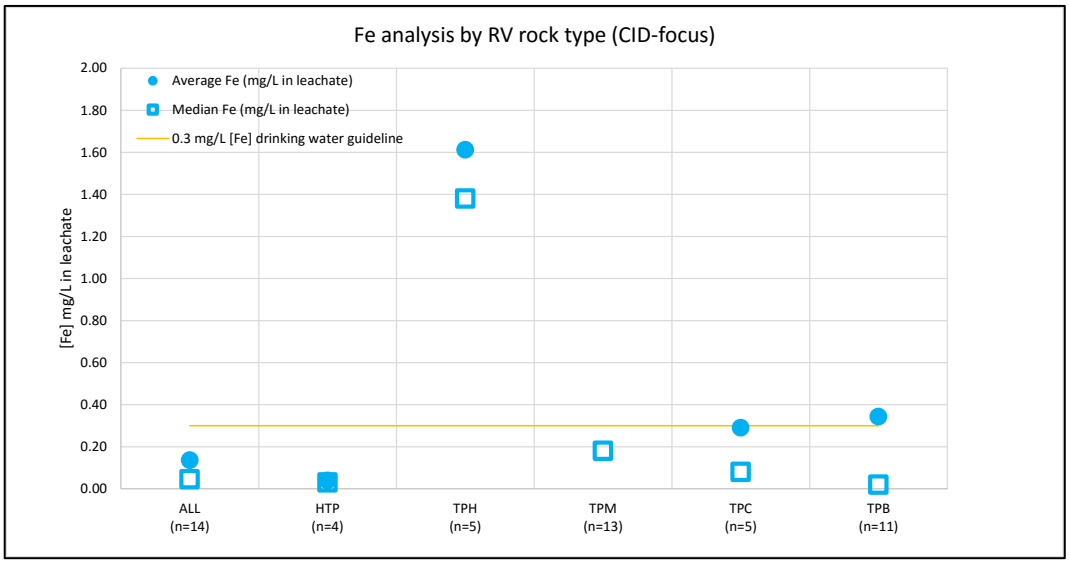
Appendix A – Static Leach Test Results – Analysis of Select Parameters

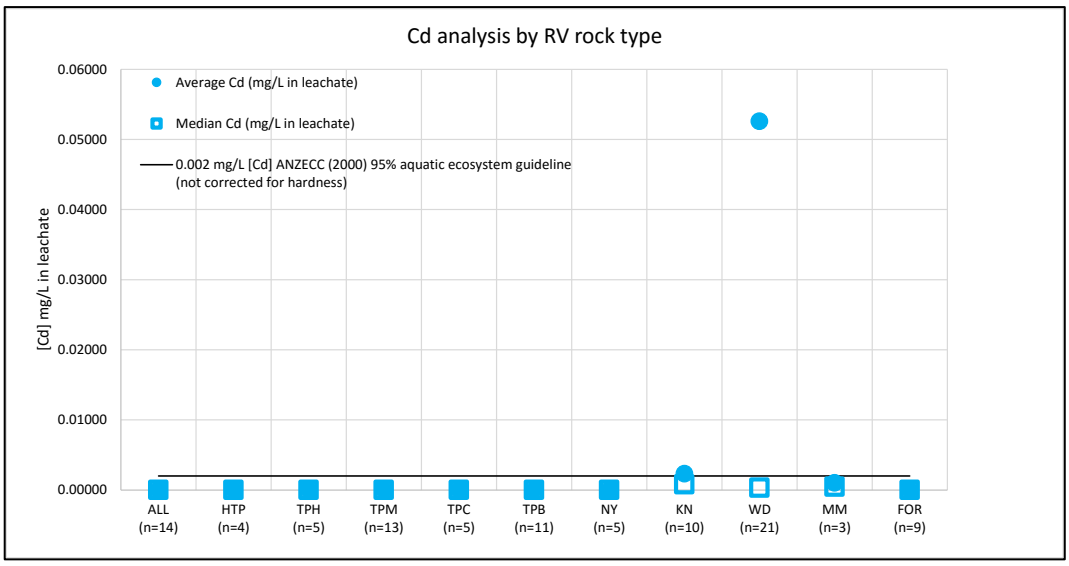


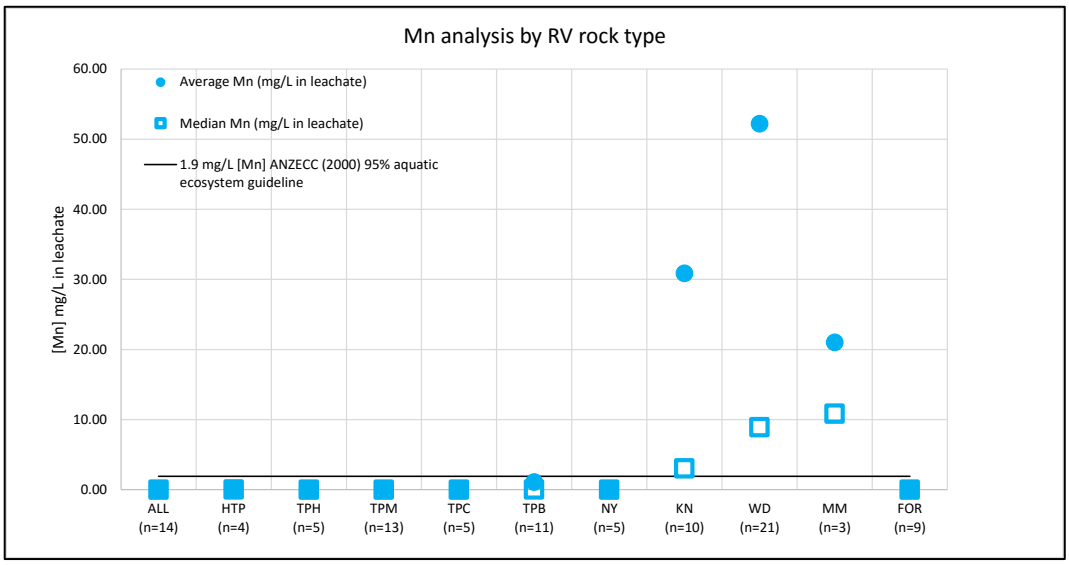


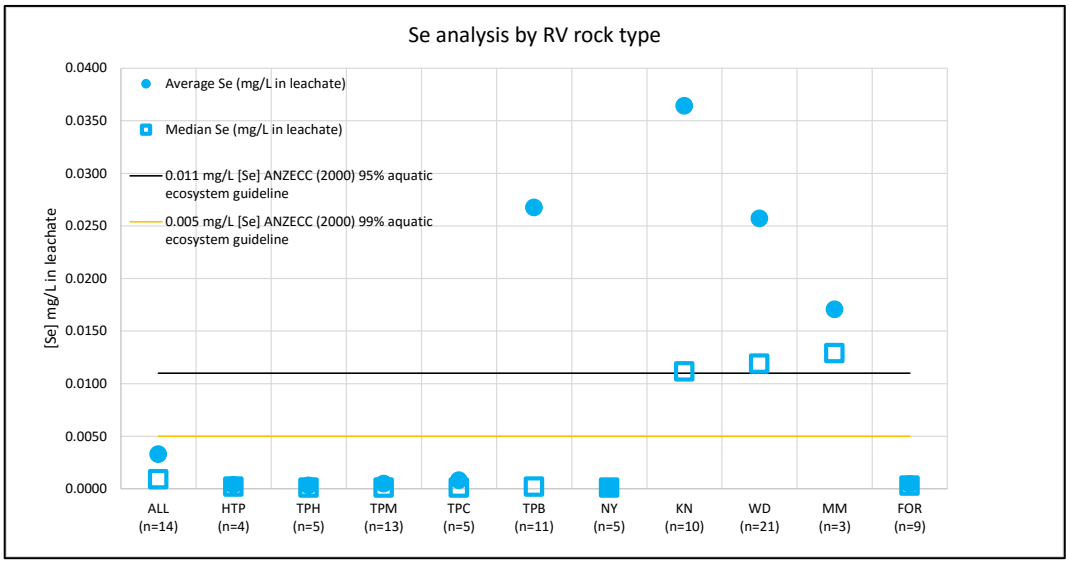


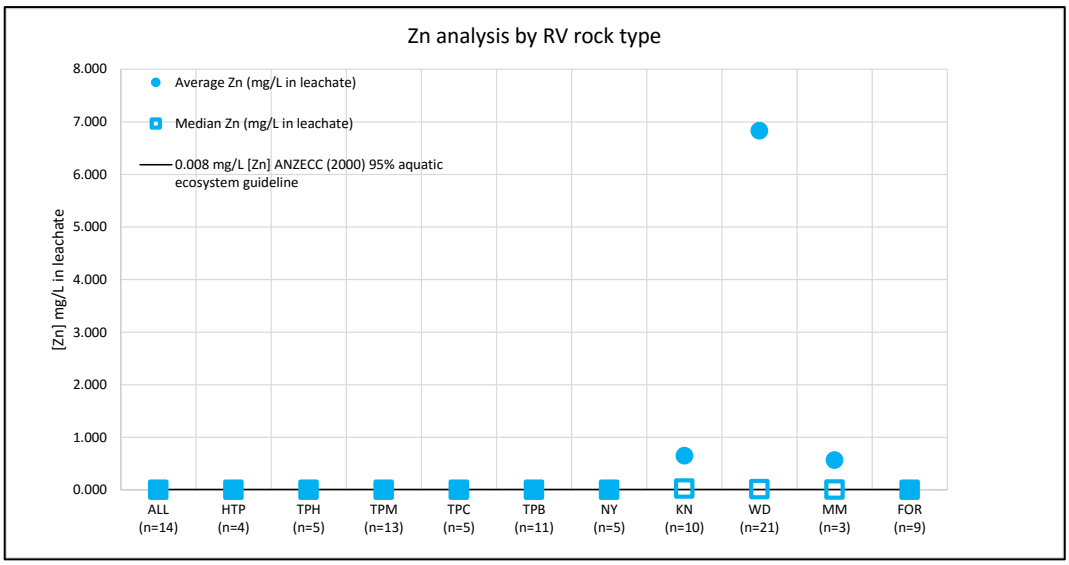

Fe analysis by RV rock type
Average Fe (mg/L in leachate)
Median Fe (mg/L in leachate)
0.3 mg/L [Fe] ANZECC (2000) drinking water guideline
[Fe] mg/L in leachate
300.00
250.00
200.00
150.00
100.00
50.00
0.00
ALL (n=14)
HTP (n=4)
TPH (n=5)
TPM (n=13)
TPC (n=5)
TPB (n=11)
NY (n=5)
KN (n=10)
WD (n=21)
MM (n=3)
FOR (n=9)


Fe analysis by RV rock type (CID-focus)
Average Fe (mg/L in leachate)
Median Fe (mg/L in leachate)
0.3 mg/L [Fe] drinking water guideline
[Fe] mg/L in leachate
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
ALL (n=14)
HTP (n=4)
TPH (n=5)
TPM (n=13)
TPC (n=5)
TPB (n=11)


Cd analysis by RV rock type
Average Cd (mg/L in leachate)
Median Cd (mg/L in leachate)
0.002 mg/L [Cd] ANZECC (2000) 95% aquatic ecosystem guideline (not corrected for hardness)
[Cd] mg/L in leachate
0.06000
0.05000
0.04000
0.03000
0.02000
0.01000
0.00000
ALL (n=14)
HTP (n=4)
TPH (n=5)
TPM (n=13)
TPC (n=5)
TPB (n=11)
NY (n=5)
KN (n=10)
WD (n=21)
MM (n=3)
FOR (n=9)


Mn analysis by RV rock type
Average Mn (mg/L in leachate)
Median Mn (mg/L in leachate)
1.9 mg/L [Mn] ANZECC (2000) 95% aquatic ecosystem guideline
[Mn] mg/L in leachate
60.00
50.00
40.00
30.00
20.00
10.00
0.00
ALL (n=14)
HTP (n=4)
TPH (n=5)
TPM (n=13)
TPC (n=5)
TPB (n=11)
NY (n=5)
KN (n=10)
WD (n=21)
MM (n=3)
FOR (n=9)


Se analysis by RV rock type
Average Se (mg/L in leachate)
Median Se (mg/L in leachate)
0.011 mg/L [Se] ANZECC (2000) 95% aquatic ecosystem guideline
0.005 mg/L [Se] ANZECC (2000) 99% aquatic ecosystem guideline
[Se] mg/L in leachate
0.0400
0.0350
0.0300
0.0250
0.0200
0.0150
0.0100
0.0050
0.0000
ALL (n=14)
HTP (n=4)
TPH (n=5)
TPM (n=13)
TPC (n=5)
TPB (n=11)
NY (n=5)
KN (n=10)
WD (n=21)
MM (n=3)
FOR (n=9)


Zn analysis by RV rock type
Average Zn (mg/L in leachate)
Median Zn (mg/L in leachate)
0.008 mg/L [Zn] ANZECC (2000) 95% aquatic ecosystem guideline
[Zn] mg/L in leachate
8.000
7.000
6.000
5.000
4.000
3.000
2.000
1.000
0.000
ALL (n=14)
HTP (n=4)
TPH (n=5)
TPM (n=13)
TPC (n=5)
TPB (n=11)
NY (n=5)
KN (n=10)
WD (n=21)
MM (n=3)
FOR (n=9)

Rio Tinto

Water Resource Evaluation – Resource Development

Report

Mesa H: H3 Hydrogeological Assessment

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Stakeholders: Studies and Technology, Environmental Approvals.

Accountability: Alexandre Russo, Specialist Hydrogeologist

Version History				
Version	**Description of Changes**	**Custodian**	**Approved**	**Date**
1.0	Draft for internal review	A. Russo	S. Trott	05/05/17
2.0	Comments from Melinda Brand	M. Brand	A. Russo	30/07/17
3.0	Comments from Jeremy English	J. English	A. Russo	18/08/17
4.0	Increased site water demand (8.7 GL/y)	A. Russo	S. Trott	2/10/17
5.0	High resolution figures added	A. Russo	M. Brand	02/08/18
6.0	Consolidation of original H3 report and H3 update memo, additional Jimmawurrada Creek alluvium assessment	A. Russo	M. Brand	15/02/19

Disclosure

This report (version 6.0) is the amalgamation of the original “H3 Hydrogeological Assessment” report (version 5.0) and the “H3 Update Memo” prepared in June 2018 based on the results of the Feasibility drilling and test programme, revised conceptualisation and updated numerical model. Both reports have been peer reviewed by “Independent Ground Water Consultants” and “RPS” consultant companies, respectively. The purpose of the consolidation of reports is to facilitate third party (EPA, Commonwealth and public) assessment and review of this document, through merging the most recent data analysis, conceptualisation, drilling and test pumping results, numerical model calibration and results and proposed management of groundwater resources in a single report.

Additional historical drillhole assessment was carried out between December 2018 and January 2019 aiming to better define the Jimmawurrada Creek base surface. This additional work was not peer reviewed, although it does not affect the hydrogeological conceptualisation and unlikely will influence the numerical model calibration and prediction, although it was used to support impact prediction of stygofauna habit along the creek.

Executive Summary

Mesa H is a channel iron deposit (CID) located immediately west and adjacent to the existing Mesa J operations, downstream from the confluence of the Robe River and Jimmawurrada Creek. It is anticipated ore extraction will occur over a mine life of approximately 18 years at combined rate with Mesa J of 15 to 20 Mtpa. Approximately 13% (~20 million tons) of the reported iron ore resource occurs below current water table (BWT) and active dewatering will be required to access ore unhindered.

Groundwater abstraction associated with dewatering and water supply has the potential to impact the ecological and heritage sensitive receptors located along the Robe River and Jimmawurrada Creek. These include riparian vegetation and associated groundwater dependant ecosystems located immediately north and west of the Mesa H deposit, and east of Mesa J. Furthermore, two Rights Reserve (KM-RR16 and KM-RR21) sites are located to the northwest and northeast of the Mesa H deposit; noting that one of these sites (KM-RR16) is associated with what is considered a permanent pool.

Based on continuous consultation with the Kumura Marthudunera people (K&M), and concerns related to the potential environmental impact caused by water table drawdown along the Jimmawurrada Creek (riparian vegetation and Blind Cave Eel habitat), Rio Tinto reviewed a number of options to reduce water demand for the Mesa J Hub. The most effective option considered viable is to include a thickener plant in order to increase reclaimed water volumes and reduce cumulative groundwater drawdown along the Jimmawurrada Creek.

Through the use of a non-toxic and non-hazardous high molecular weight anionic polyacrylamide flocculant, the inclusion of a thickener will reduce the groundwater demand by 35% or 50 billion litres (GL) during Life of Mine (LOM). This reduction in groundwater abstraction is predicted to lower the water level along the Jimmawurrada Creek by approximately 9 m immediately to the east of the Southern Cutback Borefield, having comparatively reduced impact on the local riparian vegetation and stygofauna habitat. Otherwise, without the thickener, the drawdown was estimated to be up to ~18 m, estimated to potentially cause severe stress to the local phreatophytic vegetation and locally desaturating a section of the alluvial aquifer known to support stygofauna. The reduction in the water demand and consequent limited impact to the local alluvial aquifer will have reduced impact to riparian vegetation and to stygofauna (including the Blind Cave Eel) habitat and a sustainable continuous volume (of the habitat) will be preserved.

The hydrogeological assessment described herein sets out to describe relevant field investigations, conceptual hydrogeology of the project area, groundwater flow model development and model predictions to inform assessment of impact. Key findings of this study include:

- Groundwater occurs within four main aquifers throughout the project area, specifically:
    - Robe River alluvium
    - Jimmawurrada Creek alluvium
    - Channel-iron deposits (CID)
    - Weathered basement (Marra Mamba Iron Formation and Wittenoom Formation)
- The Tertiary Basal Pisolite sits between the CID and Basement Aquifers and acts as partial barrier to groundwater flow reducing the hydraulic connection between both aquifers.
- Groundwater flow follows the CID palaeo-channel deposit from the Bungaroo valley up-gradient, down to the confluence with the Robe River immediately down-gradient of Mesa H;

- Water table in the Robe River pools are generally lower than the water level in the CID aquifer suggesting that the pools are groundwater dependent in periods of prolonged drought;
- Robe River pools chemical signatures are associated mostly with the Robe River alluvium aquifer with lesser correlation to the other regional aquifers;
- Mesa H dewatering is anticipated to start from 2024/25 with peak groundwater abstraction in 2033 of 7.1 ML/day, with a total of 15 GL to be dewatering during the life of the mine;
- The total groundwater abstraction between 2019 and 2037 from both Mesa H and Mesa J, (based on dewatering and water supply operational requirements, but excluding surface water management, seepage from waste fines storage facility and water reservoir to open pits and decant water recovery), will be approximately 100 GL with a peak of ~8 GL/a;
- Peak water abstraction, including pit dewatering, borefield water supply, direct rainfall management required to meet site water demand / management is 15 GL/a.
- Annual discharge to the environment (Jimmawurrada Creek) will range between 1 – 7 GL/year (excluding major cyclonic events).
- The surplus water discharge footprint is not expected to extend beyond 8 km from the discharge point(s), and remain within the existing Mesa J Operations discharge footprint (on dry conditions).
- Lowering of the water table across Mesa H and Mesa J is not expected to cause significant impacts to the permanent pool (Yeera Bluff) located on the Robe River northwest of Mesa H, however shallow (<0.5m) semi-permanent and seasonal pools may dry out during prolonged periods of drought as a result of natural seasonal variation combined with pit dewatering;
- Given the significance of the semi-permanent and permanent pools in the ecosystem and to the Kuruma Marthudunera People, mitigation strategies have been developed to avoid dewatering impacts to the pools by providing supplementary water directly to the permanent pools; or ceasing below water table mining in Pit 7 (Mesa H) during dry periods;
- A combination of water supply abstraction from the Southern Cutback Borefield, Mesa J dewatering and Coastal Water Supply borefield operation will lower the water table across a 12 km section of the Jimmawurrada Creek, with a maximum predicted drawdown of 9 m across a 6.5km stretch by 2030;
- If natural recharge is reduced by 50% due to an extended dry period (numerical model uncertainty run 2), the drawdown could increase by up to ~3 m, in addition to the natural seasonal fluctuation. This would translate to the water table lowering to 18 m bgl to the east of the Southern Cutback Borefield by 2030.
- Aquifer recovery is modelled to take up to 60 years to fully recover to pre-mining levels within the Mesa H and J areas. However, water levels along the Jimmawurrada Creek and Robe River are expected to mostly recover after the first significant streamflow event caused by a cyclonic event, except the permanent pool near Yeera Bluff, which will take an additional 40 years to recover the last 20cm of drawdown.
- Local and sub-regionally significant groundwater dependent vegetation communities comprising obligate phreatophytic vegetation (i.e *Melaleuca Argentea*) are present and distributed throughout sections of the Robe River, including around semi-permanent and permanent pool areas. Abstraction which leads to the reduction of groundwater levels in the river bed alluvials below the 5 percentile

level for more than 6 months is predicted by DoW (2010) to cause significant decline in resident high risk groundwater dependant ecosystems (GDE's). However, modelling for Mesa H suggests the groundwater level changes predicted are limited (<1m).

- Riparian Vegetation along the Robe River is not expected to be significantly impacted; however, facultative phreatophytic vegetation (*Eucalyptus camaldulensis* and *Eucalyptus victrix*) will likely be impacted along an approximate 12 Km section of Jimmawurrada Creek, with the main impact predicted along a 6.5km section, corresponding to the maximum area of modelled drawdown of 9m (~14mbgl);
- Within the numerical model domain, the habitat of the blind cave eel and other stygofauna in the Jimmawurrada alluvium aquifer will be reduced to approximately 44-52% of the pre-mining volume by 2030 (peak drawdown), assuming the worst case scenario (recharge reduction and maximum seasonal variation); however the central case suggests that approximately 64% of the habitat will be preserved below the water table.
- Impact to the lower Robe River is not expected to occur due to the minimal reduction of the alluvium aquifer throughflow in comparison to the stream flow volumes that recharge the aquifer yearly and proposed contingency actions (water supplementation to the permanent pool or avoidance of mining below the 120mRL in Pit 7 during dry conditions).

Bore completion reports and pumping test results can be found in the Appendix A, the latest groundwater numerical model report in Appendix B, surplus environmental discharge model extent in Appendix C and peer review reports in Appendix D.

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Appendix A: Bore Completion Reports

Appendix B: Groundwater Numerical Model

Appendix C: Surplus water discharge extent assessment

Appendix D: Peer reviews

Section 1 - Introduction

The Mesa H deposit (the **Project**) is located approximately 110 km southwest of Karratha in the Pilbara region of Western Australia, directly adjacent to the Mesa J iron ore mining operation, and approximately 20 km southwest of the Pannawonica Township (Figure 1). The Mesa J mine is operated by Robe River Mining Company Pty Ltd, as manager and agent for and on behalf of the participants in the Robe River Joint Venture (the **Proponent**).

The Proponent currently draws groundwater at Mesa J to facilitate below water table (**BWT**) mining and satisfy process and potable water demand. This occurs in accordance with the conditions of Groundwater Licences GWL 107678-12, issued under the Rights in Water and Irrigation Act 1914 (RiWI Act) and administered by the Department of Water (**DoW**).

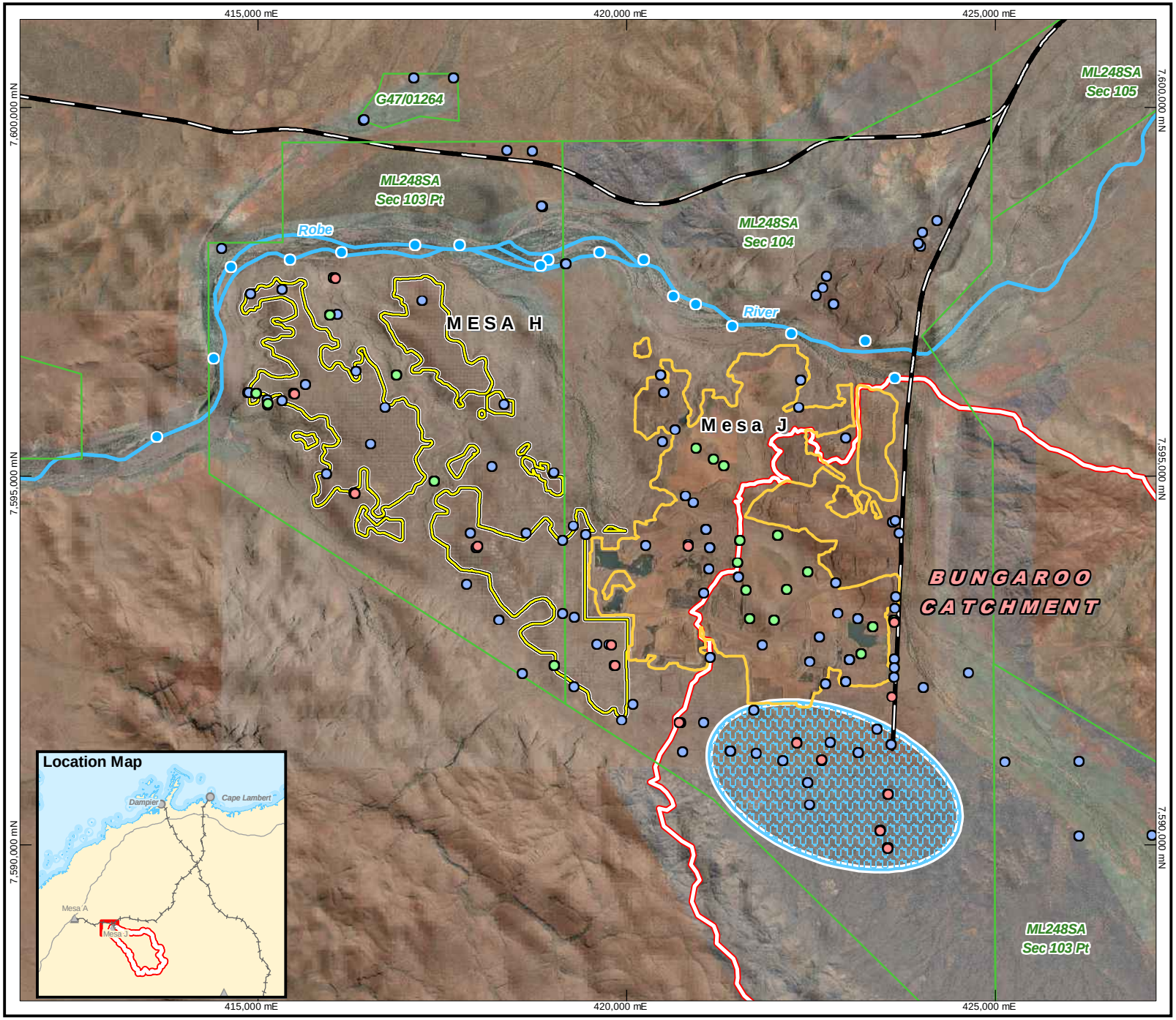
Mesa H is a channel iron deposit (**CID**) deposit that forms part of a sinuous chain of mesas (from A to N) which define the palaeochannel of the Robe River and its associated tributaries. The Project is located downstream from the confluence of the Robe River and Jimmawurrada Creek. The deposit contains high grade and low grade mineralisation, with a combined Mineral Resource of 207 Mt at 54.3% Fe. Approximately 34% of the reported resource occurred below the pre-mining water table, however due to the lowering of the water table caused by dewatering activities relating to the operation of Mesa J, the reported resource at Mesa H is approximately 13% below the present-day water table.

The local hydrogeological regime is defined by the occurrence of four major aquifers: the basement aquifer comprising the weathered Paraburdoo and Bee Gorge Members of the Wittenoom Formation and weathered Marra Mamba BIF, hereafter referred to as the “Wittenoom Aquifer”, overlayed by a sequence of pisolitic sediments, hereafter referred to as the “CID Aquifer”, the “Robe River Alluvium Aquifer” which occurs within the shallow alluvium adjacent to the Robe River and associated tributaries, and the Jimmawurrada Alluvium Aquifer which occurs within the Jimmawurrada creek bed and associated flood plain.

The Robe River regional catchment spans approximately 7,500 km^2. Major watercourses occurring within the catchment include the Robe River and the Jimmawurrada, Bungaroo and Mungarathoona Creek’s. The major water courses generally flow from the southeast to the northwest through high relief areas of the Hamersley Ranges on to the more gently sloping areas of the coastal plain before discharging into the ocean approximately 150 km south of Dampier.

Surface water runoff in the project area is typical of the Pilbara, generally only occurring following significant or long duration rainfall events. The Robe River is an ephemeral river, which carries a significant underflow in its alluvial bed. This sub-surface flow maintains permanent, and at some extent, semi-permanents pools in the river channel, and these pools play an important role in the river ecosystem, supporting a diverse range of aquatic fauna and acting as refuges during periods of drought.

The Bungaroo creek joins the Jimmawurrada creek in lower Bungaroo. The Jimmawurrada Creek catchment has an area of about 470km^2, but the upstream valley is a lot narrower than Bungaroo Creek; however the flood plain is wider in lower Bungaroo upstream of Bungaroo-Jimmawurrada creek confluence. The Jimmawurrada Creek is an ephemeral river, which carries limited underflow in its alluvial bed.



LEGEND

- Water Bore
- Vibrating Wire Piezometer
- Monitoring Bore
- Pool
- Southern Cutback Borefield
- Bungaroo Catchment
- Pit
- Proposed Pit
- Rio Tinto Mining Act Tenure
- Railway

N

SCALE

1 0 1 2km

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Figure 1: Location map and existing bores

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Date: Aug, 2018

Plan No: PDE0162442v1
Proj: MGA94 Zone50

Geospatial Information and Mapping

Section 2 - Climate and Rainfall

Rainfall in the Pilbara is highly variable, temporally and spatially, predominantly occurring in summer (Figure 2), with major events typically associated with tropical cyclones, low pressure systems and convective thunderstorms. However, the Robe Valley can also receive winter (June through August) rainfall from frontal systems that cross the southwest land division and extend to the southern Pilbara and rain-bearing northwest cloud bands.

Climatic conditions experienced within the vicinity of Mesa H and the Robe Valley more broadly, are categorised on the basis of the Köppen classification scheme (BoM, 2006), as grassland: hot (summer drought). Details of the four long-term rainfall stations operational in the Robe Valley are summarised in Table 1. The long-term mean annual rainfall for the Mesa H project is 342 mm; however, this is highly variable, historically ranging between 54 mm and 736 mm (BOM, 2009).

The mean annual pan evaporation is 3,400 mm (BOM, 2008) which greatly exceeds the mean annual rainfall, highlighting the water limited environment. This is particularly relevant given the presence of permanent water bodies proximal to Mesa H.

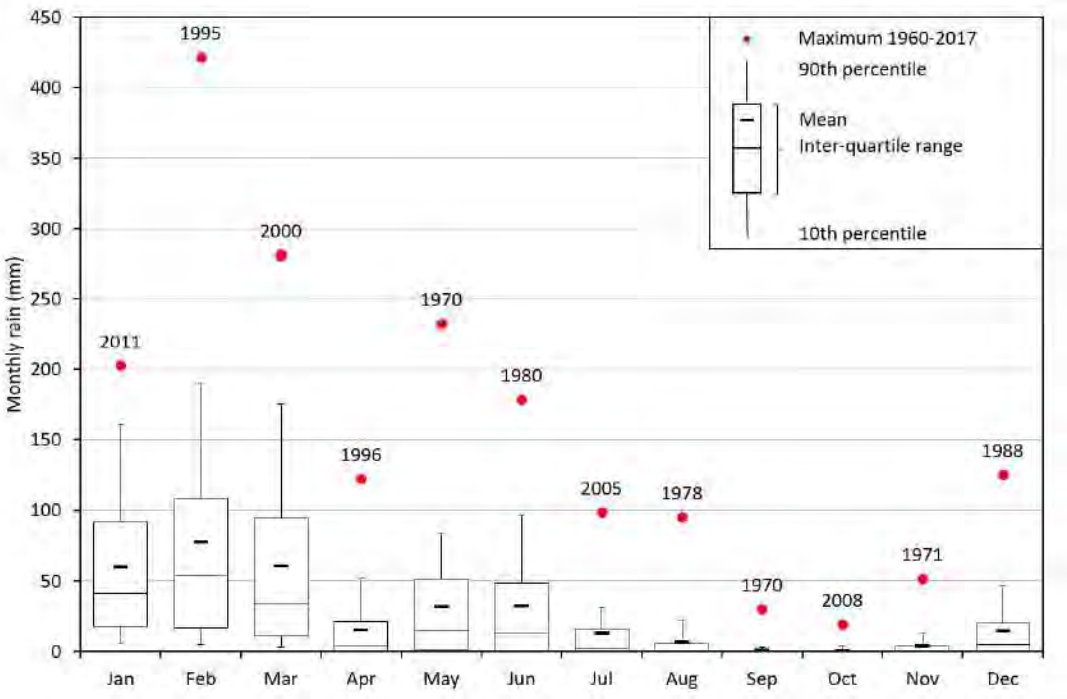


Figure 2: Mesa H monthly rainfall distribution (derived from BoM, 2009)

Table 1: Current operating, long term daily rainfall stations in the Robe River catchment

Number	Name	Location	Record Period	Data Recorded
005032	Yarraloola	383,897 mE 7,614,316 mN	1899-present	94%
005022	Red Hill	403,499 mE 7,569,646 mN	1898-present	92%
005029	Yalleen	437,182 mE 7,602,834 mN	1930-present	53%
005069	Pannawonica	430,750 mE 7,606,959 mN	1971-present	80%

While the Yarraloola station has a long rainfall record period and 94% of the data is available, gaps in the data record occurred in the most recent period (1999-present). To provide a complete and representative rainfall dataset for the Project, the BoM's long-term daily gridded rainfall data has been adopted (BOM, 2009). The annual gridded rainfall series is shown in Figure 3. On average, the Mesa H deposit experiences 36 rain days per year, with daily rainfall totals larger than 50 mm being uncommon.

The total catchment area contributing flow to the Robe River in the Mesa H project area is approximately 34 km^2 (Figure 4). The Jimmawurrada catchment area is approximately 470 Km^2 , however flows from the Bungaroo catchment (800 km2) merge to the Jimmawurrada Creek as presented in Figure 5 and discharge in the Robe River immediately northeast of Mesa J.

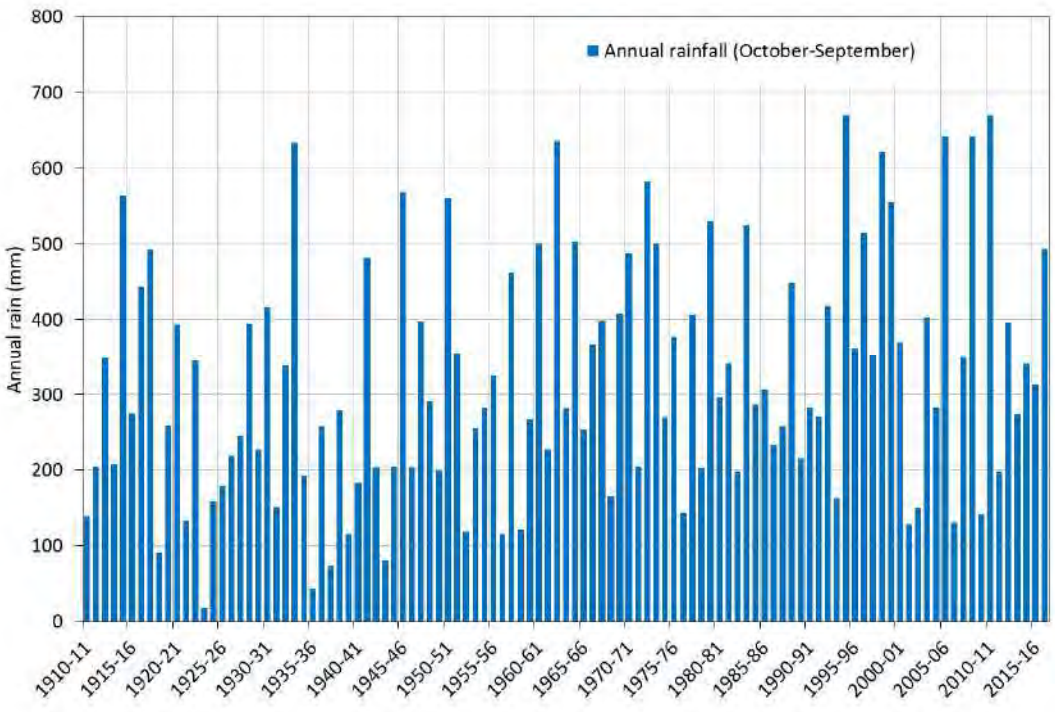
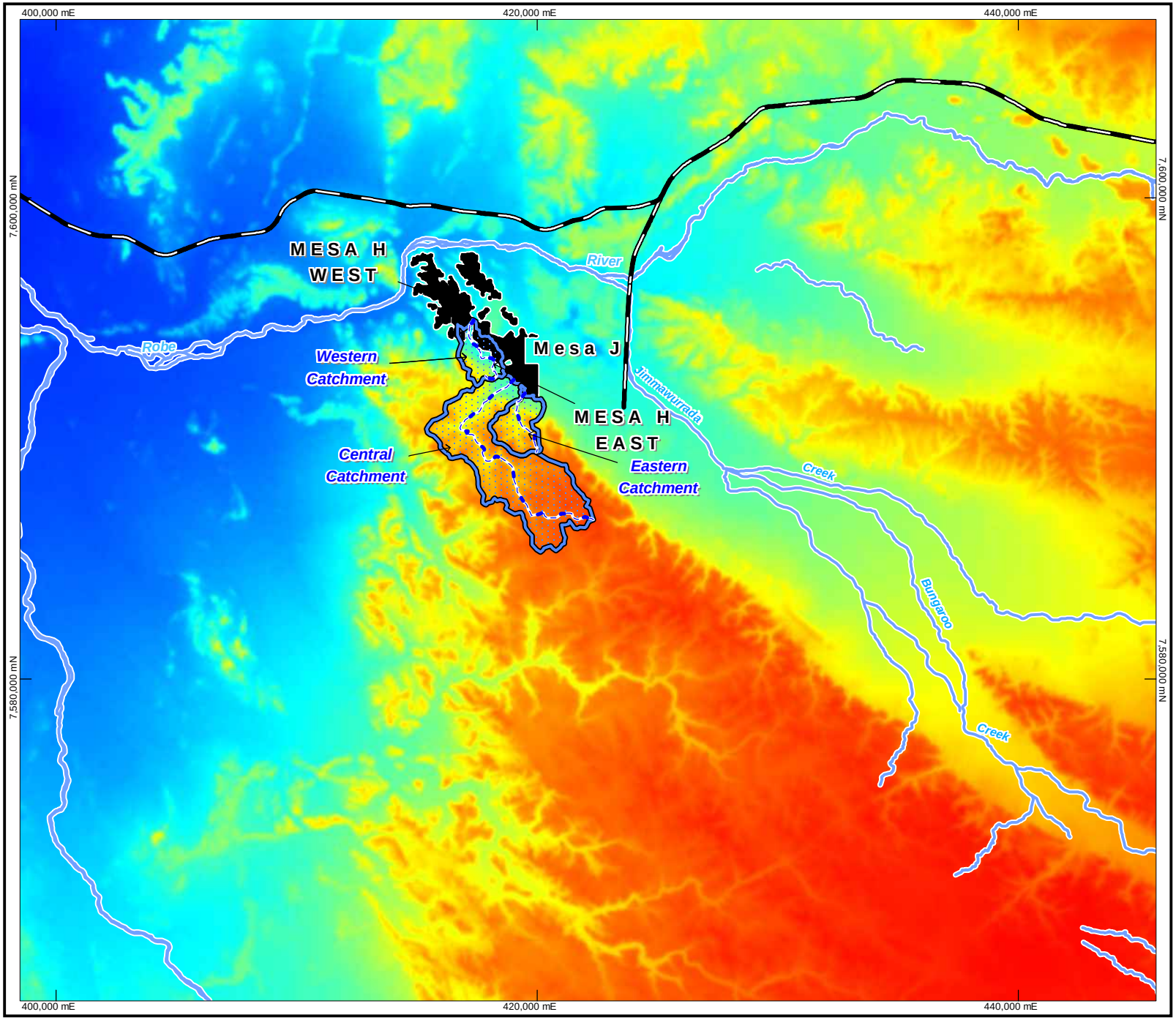


Figure 3: Mesa H annual (October- September) rainfall (derived from BoM, 2009)



LEGEND

- Mesa H Proposed Pit
- Mesa H Catchments
- Longest Flowpaths
- Railway
- Hydrology

Elevation SRTM

374m

48m

N

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2.5 0 2.5 5 7.5km

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Figure 4: Surface water catchments contributing to Mesa H

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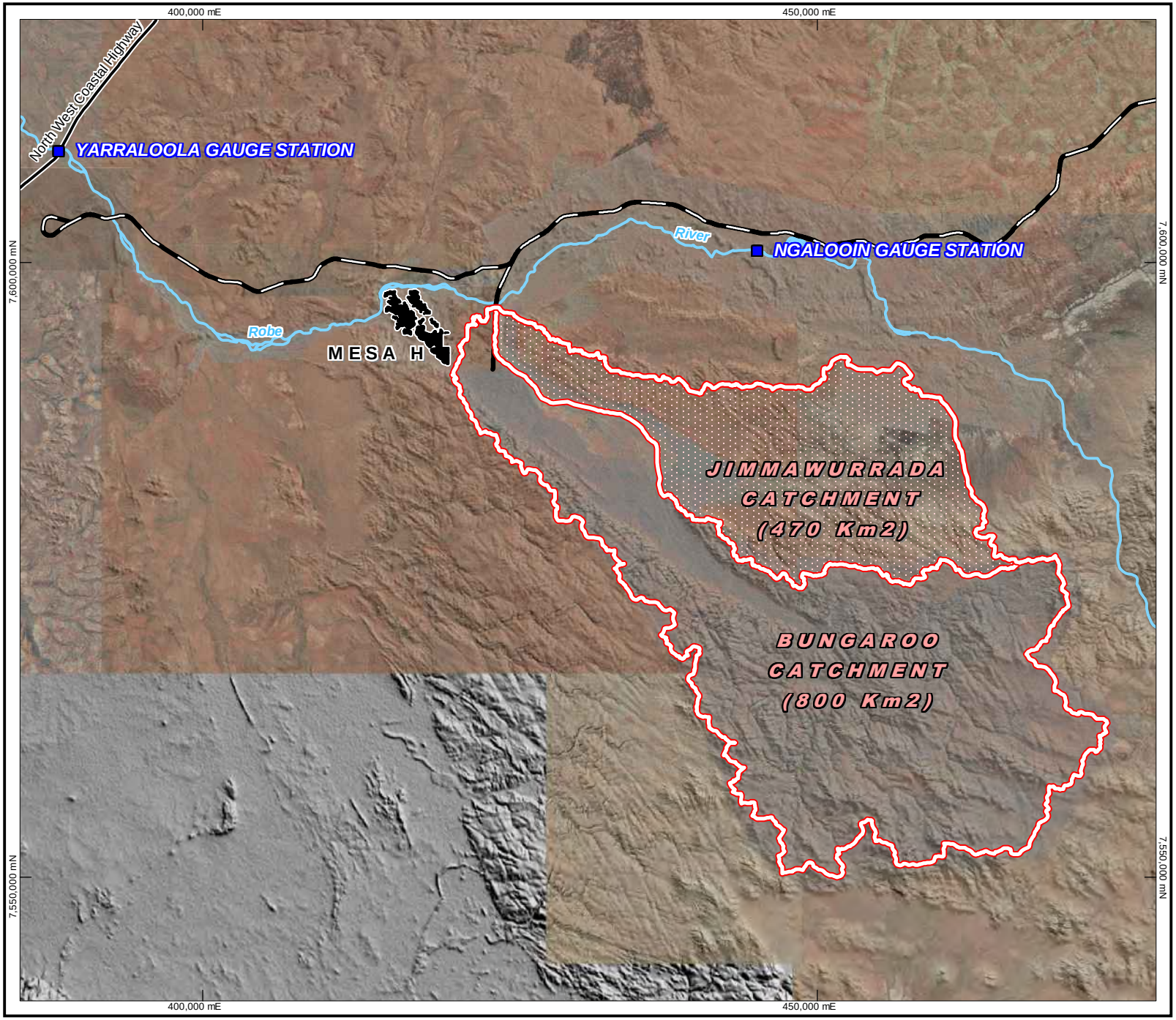
Geospatial Information and Mapping



LEGEND

- Gauge station
- Mesa H Proposed Pit
- Jimmawurrada Catchment
- Bungaroo Catchment
- Robe River
- Highway
- Railway

N

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5 0 5 10 15km

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Figure 5: Jimmawurrada / Bungaroo catchments and gauge station locations

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Plan No: PDE0162442v1
Proj: MGA94 Zone50

Geospatial Information and Mapping

There are two stream gauge stations located up gradient (Ngalooin Pool, Site Ref 707004) and down gradient (Yarraloola, Site ref 707002) from Mesa H deposit, approximately 34 Km and 36 Km respectively. The Ngalooin Pool records from 1976 and 1999 shows that the average annual flow through the Robe River was 42 GL, meanwhile the Yarraloola records indicate over the period from 1974 to 2016, that the mean annual flow through Robe River was 119 GL. Figure 6 shows the annual total recorded flows.

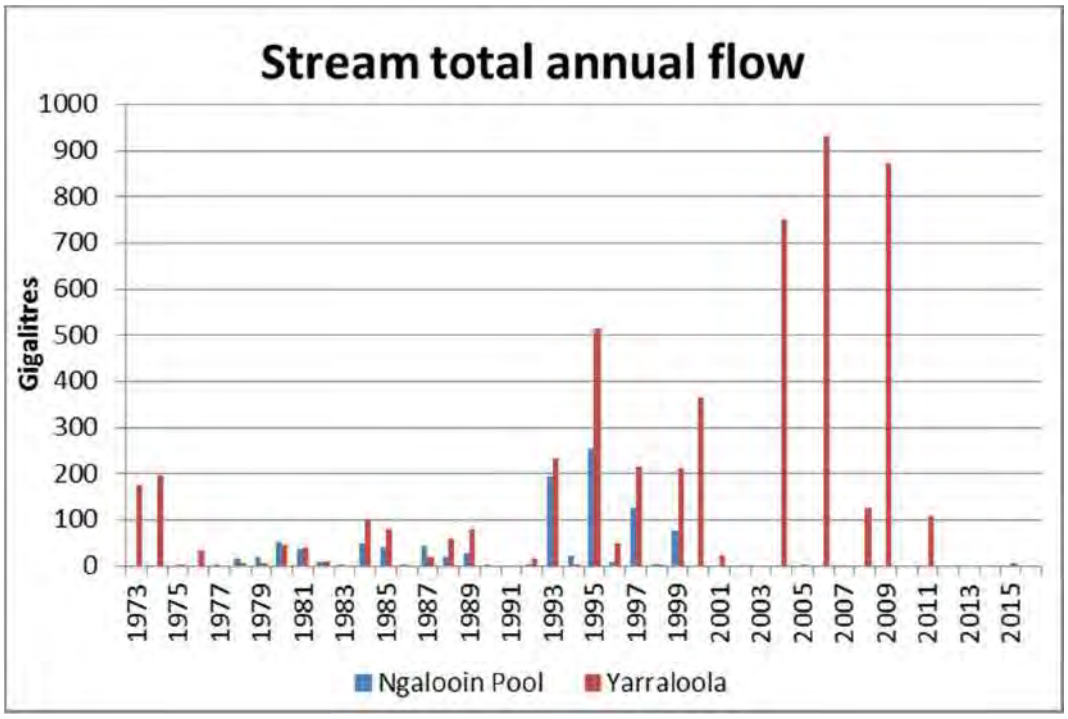


Figure 6: Stream gauging stations annual total flows

Section 3 - Hydrogeology

Groundwater within the Pilbara region originates from direct infiltration of rainfall and indirectly from surface water flows. The occurrence of groundwater within the project area is predominantly associated with primary porosity of the creek alluvials where saturated, primary porosity of the CID with secondary weathering induced permeability and with secondary permeability and porosity developed as a result of weathering in the Marra Mamba and Wittenoom Formation.

The conceptual hydrogeological model presented in subsequent sections of this report provides more detail on the overall hydrogeology and specifically on the key hydrogeological features that will determine dewatering and water supply requirements and the potential impacts of groundwater abstraction on local and regional water resources and environments that depend on groundwater.

The conceptual hydrogeological model is based on the integration of all available information, including background information from previous investigations, ongoing monitoring at Mesa J and information generated by the specific investigations described in Section 5. The conceptual hydrogeological model represents a simplified understanding of the natural behaviour and dynamics of the aquifer systems and provides the technical foundation for the detailed numerical modelling process described in Section 8.

3.1 Hydrostratigraphic units

Groundwater flow occurs from the southeast to northwest along the Jimmawurrada catchment. A series of cross-sections through the project are presented in Figure 7 to Figure 11. Pre-mining depth to groundwater is generally between 25 and 45 mbgl (Figure 12 and Figure 14). Groundwater occurs predominantly within four key aquifers:

- Wittenoom Aquifer: consisting of *weathered* dolomite and dolomitic shale (Paraburdoo and Bee Gorge Member) and *weathered* BIF (Marra Mamba Iron Formation.) with approximately 25 m thickness;
- CID Aquifer: consisting of channel iron deposit pisolitic sediments with an average of 20-30 m thickness below the pre-mining water table;
- Robe River Alluvium Aquifer: consisting of Quaternary alluvial sediments deposited along the Robe River with an approximate 20 m thickness and average width of 400 m.
- Jimmawurrada Creek Alluvium Aquifer: consisting of Quaternary alluvial sediments deposited along the Jimmawurrada Creek and associated flood plain with a maximum observed thickness of 40 m thickness along the thalweg.

The basal Robe Pisolite (TPB) is a 5 to 10 m thick layer deposited at the base of the CID Aquifer, consisting of a variable clay-rich pisolite. Hydraulic properties have not been defined, however, due to the largely impermeable physical characteristics of the unit; it is expected to function as a partial

barrier to horizontal groundwater flow between the CID Aquifer and the underlying Wittenoom Aquifer.

The Wittenoom Aquifer and the CID Aquifer are bounded by the unmineralised fresh Marra Mamba Iron Formation in the east and the Brockman Iron Formation in the west. The CID Aquifer is bound to the north by the Robe River, and although the Wittenoom Aquifer continuity to the north of the Robe River was confirmed (through drilling of 3 production bores and 6 monitoring bores), he groundwater flow direction from the north has an southern direction towards the Robe River, therefore the CID and basement flow from Mesa J and H discharges in the Robe River

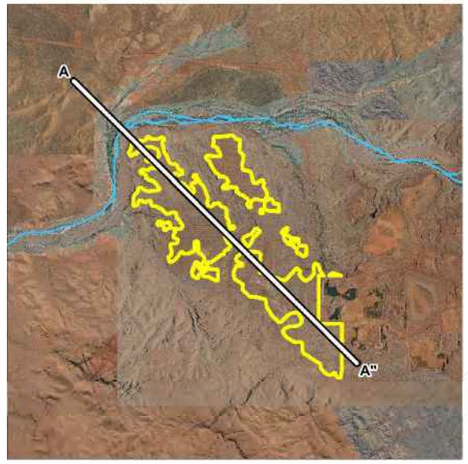
Although the water level between the CID and the basement formation is broadly the same, pumping test data carried out in bores slotted against the each unit shows a much higher drawdown in the basement than in the CID, suggesting the confinement of the weathered Wittenoom and Marra Mambas Formations in areas of limited vertical extension.

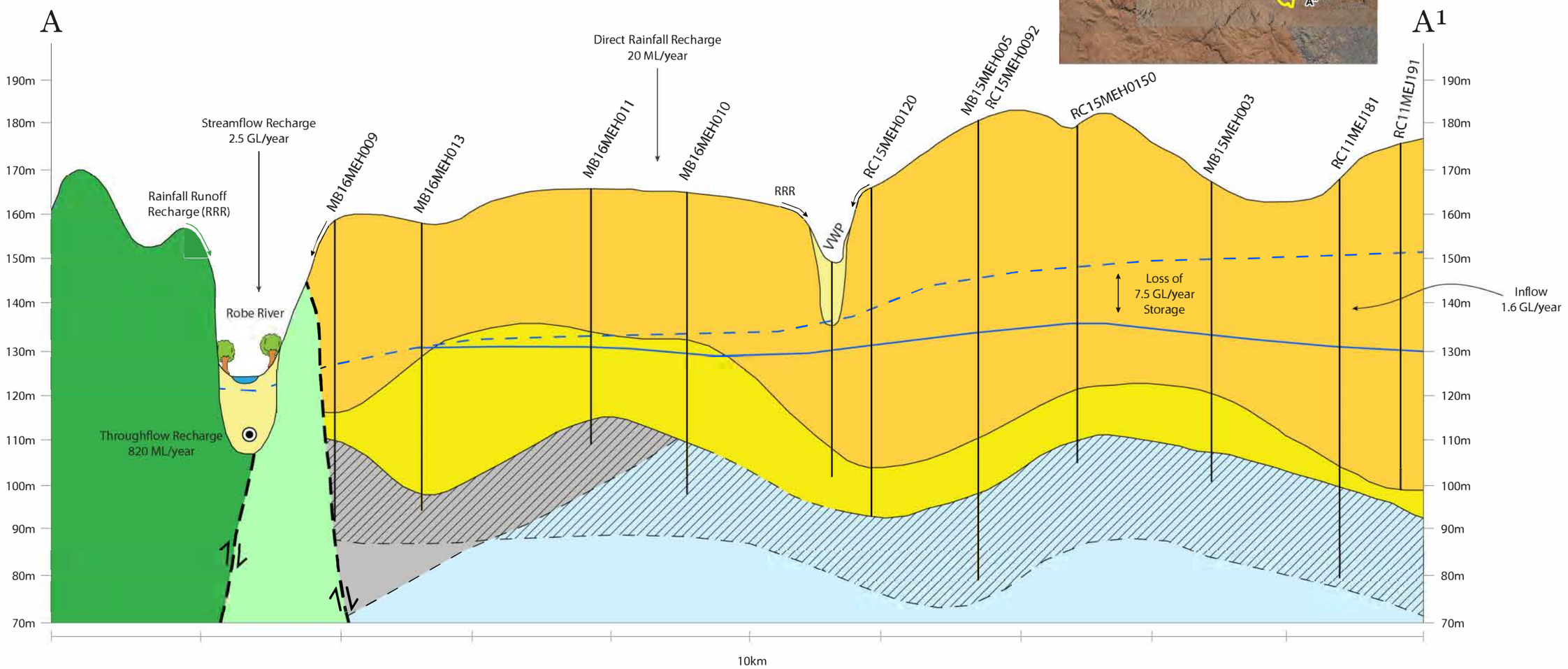
Table 2 summarises characteristics of the 4 key hydrostratigraphic units identified in the study area.

Table 2: Summary of local key hydrogeological characteristics

Unit	Aquifer Type	Formation Name	General Lithology	Hydraulic Characteristics
Robe River Alluvium	unconfined, sedimentary, vertical isotropy, regional	Quaternary alluvium	Shingles, conglomerates and coarse sand	heterogeneous, high permeability, high storage, horizontally and vertically limited
Jimmawurrada Alluvium	unconfined, sedimentary, vertical anisotropy, local	Quaternary alluvium	Conglomerates coarse to fine sand and silt / clay in the base	heterogeneous, high permeability, high storage, horizontally and vertically limited
Channel Iron Deposit	unconfined, sedimentary, vertical anisotropy, local	Robe Pisolite	clay-rich basal layer, pisolite ore, and hard-capped pisolite	heterogeneous, high and low permeability, horizontally limited
Basement	confined, weathered, fractured, anisotropic, regional	Wittenoom Formation and Marra Mamba Iron Formation	Dolomite, shale and BIF	highly heterogeneous, permeability domains associated with faults and fracturing, permeability decreases with depth

Robe Valley - Mesa H
Section A A¹ - North East



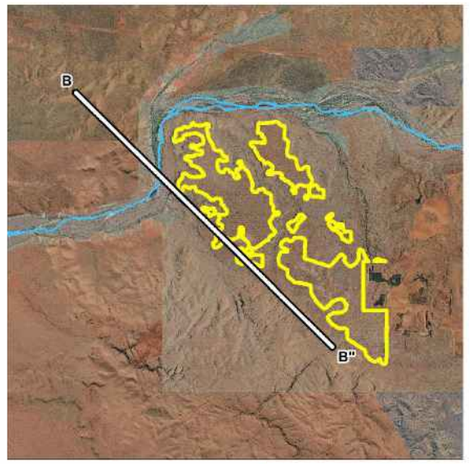


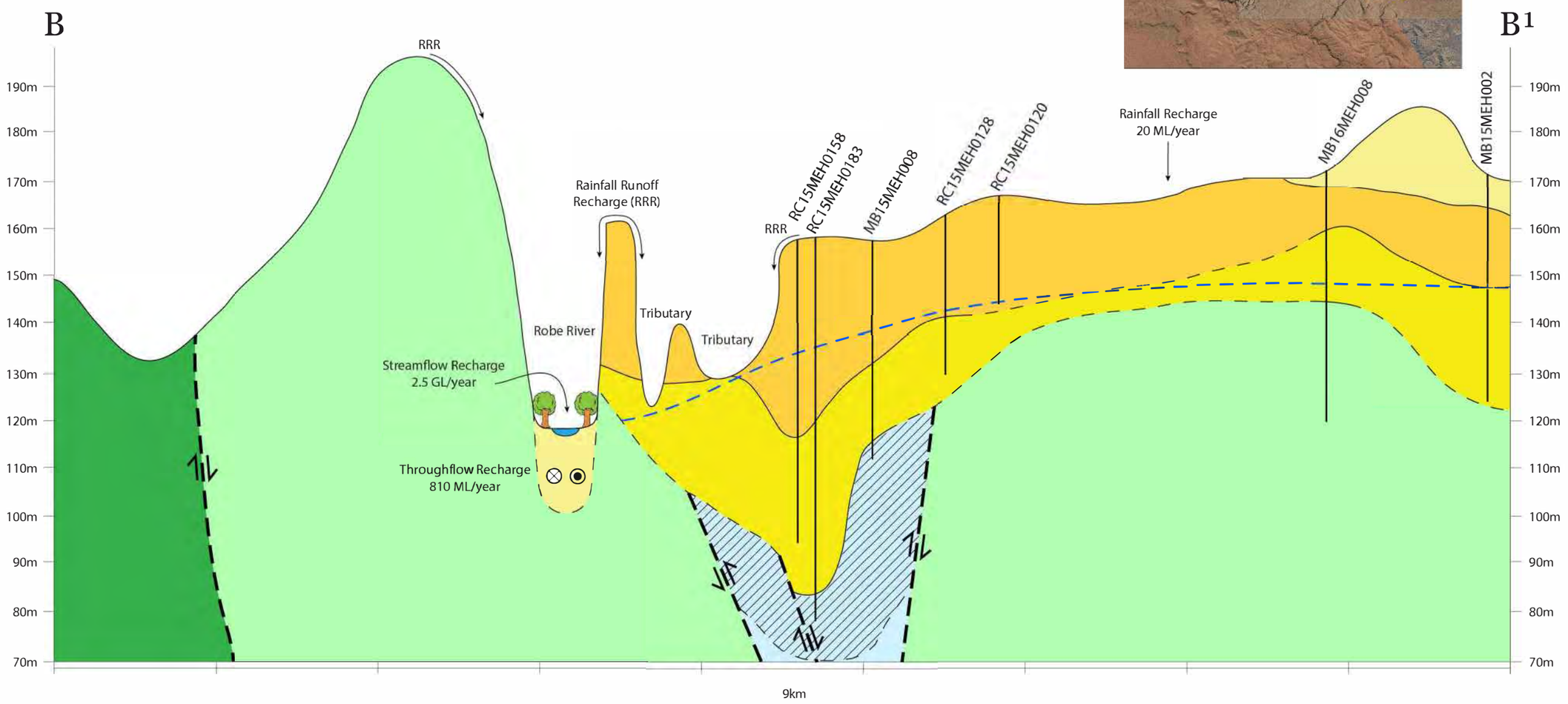
Legend

- Alluvials
- Robe Pisolite
- Robe Pisolite (TPB)
- Boolgeeda
- Brockman
- Marra Mamba
- Wittenoom
- Weathered Marra Mamba
- Weathered Wittenoom
- Drill Hole
- Fault Zone (Inferred)
- Pre-Mining Water Level
- Current Water Level
- Inferred Contact
- Alluvial Throughflow

Figure 7: Mesa H Hydro-stratigraphic cross section A-A" looking north-east

Robe Valley - Mesa H
Section B B¹ - North East



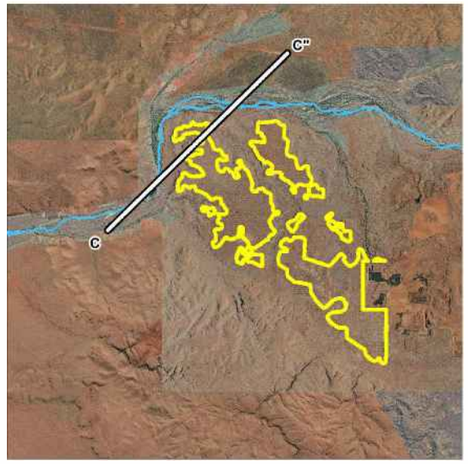


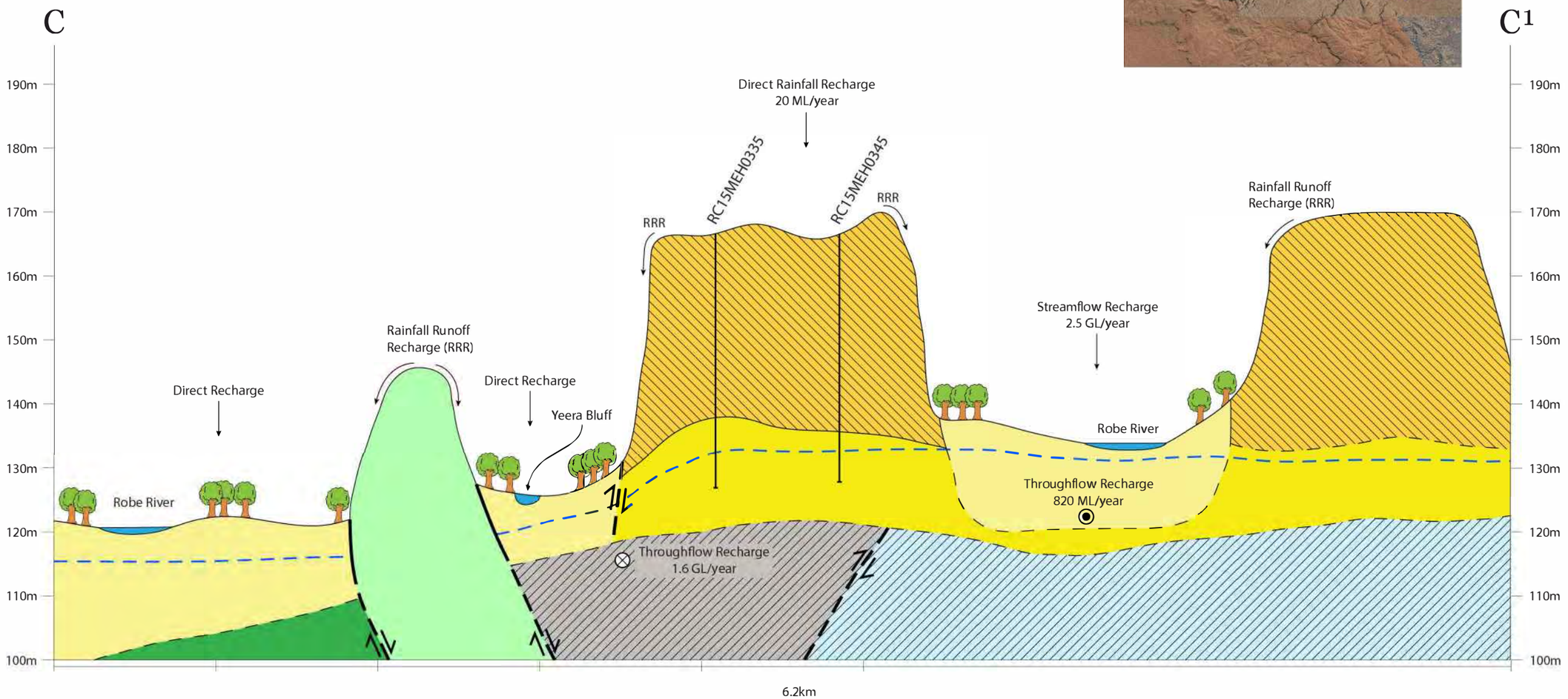
Legend

- Alluvials
- Robe Pisolite
- Robe Pisolite (TPB)
- Boolgeeda
- Brockman
- Marra Mamba
- Weathered Marra Mamba
- Drill Hole
- Fault Zone (Inferred)
- Pre-Mining Water Level = Current Water Level
- Inferred Contact
- Alluvial Throughflow
- Basement Throughflow

Figure 8: Mesa H Hydro-stratigraphic cross section B-B" looking north-east

Robe Valley - Mesa H
Section C C¹ - North East



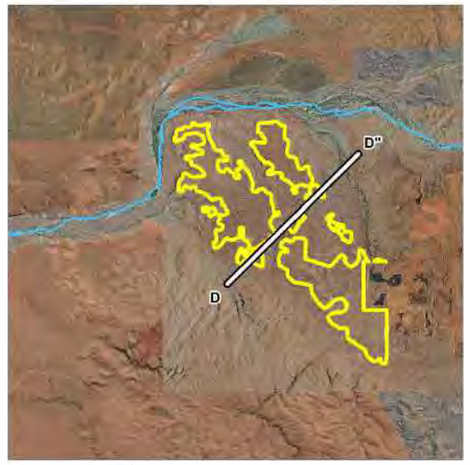


Legend

- Alluvials
- Mineralised Robe Pisolite
- Robe Pisolite (TPB)
- Boolgeeda
- Brockman
- Wittenoom
- Weathered Marra Mamba
- Weathered Wittenoom
- Drill Hole
- Fault Zone (Inferred)
- Pre-Mining Water Level = Current Water Level
- Inferred Contact
- Alluvial Throughflow
- Basement Throughflow

Figure 9: Mesa H Hydro-stratigraphic cross section C-C" looking north-west

Robe Valley - Mesa H
Section D D¹ - North West



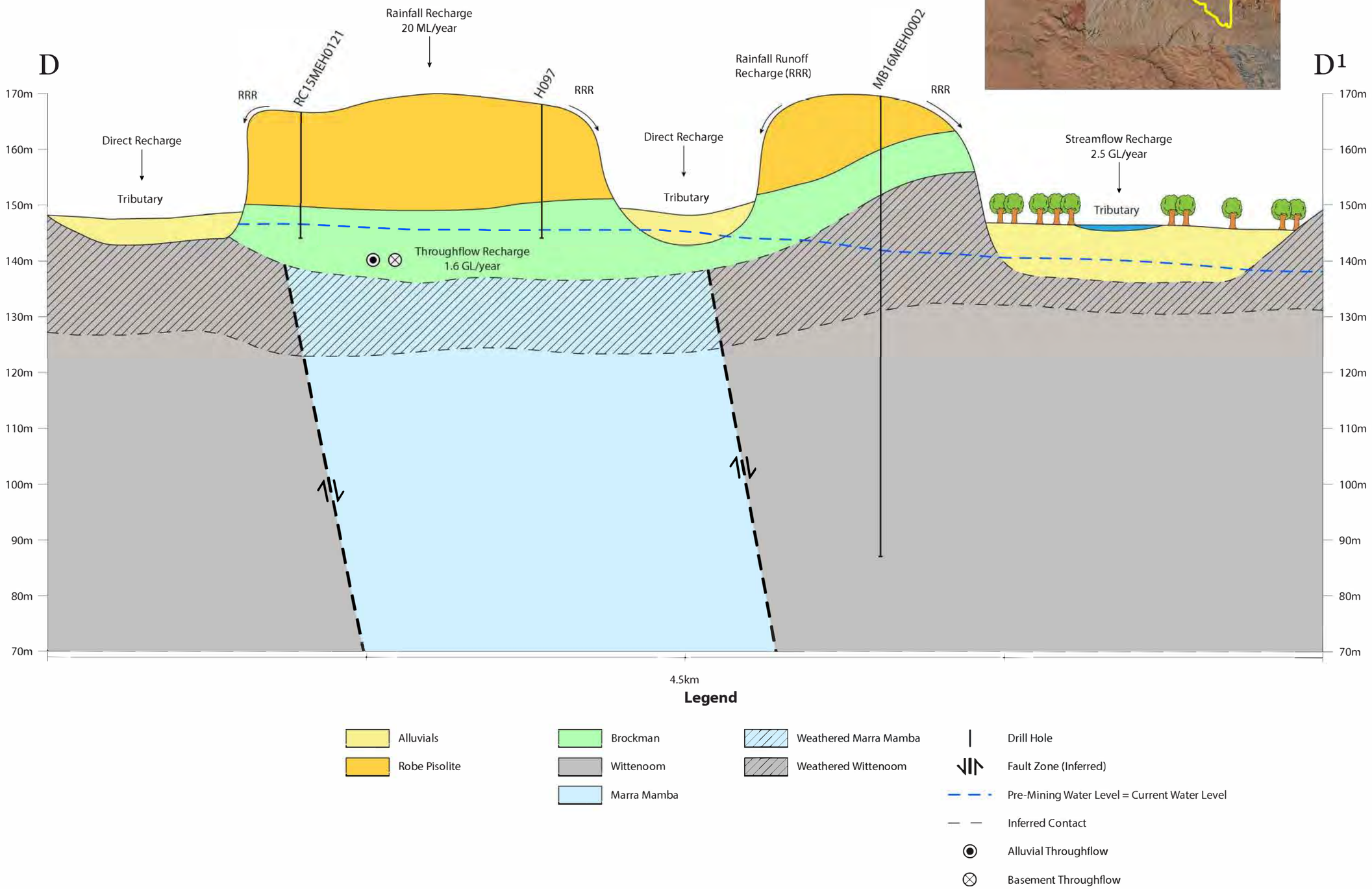
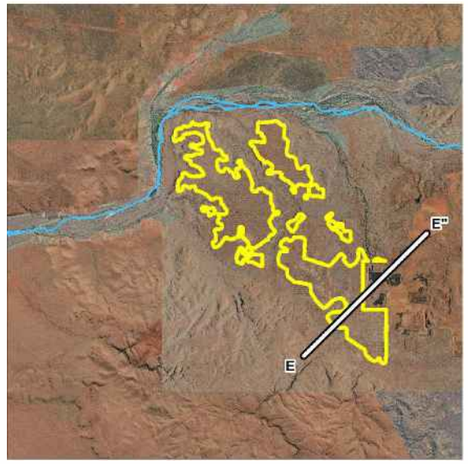
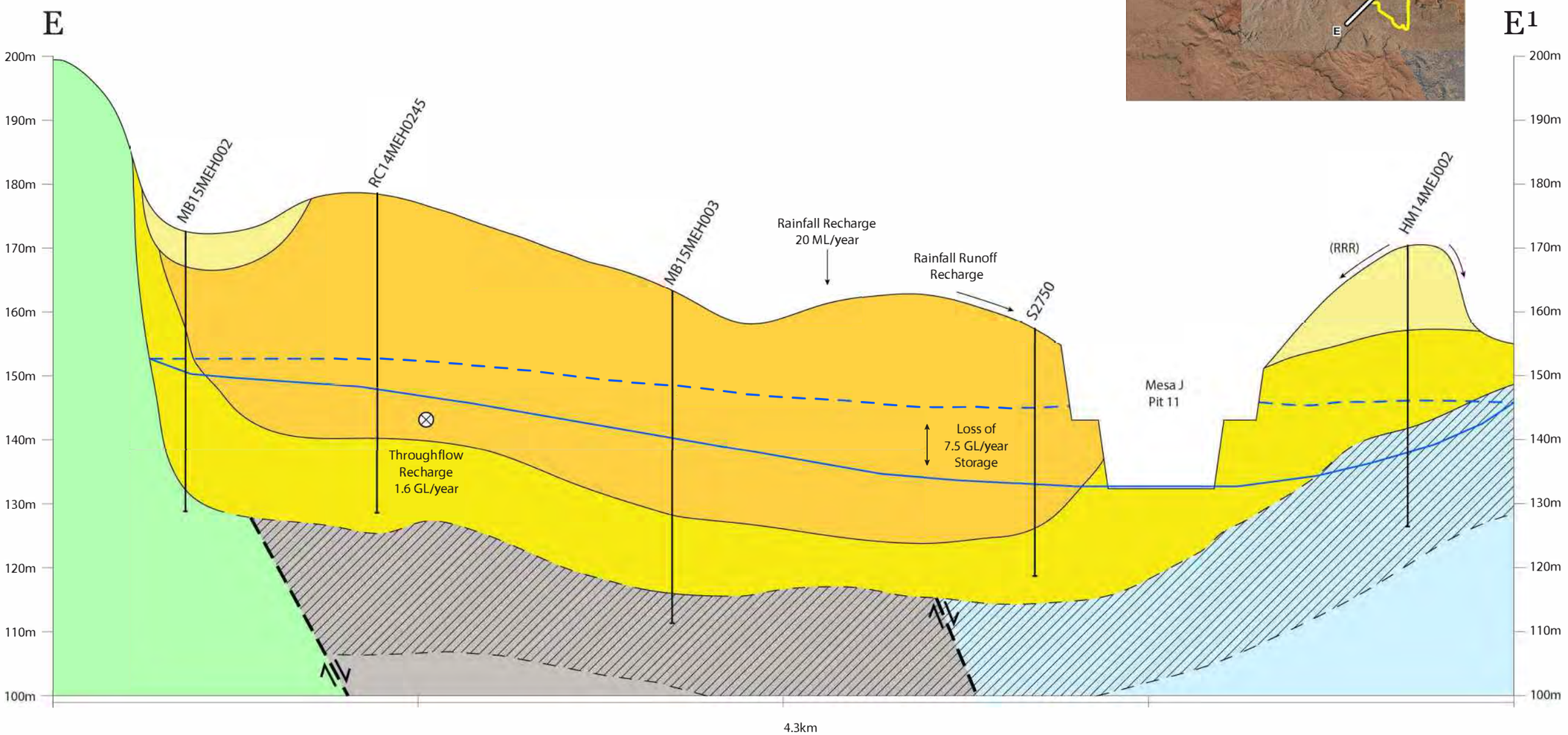


Figure 10: Mesa H Hydro-stratigraphic cross section D-D" looking north-west

Robe Valley - Mesa H
Section E E¹ - North West





Legend

- Alluvials
- Robe Pisolite
- Robe Pisolite (TPB)
- Brockman
- Wittenoom
- Marra Mamba
- Weathered Marra Mamba
- Weathered Wittenoom
- Drill Hole
- Fault Zone (Inferred)
- Pre-Mining Water Level
- Current Water Level
- Inferred Contact
- Basement Throughflow

Figure 11: Mesa H Hydro-stratigraphic cross section E-E" looking north-west

3.2 Groundwater levels

Contours reflecting the regional water table are presented in Figure 13. The regional groundwater level prior to mining activity at Mesa J ranged between 150 mAHD to the south declining to about 120 mAHD at the confluence of Robe River in the northwest, under a relatively low hydraulic gradient of 0.003.

The groundwater level has been altered significantly by pit dewatering and water supply at Mesa J, with groundwater levels declining by between 4 and 20 metres since 1995, extending approximately 3 Km laterally, especially towards west. Present day groundwater levels contours are presented in Figure 12. Figure 14 shows the hydrograph of two monitoring bores installed at Mesa H approximately 400 m west of Pit 11 (Mesa J) highlighting a decline in groundwater level of 20 meters between 1995 and 2015.

Depth to water in the Robe River ranges between 2 and 5 mbgl, whilst along the Jimmawurrada Creek between 4 and 12 metres.

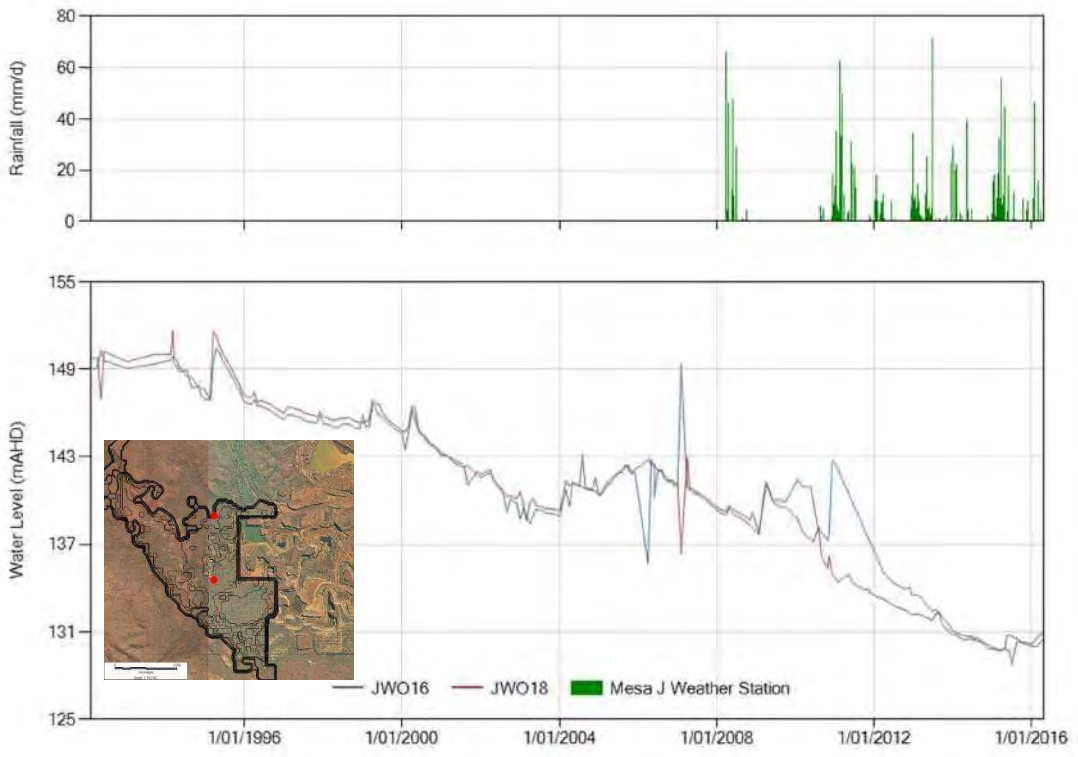
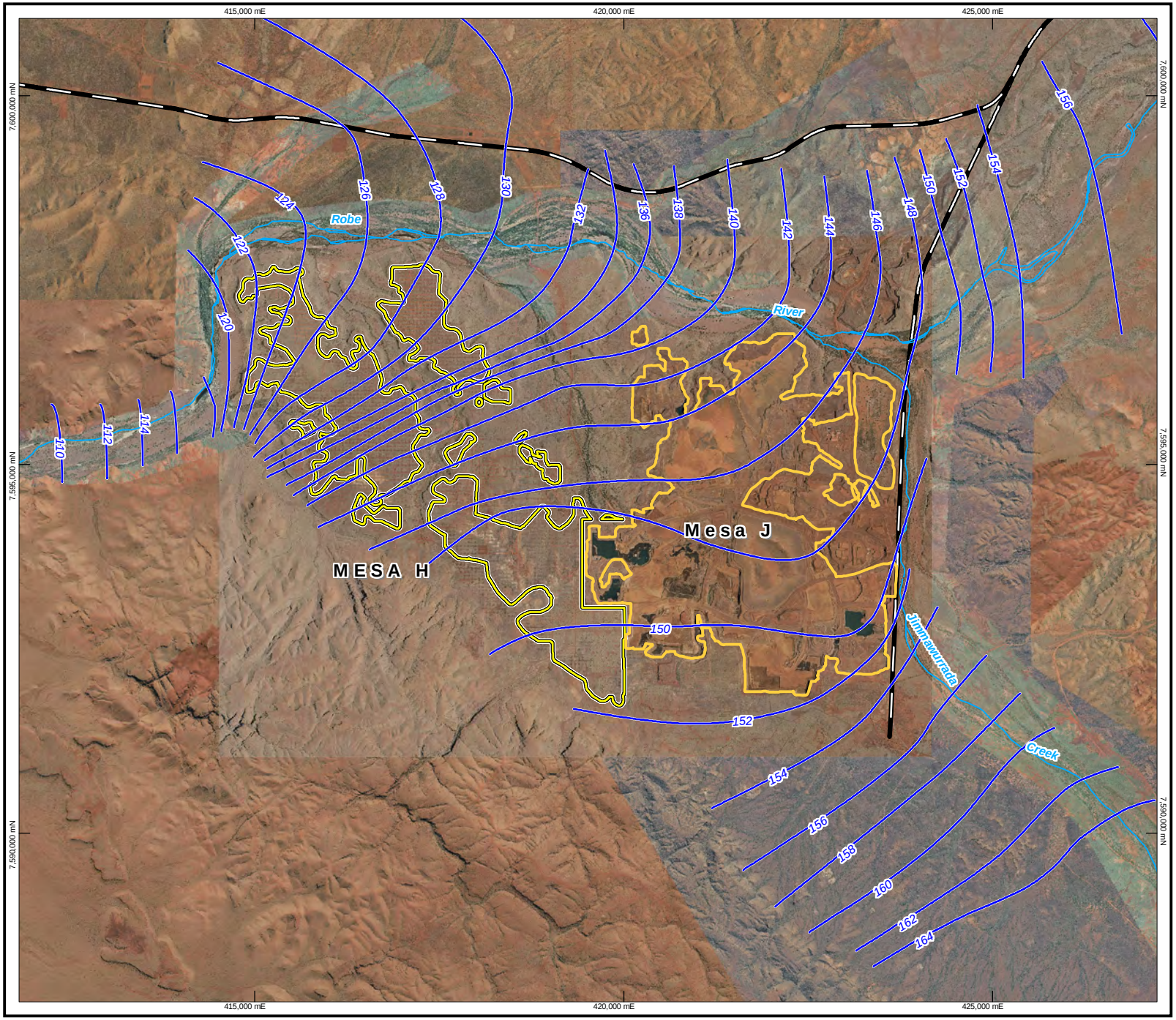


Figure 12: Mesa H monitoring bore hydrographs indicating groundwater drawdown due to Mesa J's dewatering and recorded rainfall



LEGEND

- Water table contour
- Mesa H proposed pit
- Mesa J Pit
- Railway
- Major Watercourse

N

SCALE

1 0 1 2 3km

1:75 000 @ A4

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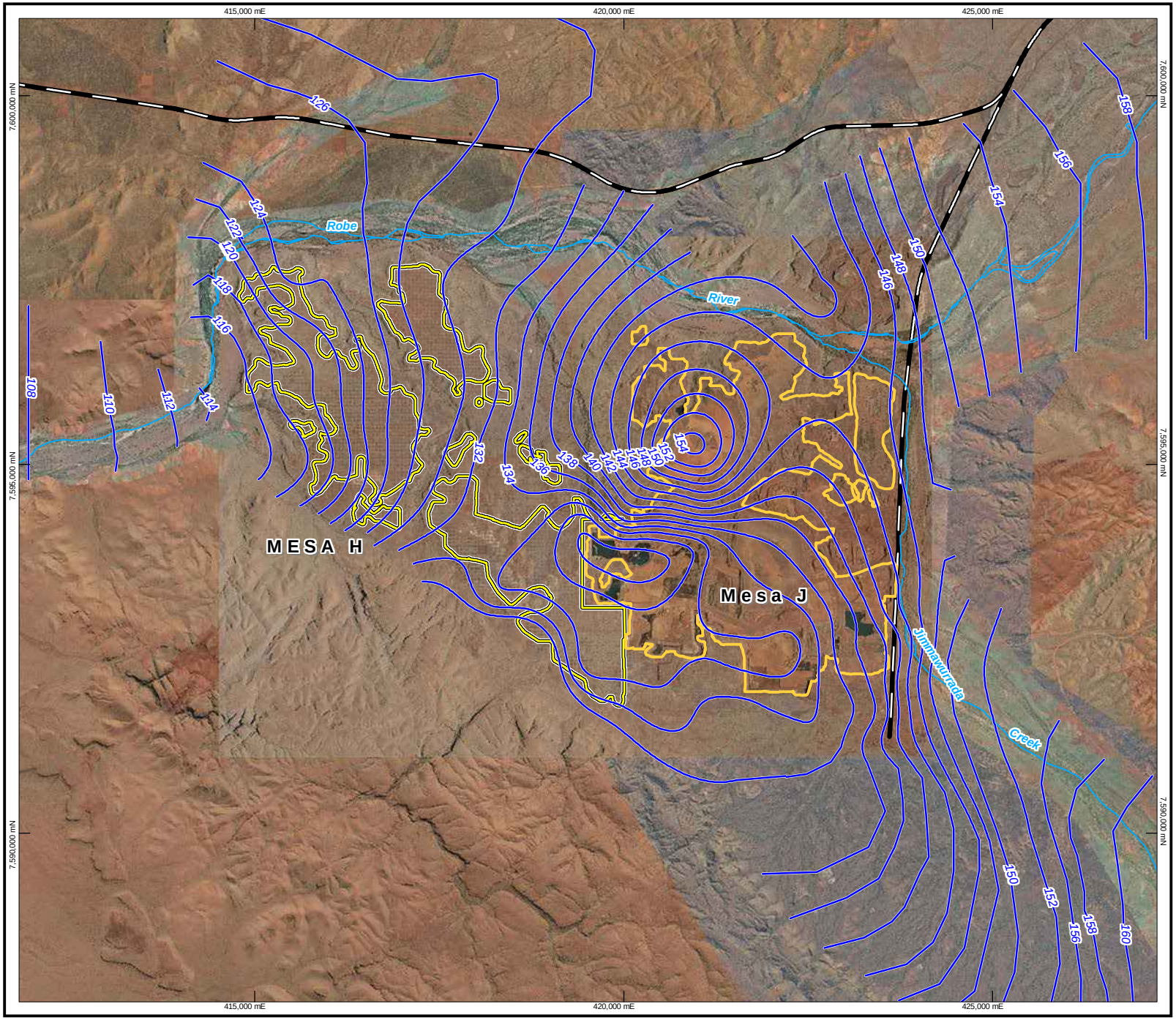
Iron Ore (WA)

Figure 13: Pre-mining water tabel depicting the groundwater flow towards the Robe River from the catchment north of Mesa H

Drawn: T.M
Date: Aug, 2018

Plan No: PDE0162442v1
Proj: MGA94 Zone50



LEGEND

- Water table contour
- Mesa H proposed pit
- Mesa J Pit
- Railway
- Major Watercourse

N

SCALE

1 0 1 2 3km

1:75 000 @ A4

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Iron Ore (WA)

Figure 14: Current water table contours

Drawn: T.M
Date: Aug, 2018

Plan No: PDE0162442v1
Proj: MGA94 Zone50

3.3 Recharge and throughflow

Recharge to the Wittenoom and CID Aquifers occurs as a result of multiple inputs, specifically:

- Recharge from rainfall has been estimated at **20 ML/year** over a 50 km^2 model domain, which equates to 3.5 mm or 1.1% of annual rainfall. This is determined on the basis of chloride concentrations in groundwater whereby:

$$Rainfall\ recharge\ (mm) = \frac{Rainfall^{Cl} \times Ave.Rainfall}{Groundwater^{Cl}}$$

$$Rainfall\ recharge\ (mm) = \frac{0.65\ mg/L \times 340mm}{64\ mg/L}$$

- Leakage from the waste fines storage facility (WSFS) at Mesa J and the water reservoirs (Lake Phil and / or Dan's Dam) is estimated to be approximately **0.5 GL/year**. Calculated as the area of the WFSF / water reservoir (430,000 m^2) adopting a vertical conductivity of 3 m/day.

Aquifer recharge resulting from leakage of the WFSF and water reservoirs appear to play an important role in limiting the extent of the dewatering cone of depression from mine dewatering to the north towards the Robe River, based on several observations:

- Monitoring of the Robe River ecosystem indicates no measurable ecological impact from more than twenty years of dewatering (RTIO-HSE-0211538);
- Dewatering drawdown has expanded towards the west of the deposit rather than down gradient (where the WFSFs are located) with the long-term monitoring indicating less than 20 metres of drawdown at Mesa H.

Throughflow is estimated across a 3500 m section of the valley south of Mesa H / J using a saturated profile of 60 m and 7 m/day horizontal hydraulic conductivity with a gradient of 0.004; the throughflow is estimated as 1.6 GL/year. This is consistent with findings of a previous study in the Bungaroo valley, up gradient from Mesa H, which indicated groundwater throughflow of between 1.8 and 3.8 GL/year (RTIO-PDE-0081114).

3.4 Groundwater discharge

Pan evaporation in the local catchment is estimated at 3400 mm/year. Evapotranspiration in within the project area is considered to occur in two primary systems, specifically:

- Evaporation from the water reservoirs and WFSFs: estimated to be in the order of **1.4 GL/year**;
- Evaporation from Mesa J trenches and in-pit sumps: estimated to be in the order of **0.2 GL/year**.

Groundwater discharge occurs via:

- The fractured bedrock: however it is unclear if this discharge follows the shallow aquifer flow direction to the west along the Robe River alluvium aquifer, or if it flows underneath the Robe River to the north continuing through the basement, the throughflow has been estimated at **1.4 GL/year** (10 km x 25 m x 5 m/day x 0.003).
- The CID Aquifer discharge to the Robe River with an estimated throughflow of **0.2 GL/year** (10 Km x 10 m x 2 m/day x 0.003);

Annual groundwater abstraction at Mesa J from sump-pumping and water supply bores is approximately **7 GL**. Discharge of surplus water to the environment is between 1.5 and 3 GL/year with most of the discharge occurring in Jimmawurrada Creek, east of Mesa J, reaching the Robe River downstream and partially recharging the alluvial aquifer, however this is considered to be a low volume in relation to the storage volume in the Robe River alluvium.

Natural evapotranspiration in the Mesa H / J was considered negligible due to depth to water greater than 20 m.

3.5 Water Balance

To meet water demand for process plant water supply, Mesa J has also harvested surface run-off from the Mesa H central catchment drainage, which runs in a north-easterly direction, into Pit 11 at Mesa J which couldn't be estimated due to lack of appropriate data.

A summary of the current estimated water balance in-flows and out-flows, excluding the Robe River and Jimmawurrada Creek flows, is presented in Table 3.

Table 3: Water Balance summary

Inflow	ML/year	Outflow	ML/year
Throughflow	1600	Throughflow	1600
Rainfall recharge	20	Evaporation	1600
Seepage	500	Abstraction (Environmental Discharge)	7000 (3000)
Loss of storage (drawdown)*	8080		
Total	**10020**	**Total**	**10020**

**value likely overestimated due to inability to precisely calculate seepage*

3.6 Robe River Hydraulics

A major alluvial aquifer underlies the lower Robe River. It consist of gravels beds with a saturated thickness of up to 25 m adjacent to the river; gradually reducing in thickness laterally from the river and downstream locally creating surface expressions of groundwater. Underlying this is the CID consisting of pisolitic sediments of Tertiary age over the Hamersley Group basement, comprising the Marra Mamba Iron Formation or Wittenoom Formation represented largely by the Paraburdoo Member.

There is potentially a strong hydraulic correlation between the Robe River alluvium and the underlying aquifer, the direction of interaction changes seasonally in response to stream flow events and evapotranspiration. Streamflow events also recharge groundwater, causing the groundwater level to rise creating large and continuous pools. After a period of no flow the hydraulic gradient between the groundwater and the pools reverse and groundwater discharges into the pools. Ephemeral pools will eventually become disconnected from intermittent pools and as surface water evaporates these pools reduce in size or disappear.

Drought conditions and declining groundwater levels result in shallower pool depths and semi-permanent pools becoming disconnected from the groundwater. Permanent pools have long-term connectivity to the groundwater and are expected to be maintained by groundwater discharge during drought periods (Department of Water, 2010). Figure 15 shows a conceptual cross-section of the interdependency between ephemeral, semi-permanent and permanent pools and surface water / groundwater interaction.

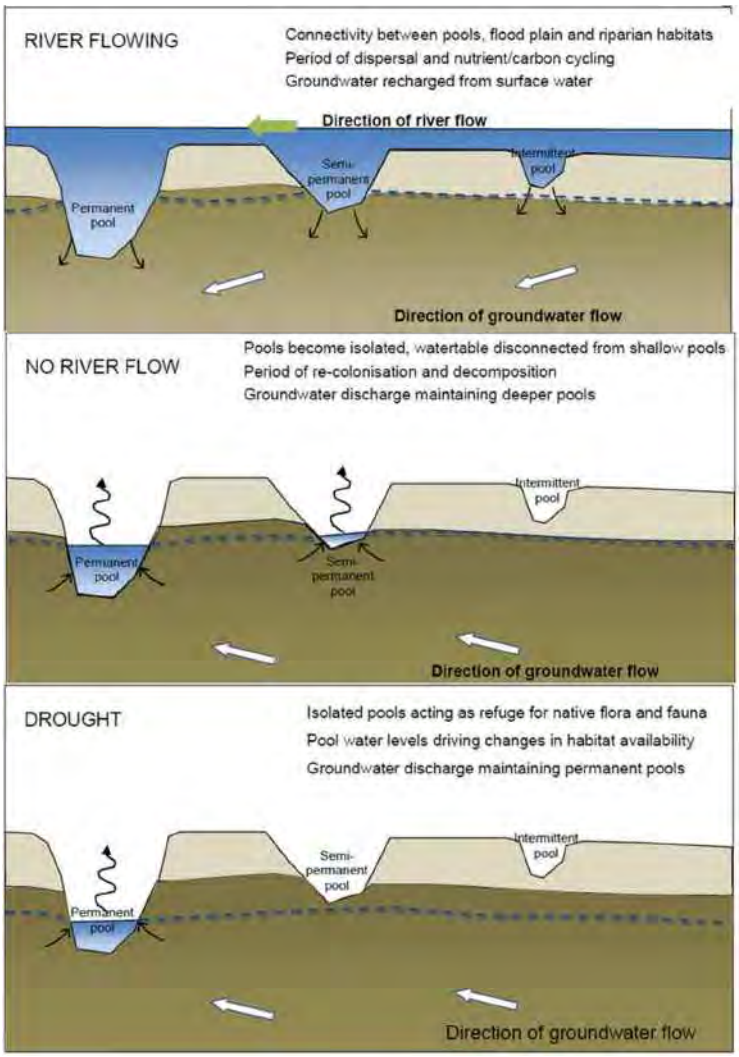


Figure 15: Conceptual diagram of a longitudinal cross-section of the Robe River during seasonal climate changes (Department of Water, 2010)

Depth to groundwater along the Robe River channel is shallow (2 – 5 mbgl) and has the potential to fluctuate up to 3 m annually in response to high rates of recharge and evapotranspiration (Department of Water, 2012). Aquifer recharge occurs through river recharge and rainfall via infiltration through the alluvial riverbed. Due to the high effective porosity of the aquifer it has the potential to absorb a significant volume of the river flow. The recharge volume is controlled by the frequency, size and duration of flow events, as well as the available storage of the aquifer, i.e. antecedent water levels. Average stream flow is estimated to be in the order of 50 GL/year in the section of the Robe River north of Mesa H.

Pre-mining groundwater throughflow is estimated across a 400 m section using a saturated profile of 20 m and 100 m/day hydraulic conductivity (RTIO-PDE-0143871) with a gradient of 0.0028; the throughflow is estimated as 820 ML/year. Due to the continuous mine surplus water discharge into the Jimmawurrada Creek, the groundwater throughflow has been potentially increased locally due to this extra recharge (~2 GL/year) up gradient. This discharge makes it difficult to understand the chemical signature of the down gradient pools along the river through surface and groundwater chemical analysis (RTIO-PDE-0144245).

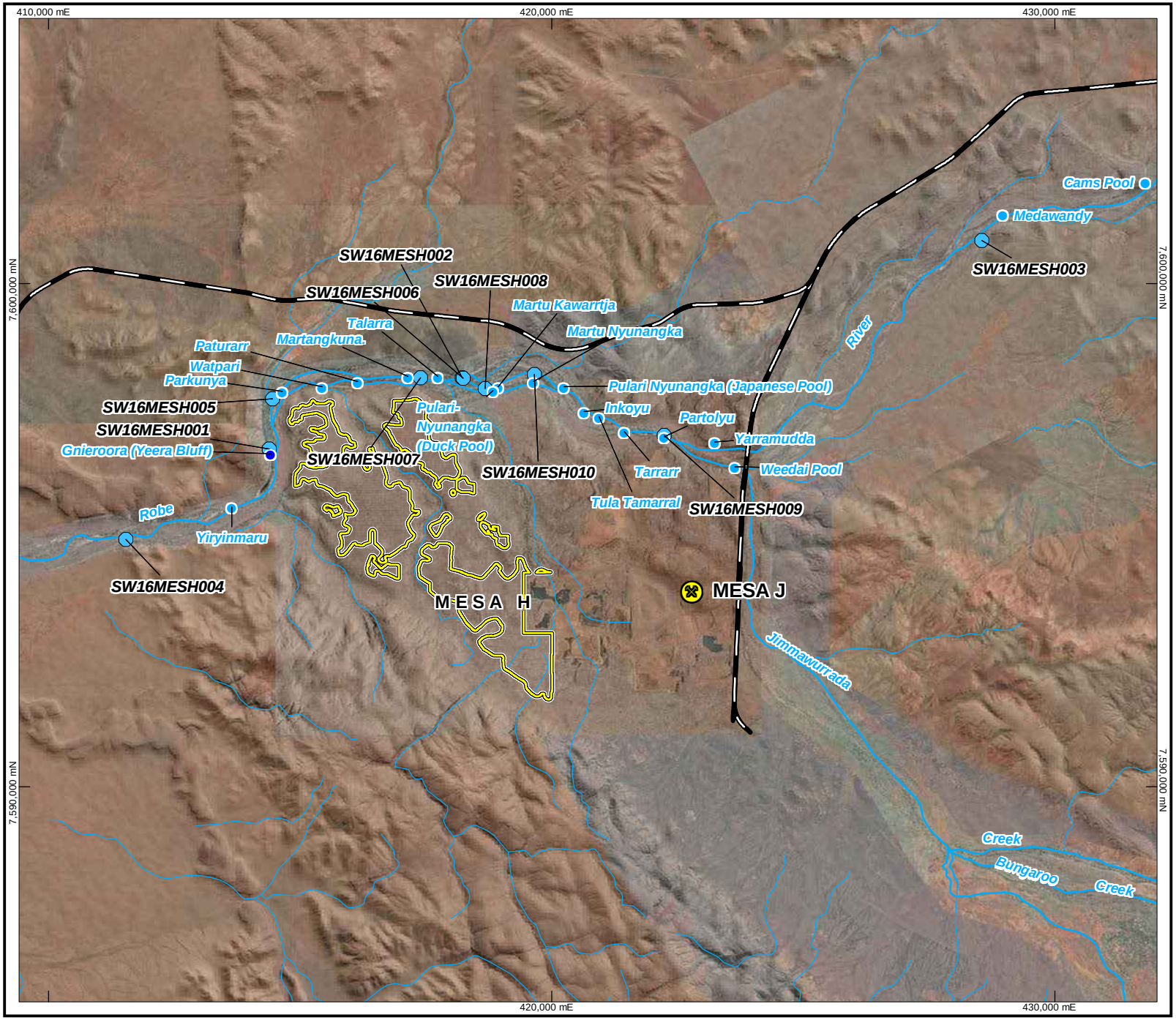
The Robe River is dry for most of the time with large flows usually associated with cyclonic activity or rain bearing depressions bringing high intensity rainfall. After the recession of surface flow and extended periods without recharge, the Robe River is reduced to a series of isolated pools which, as suggested by available water chemistry and isotope data, are sustained by groundwater and as such, are a surface expression of the alluvium aquifer (RTIO-PDE-0149324). When a rainfall event occurs, the underlying alluvium aquifer is recharged causing the water table to rise and groundwater daylights through local depressions as pools. These pools may last for considerable periods, however, extended dry periods will lower the water table resulting in shallower pools or drying up altogether.

As the pools are located within the channel it is likely that any river flow event will result in recovery of the pool water levels (Charles et al., 2015). Therefore, the frequency of full water level recovery of the pools will be defined by the frequency of streamflows (Charles et al., 2015). Furthermore, the position of the pools tends to change following seasonal flood events. It therefore follows that the regime of the pools is dictated by both the surface water and groundwater regimes, and their interactions. However, as reported by Dobbs and Davies (2011), the greatest influence on pool morphology, water chemistry and the resulting aquatic fauna is rainfall and river flows.

These Robe River pools play an important role in the river ecosystem, by supporting a diverse range of aquatic fauna and acting as refuges during periods of drought (RTIO, 2011). This has been acknowledged in this study with the installation of 9 monitoring sites specifically targeted at pool locations (Figure 16). The aim of this monitoring programme is to assist in understanding the baseline hydrologic conditions of the region and will form an integral part of an adaptive management strategy for the pools during operations.

Initial results of the monitoring for two selected sites are presented in Figure 17, which shows the response of the respective pools after a 50 mm rainfall event on 29/30 January 2016. The record

at both locations indicates water level recovery in response to the rainfall/flow event. The water level at Medawandy (located ~10km northeast of Mesa J) is shown to decline at a uniform rate after the event, whereas at Yeera Bluff, the water level remains relatively constant, which is likely owing to the potential impermeable underlying geology at Yeera Bluff.



LEGEND

- Surface Water Logger
- Pool
- Permanent Pool
- Major Watercourse
- Minor Watercourse
- Railway
- Mine

N

SCALE

2 0 2 4km

1:110 000 @ A4

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Iron Ore (WA)

Figure 16: Major pools and surface water logger locations

Drawn: T.M.
Date: Aug, 2018

Plan No: PDE0162442v1
Proj: MGA94 Zone50

Geospatial Information and Mapping

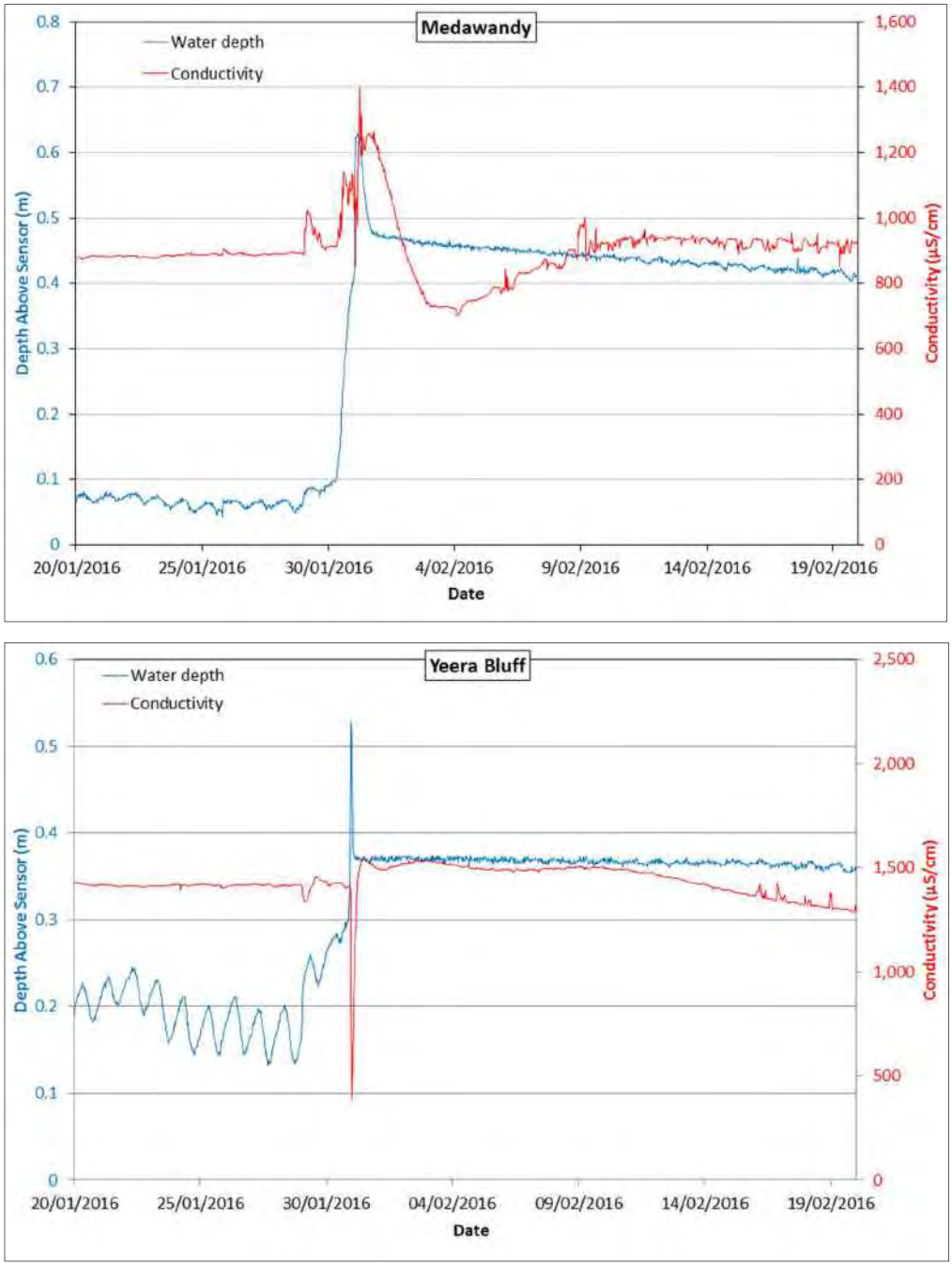


Figure 17: Observed response at SW16MESH003 (Medawandy) and SW16MESH001 (Yeera Bluff) to January 2016 rainfall event

A typical conductivity response to the January 2016 rainfall event is evident at Medawandy, with an initial spike in conductivity as the accumulated salts in the riverbed are flushed through pool, followed by a freshening up of the water before returning to approximately the pre-event conductivity levels (Figure 17). In contrast, the conductivity recorded at Yeera Bluff declines quickly initially and then increases to moderately above pre-event conductivity levels. This may be indicative of a flush of fresh water entering the pool directly from the catchment to the north of the pool, which in turn blunts the subsequent spike that would have resulted from the flow coming down

the Robe River. The declining conductivity (freshening of the water) that occurs approximately 2 weeks after the event at Yeera Bluff may be the delayed response of subsurface flow from the same event. That this response is not evident at Medawandy may be indicative of contributions from Jimmawurrada Creek.

A further observation from Figure 17 is the difference in conductivity between Medawandy and Yeera Bluff. These findings are consistent with long-term monitoring conducted by Dobbs and Davies (2009) who analysed a 17 year Robe River pools dataset and identified a salinity gradient from upstream to downstream, with salinities increasing along the length of the river. Notwithstanding this salinity gradient, the water in these pools is categorised as fresh (Dobbs and Davies, 2009).

At Yeera Bluff the effects of the relatively dry period since 2000/2001 is reflected in Figure 18, which shows relatively stable conductivity trends during periods of regular flow, but increasing conductivity trends during extended dry periods resulting from the evapo-concentration of salts in the pool. This provides valuable information regarding the water quality response of this pool to a lowering water table, whether by extended dry periods or artificial drawdown.

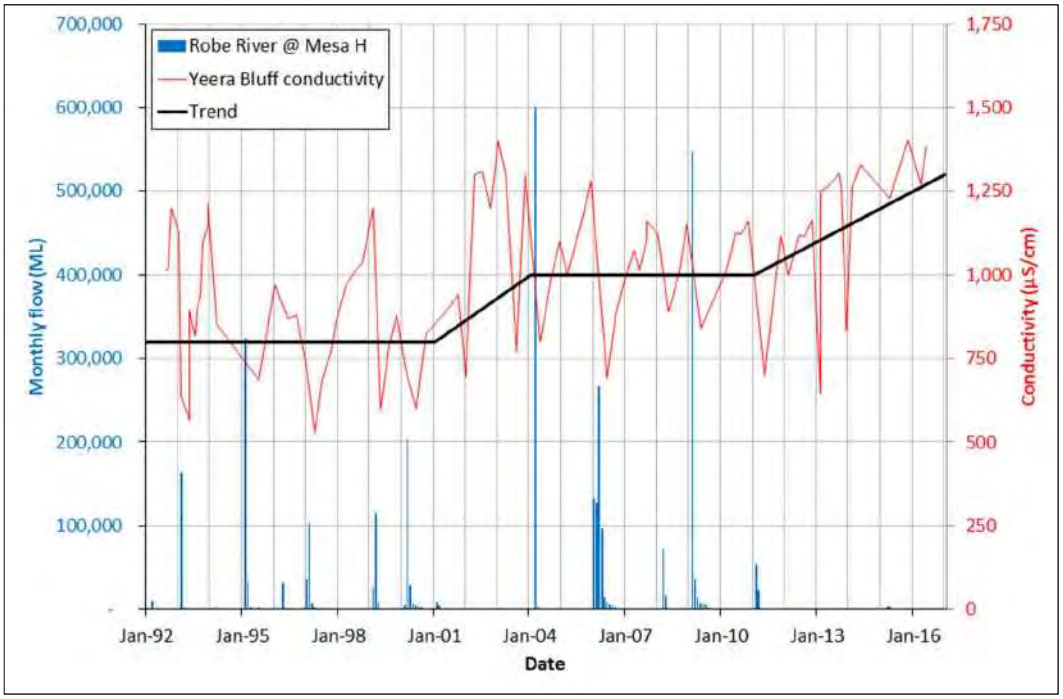


Figure 18: Long-term conductivity measurements at Yeera Bluff vs flow at Mesa H

Figure 19 shows the relative water level between bores slotted in the Wittenoom, CID and Robe River alluvium aquifers in relation to the water level in the pools (as per October 2016). Groundwater level from the aquifers is higher than the water level in the pools suggesting the groundwater gaining characteristics of the pools. The bore located north of the Robe River and slotted against the basement (Wittenoom Formation) indicates a water level lower than the pool and overlying aquifer, hence suggesting the groundwater in the basement flows from south to north

perpendicular to the Robe River, and has possibly very little (or no) contribution to the Robe River pools.

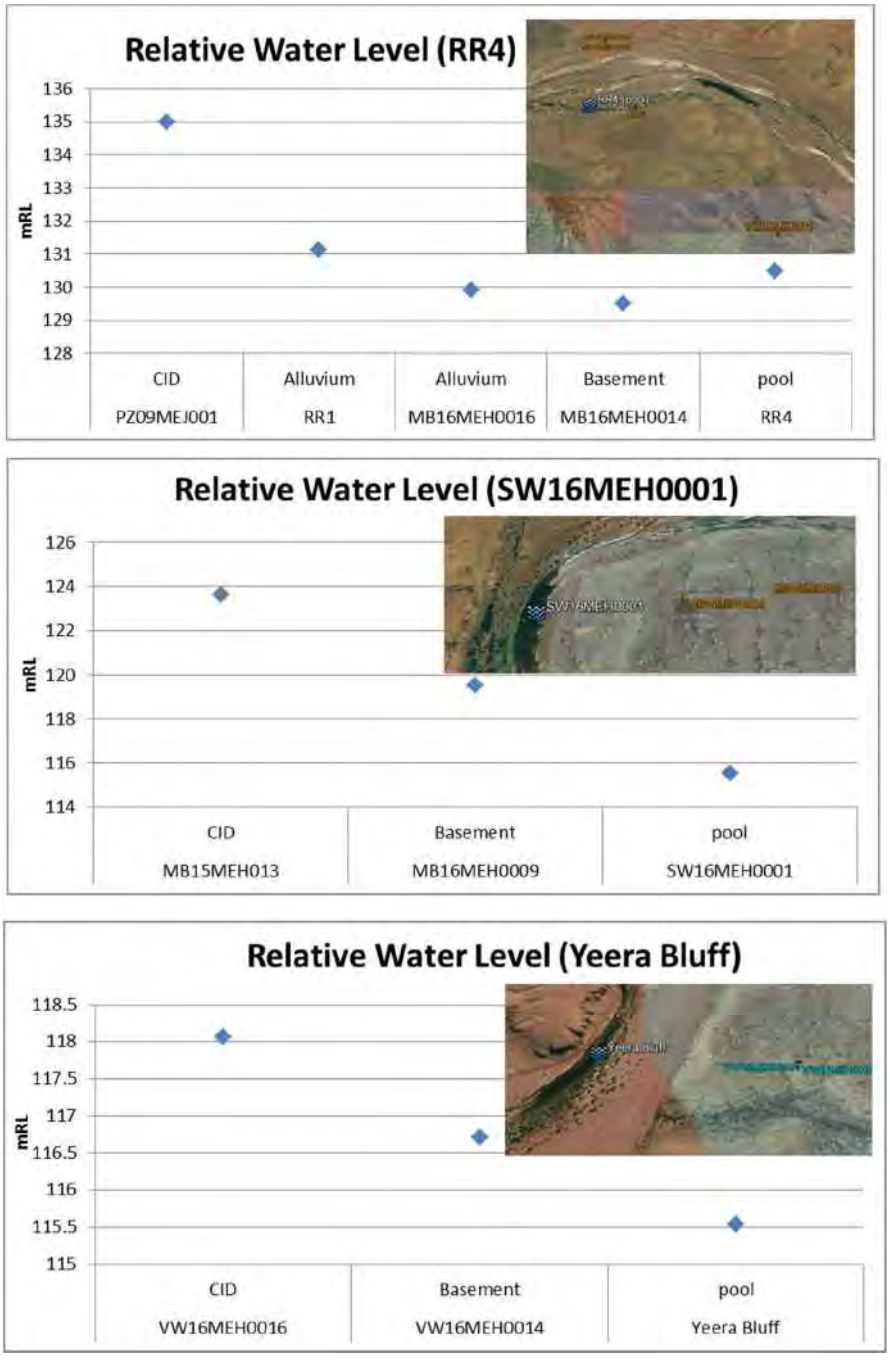


Figure 19: Relative water level between aquifers and pools

A survey was undertaken to determine the depth of nine pools located to the north of Mesa J and H along the Robe River. This survey consisted of an assessment of the bathymetry of major permanent and semi-permanent pools utilising a remote controlled boat with an inbuilt sonar recorder mounted underneath. The determination of the pools depth was undertaken over two sampling events between 2016 and 2017 to define minimum and maximum seasonal depth of the

pools. For example: for pools with 2-4m depth, the lowering of the water table by 0.5m is not considered significant, although the same impact could be significant for a pools with less than 1m depth. The results from this survey are summarised in Table 4.

Table 4: Bathymetry of the Robe River Pools

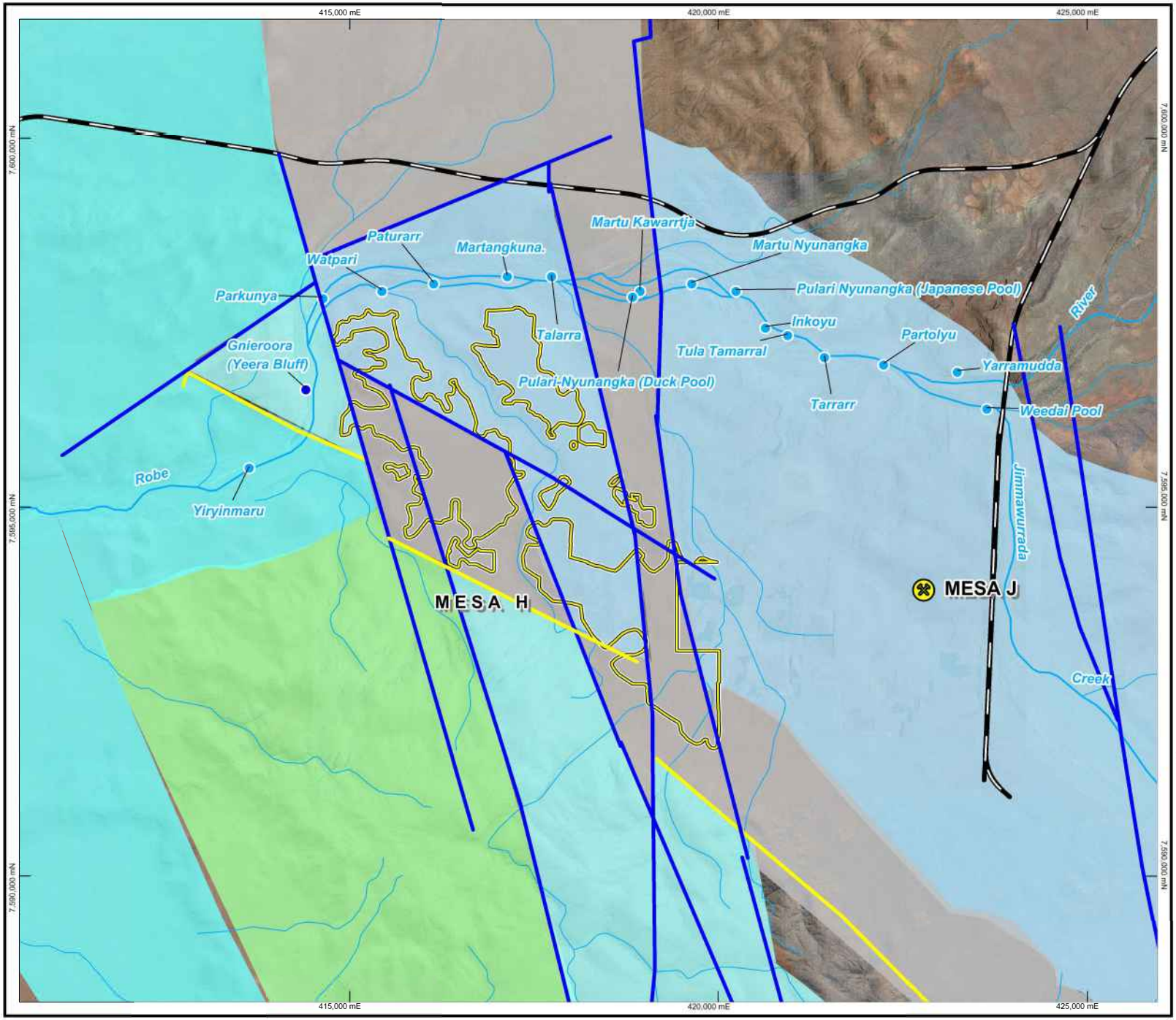
Pool Name(s)	Pool Type	Measured Depth (April – Oct 2016 extended dry)	Measured / Modelled depth (June 2017 – Seasonal high)
Partolyu	Semi - permanent	N/A	2.7m (137.3 m RL)
Tula Tamarall	Semi - permanent	N/A	2.3m (135.7 m RL)
Martu Nyunangka / Japanese Pool	Semi - permanent	1.5m	2.5m (130.5 m RL)
Duck Pool	Intermittent	Dry	N/A
Martangkuna	Semi - permanent	<0.5m	N/A
Watpari	Semi - permanent	N/A	2.4m (120.6 m RL)
Parkunya / New Yinta	Semi - permanent	2.4m	3.2m (116.3 m RL)
Nyithura / Yeera Bluff	Permanent	3.6m	4.1m (112.3 m RL)
Downstream Nyithura / Yeera Bluff	Semi - permanent	N/A	3.2m (113.2 m RL)

N/A: not assessed

3.6.1 Yeera Bluff

Based on the structural analysis of Mesa H and J, the Yeera Bluff pool is believed to be a surface expression of the groundwater controlled by geological structures and a complex fault system that has displaced the basement to the west of the pool with the basement outcropping in both sides of the valley (Figure 20). This structural feature has caused a sharp curve of the Robe River to the south and constrained the groundwater flow within a very narrow gap between the hill and Mesa

H, causing the water table to be locally “trapped” and raised, resulting in a steeper hydraulic gradient to the west beyond the basement constriction. The Brockman Iron Formation underlying Yeera Bluff was confirmed to be impermeable through the drilling of a water bore at the edge of the Mesa H, this bore produced no water (“dusty”) and was later decommissioned / capped.



LEGEND

Basement contact with CID

- Wittenoom Formation
- Marra Mamba Formation
- Brockman Fomation
- Boolgeeda Formation
- Weeli Wolli Formation
- Major fault
- Robe Valley fault
- Permanent Pool
- Pool
- Minor Watercourse
- Major Watercourse
- Railway
- Mine

N

SCALE

1 0 1 2 3km

1:75 000 @ A4

Disclaimer

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Iron Ore (WA)

Figure 20: Mesa H map of Robe River pools, major faults and basement geology contact with CID

Drawn: T.M.
Date: Aug, 2018

Plan No: PDE0162442v1
Proj: MGA94 Zone50

Geospatial Information and Mapping

3.7 Jimmawurrada Hydraulics

To estimate the flows for the Jimmawurrada creek a rainfall-runoff routing 2D model (RORB) was developed for Bungaroo and Jimmawurrada catchments and calibrated to the Yarraloola (707002) gauging station located approximately 57 km downstream from the Jimmawurrada / Bungaroo Creek confluence. The modelled 100 year average recurrence interval (ARI) design peak flow was estimated to be 3,100 m^3/s for Bungaroo Creek and 2,100 m^3/s for Jimmawurrada Creek, hence the lower Jimmawurrada Creek estimated peak flow is greater than 5,000 m^3/s in the modelled 100 year occurrence.

Qualitative evidence of flooding in Bungaroo Creek is available from photographs (Figure 23) and video footage collected on an ad hoc basis during mining operations at Mesa J and exploration activities within the Bungaroo Valley. At least four significant flow events have occurred in Bungaroo Creek in the last fifteen year. Other significant events within the last thirteen years include Tropical Cyclone (TC) Monty in February 2004 and an unnamed tropical low depression system in February 2009. The qualitative evidence from TC Clare, a 20 year ARI event, provides some validation of the 2D hydraulic model, with modelled flood levels from a 20 year ARI design rainfall event comparable to flood levels observed from photographs of the event.

Figure 21 Significant flows upstream of the Jimmawurrada study area (TC Clare, 2006).

Shallow groundwater table exists in much of the Jimmawurrada flood plain area where the water table ranges between 4 m and 12 m below ground level. Concentration of salts due to evaporation was observed in some parts of the Jimmawurrada area. Airborne geophysical data interpretation

suggests that there is a fair degree of hydraulic connectivity between the Jimmawurrada Creek sediments and Bungaroo palaeochannels aquifer in the Upper Jimmawurrada area. The water bores constructed in Quaternary and Tertiary material in Jimmawurrada flood plain were capable of producing modest bore yields (15-20L/s).

Based on available data along the Jimmawurrada Creek alluvium, geological cross sections and a Leapfrog model were prepared to support the assessment of potential impact to the riparian vegetation and stygofauna habitat caused by the lowering of the water table. A revision of historical drillholes was completed in 2019 to further refine the model resulting in an observed thalweg thickness between 28 and 40 m (Figure 22), with the deepest part located east/southeast of the SCB borefield.

Figure 22 also presents the pre-mining water level, and predicted water levels by 2030 (base case), additional drawdown caused by a reduction in the rainfall recharge events (uncertainty run #2) including an assumed seasonal variation buffer; numerical model predictions are presented on Chapter 7.3.

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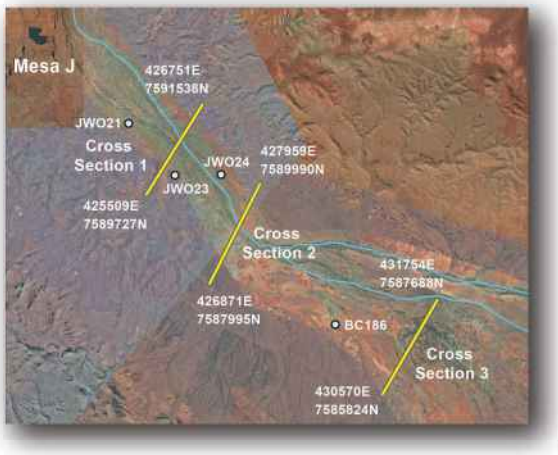
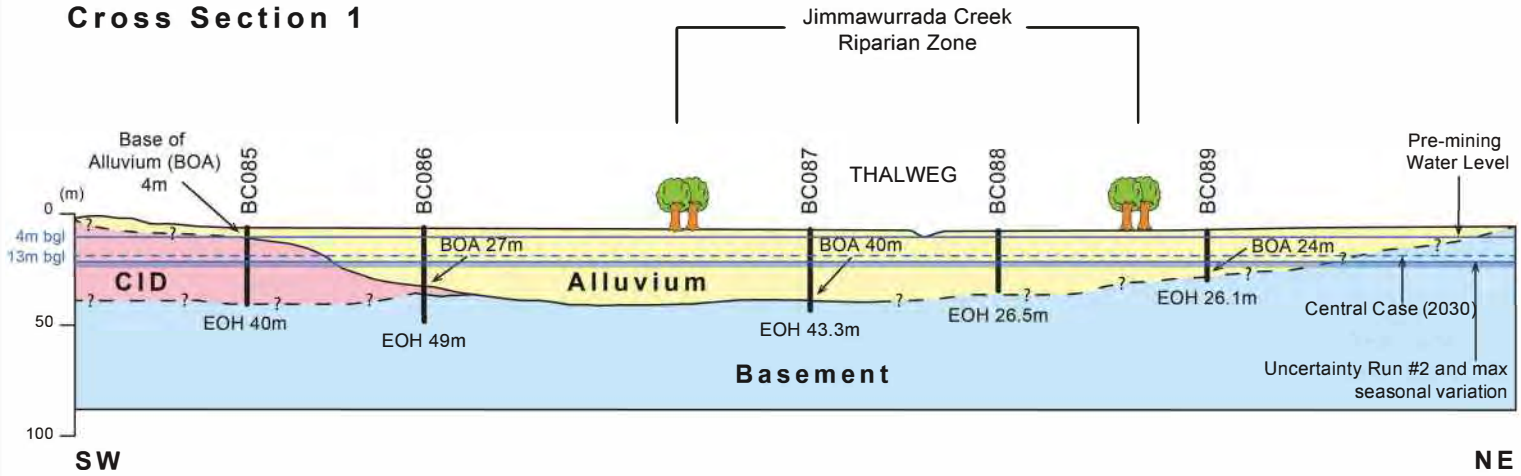
(x2 vertical exaggeration)



Cross Section 1



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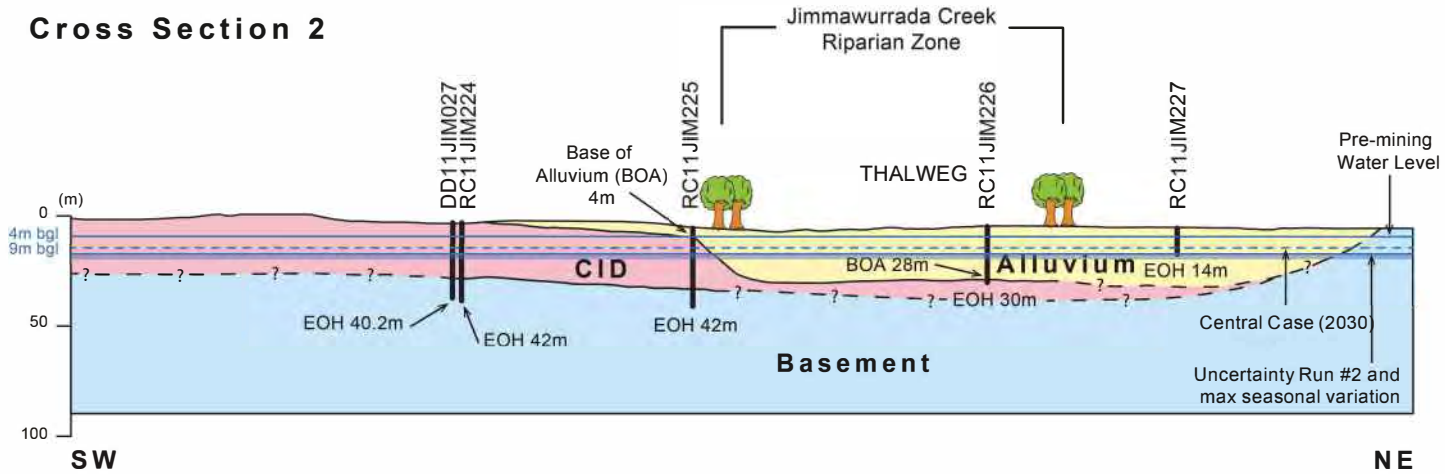

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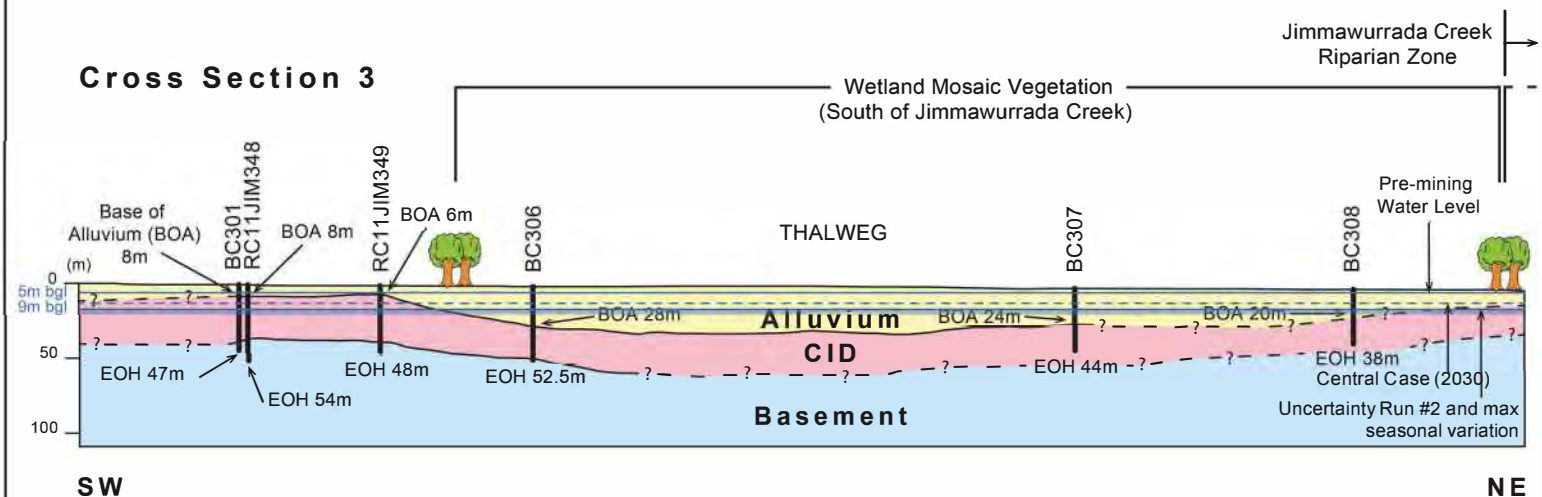


Figure 22: Jimmawurrada Creek geological cross sections

PDE0165476v4

3.8 Conceptual model uncertainties

During the development of the hydrogeological conceptualisation of the project area, a series of unknowns and uncertainties have been recognised (and even addressed during the Feasibility Study phase of the project) which could potentially affect the determination of potential impact to the Robe River pools, specifically:

- *The Brockman Iron Formation underlying Yeera Bluff is impermeable;* The conceptual model for Brockman Iron Formation northwest of the deposit underlying the Yeera Bluff pool and whether it is considered an aquiclude or an aquifer could have direct repercussions for the predicted impacts on the Robe River pools, although drilling has confirmed it as an aquiclude, fractures could still cause preferential pathways to the groundwater flow;
- *Wittenoom Aquifer continuity*: uncertainty with respect to individual basement heads and flow direction owing to lack of bores north of the Robe River. The Wittenoom Aquifer flow direction could continue under the Robe River to the north or discharge into the Robe River and flowing westward. This uncertainty was confirmed during the Feasibility drilling program indicating the Wittenoom Aquifer discharging directly to the Robe River alluvium; and
- *Alluvial aquifer heterogeneity*: Local alluvium aquifer permeability and specific yield can vary greatly locally and regionally with inferred numbers based on very limited data.

Based on the unknowns, the numerical model was calibrated to one Base Case and three conceptual uncertainties were run to predict potential changes based on a multiple conceptualisation approach to the project. Table 5 shows a summary of the four conceptualisations predicting, the “base case” and “worst case” scenarios, in terms of potential impact to the Robe River pools.

Table 5: Summary of hydrogeological conceptualisations

Permeability \ Throughflow	Wittenoom aquifer flow continues north under Robe River Alluvial Aquifer	Wittenoom aquifer flow discharges into Robe River Alluvial Aquifer flowing west
Brockman Iron Formation underlying Yeera Bluff pool is aquiclude	Conceptualisation 1	Conceptualisation 3 (*Base Case*)
Brockman Iron Formation underlying Yeera Bluff pool is permeable	Conceptualisation 2 (*Worst case - increased risk of dewatering impacts on pools*)	Conceptualisation 4

Section 4 - Existing Groundwater Use

4.1 Mesa J

The Mesa J operation, located immediately to the east of Mesa H, is covered under GWL 107678(12) with a maximum approved annual abstraction licence of up to 30 GL for operational supply, mineral ore processing, dust suppression and dewatering purposes. Dewatering is achieved through the use of in-pit sumps and trenches, with external borefields (e.g. Southern Cutback Borefield) providing process water supply and potable water. A large supply of water used for mine process purposes is recycled at Mesa J through the use of decant water from WFSF.

The total groundwater abstraction currently averages 11 GL per year, representing approximately 36% of the allocated licence. Figure 23 and Figure 24 shows the Mesa J groundwater abstraction, rainfall and hydrographs from selected monitoring bores.

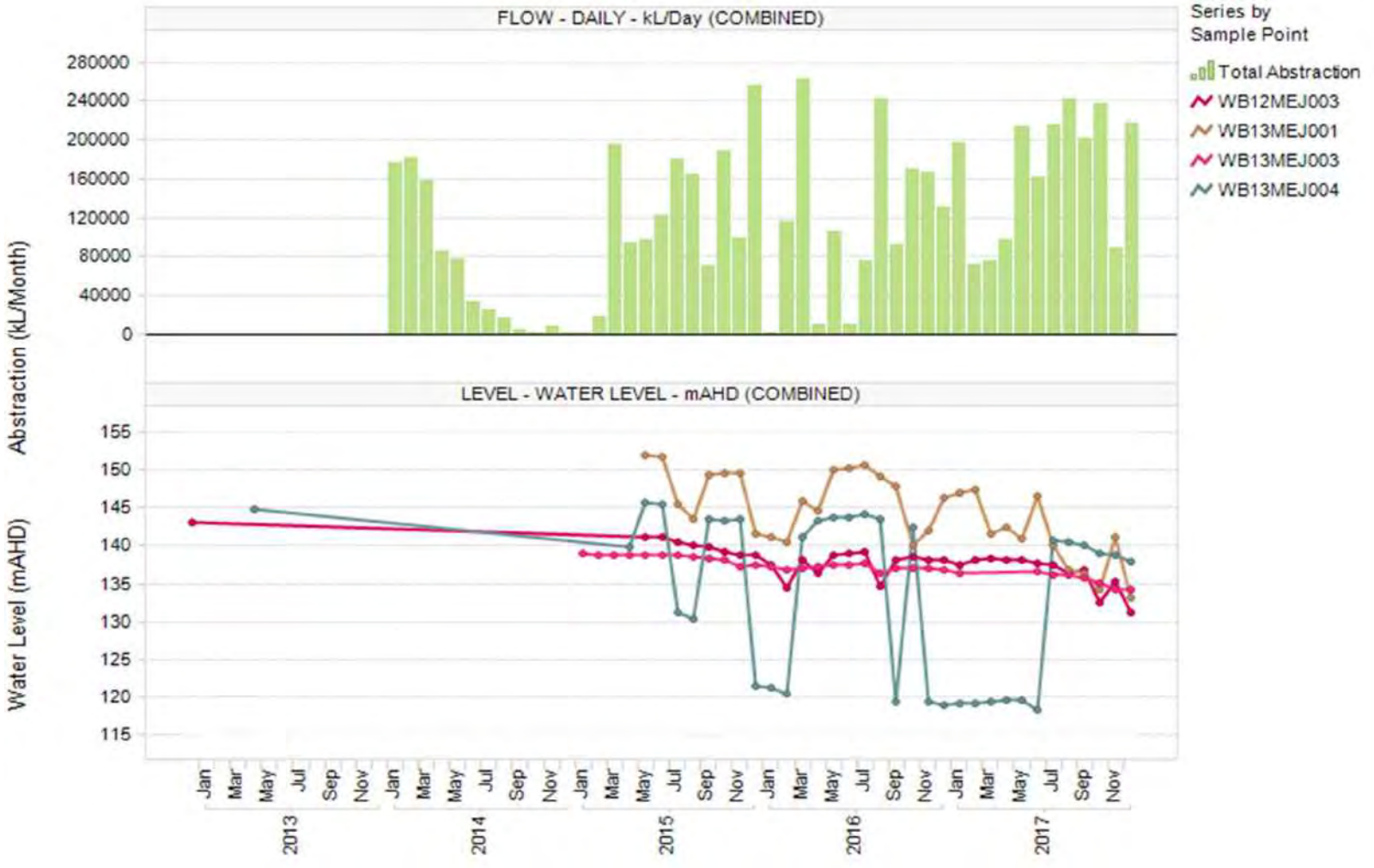


Figure 23: Mesa J Abstraction Vs Water Level hydrographs

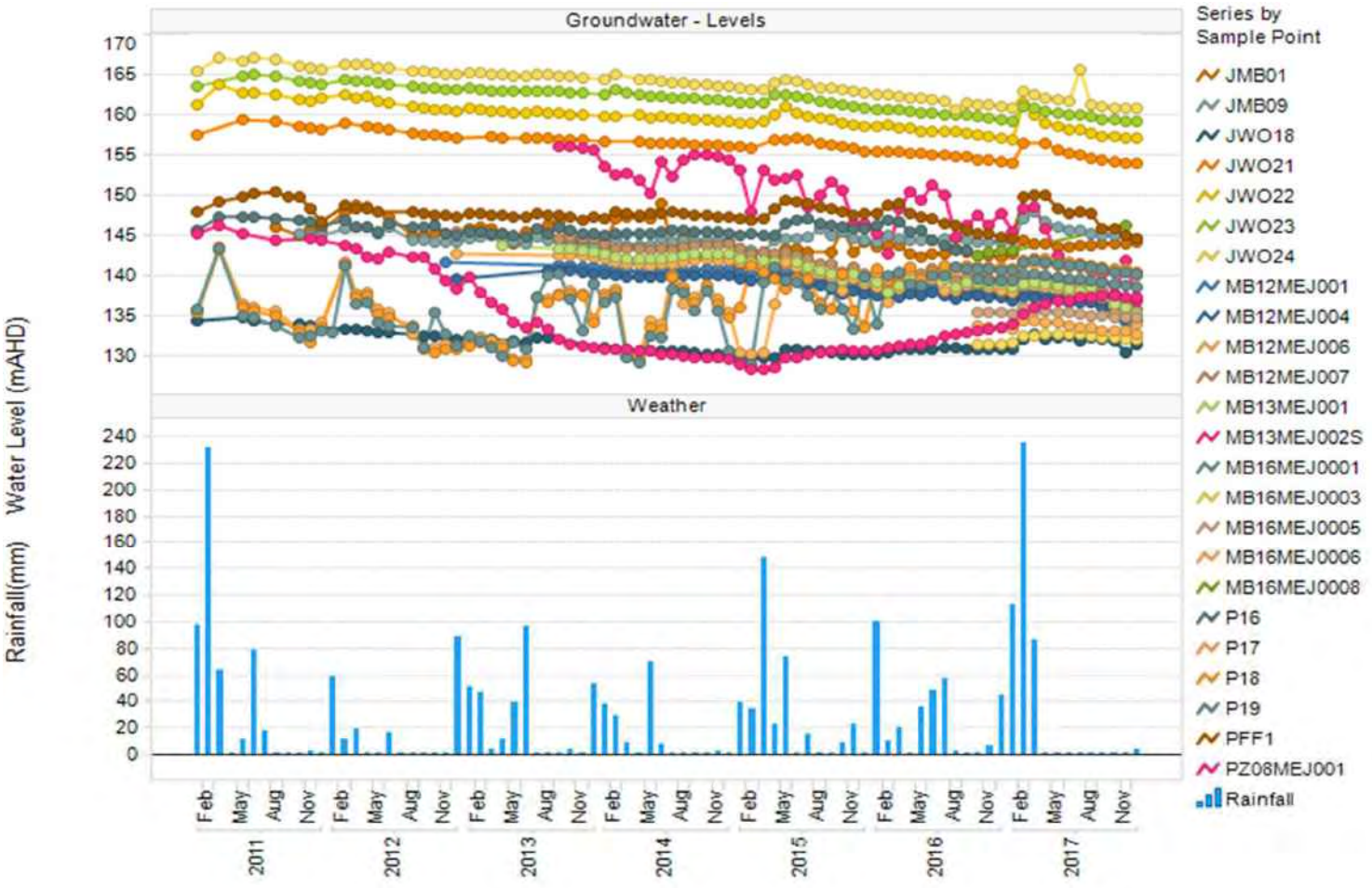


Figure 24: Mesa J Rainfall Vs Water Level hydrographs

The SCB is located immediately to the south of Mesa J, approximately 2 Km west of the Jimmawurrada Creek, and consists of five production bores ranging between 70 and 110 m deep, slotted against the CID and the Basement aquifers, capable of producing between 20 and 70 L/s. The six monitoring bores located to the east of the SCB, close to the Jimmawurrada Creek, indicates a continuous decline in the water level since 2010 (Figure 25) possibly attributed to a combination of long period of drought, Mesa J dewatering, SCB operation and Coastal Water Supply throughflow reduction.

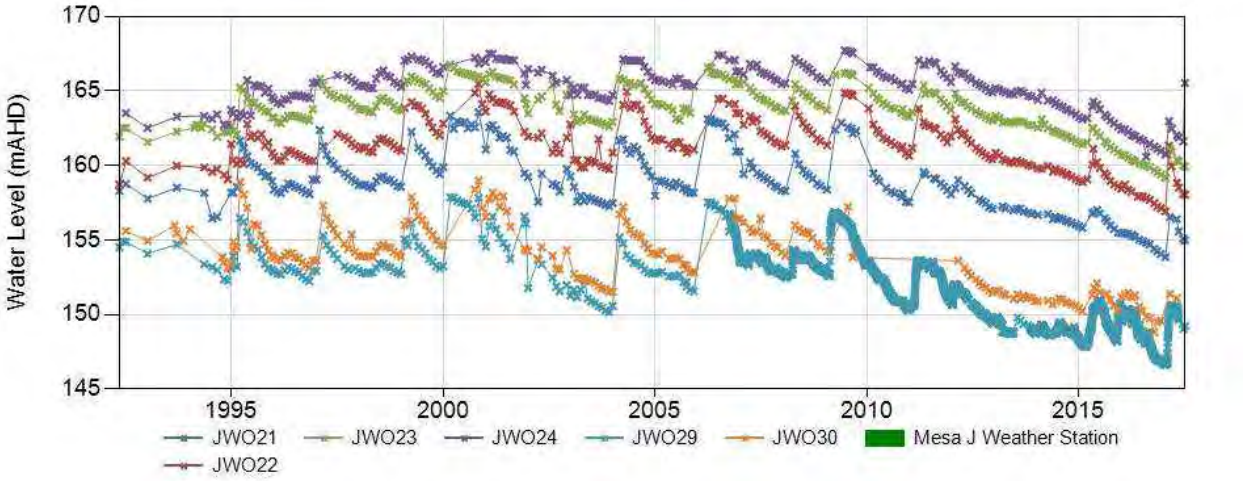


Figure 25: Water Level hydrographs close to Jimmawurrada Creek

4.2 Pannawonica

The Pannawonica town borefield is located approximately 5 km south of the Pannawonica town site in the Robe River flood plain. The Pannawonica town borefield abstracts groundwater for the purpose of potable water supply and dust suppression. Groundwater abstraction is covered under the licence GWL 107677 (7) and permits abstraction of up to 700,000 kL/year.

The borefield comprises of five active production bores screened within the Robe River alluvium, with an average abstraction of 650,000 kl/year. Long term data indicate the Pannawonica Town aquifer is periodically recharged by direct rainfall and or stream flow events.

A steady decline of up to 2m in the water level caused by the groundwater abstraction can be observed in the monitoring bores immediately adjacent to the borefield (Figure 26 and Figure 27), however, such decline is temporarily lessened by seasonal recharge.

Groundwater quality also remains consistent and in line with long term trends. Groundwater quality of the aquifer has not been impacted by abstraction activities at the Pannawonica Borefield.

Figure 26 and Figure 27 shows the Pannawonica groundwater abstraction, rainfall and hydrographs from selected monitoring bores.

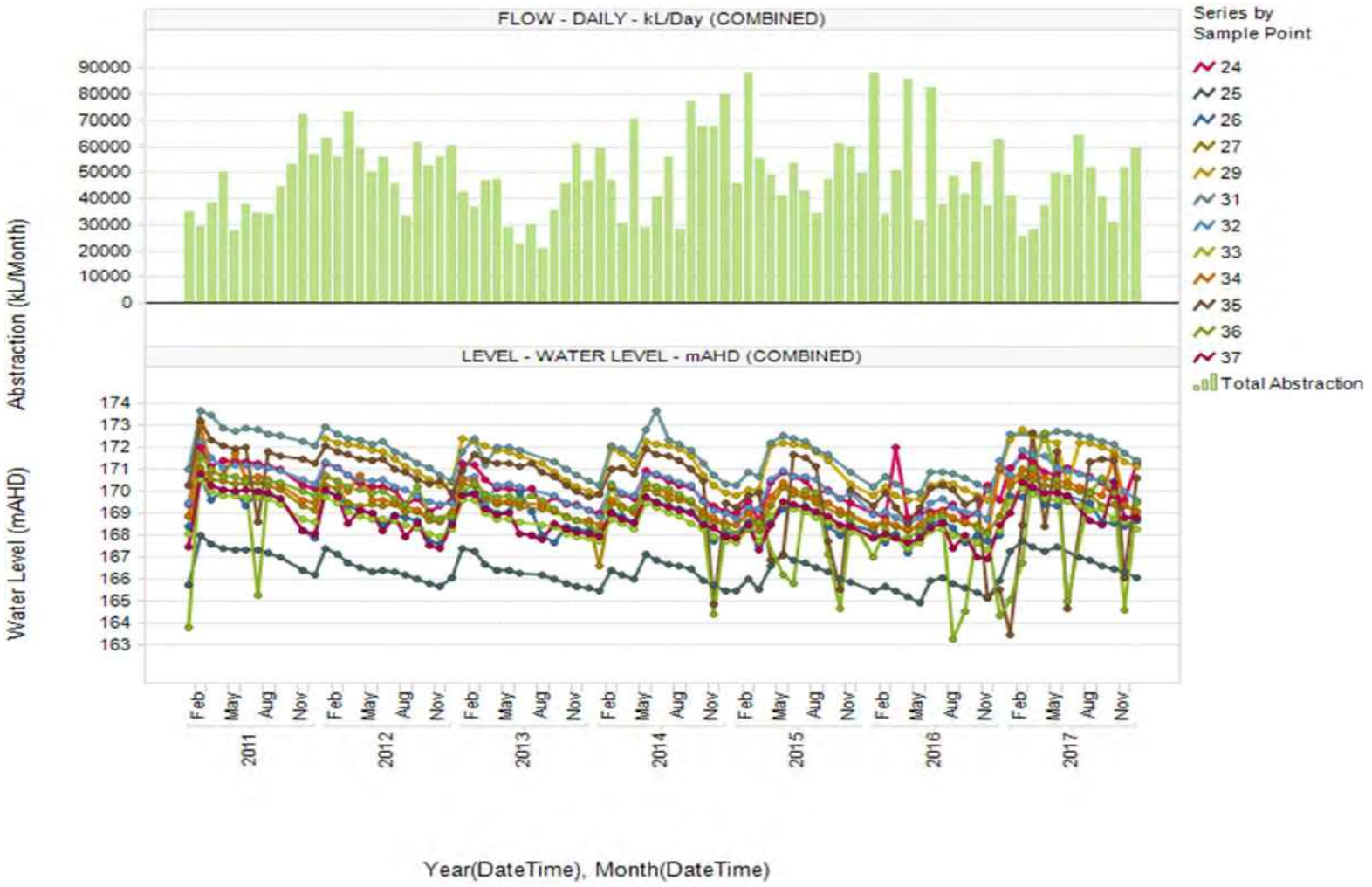


Figure 26: Mesa J Abstraction Vs Water Level hydrographs

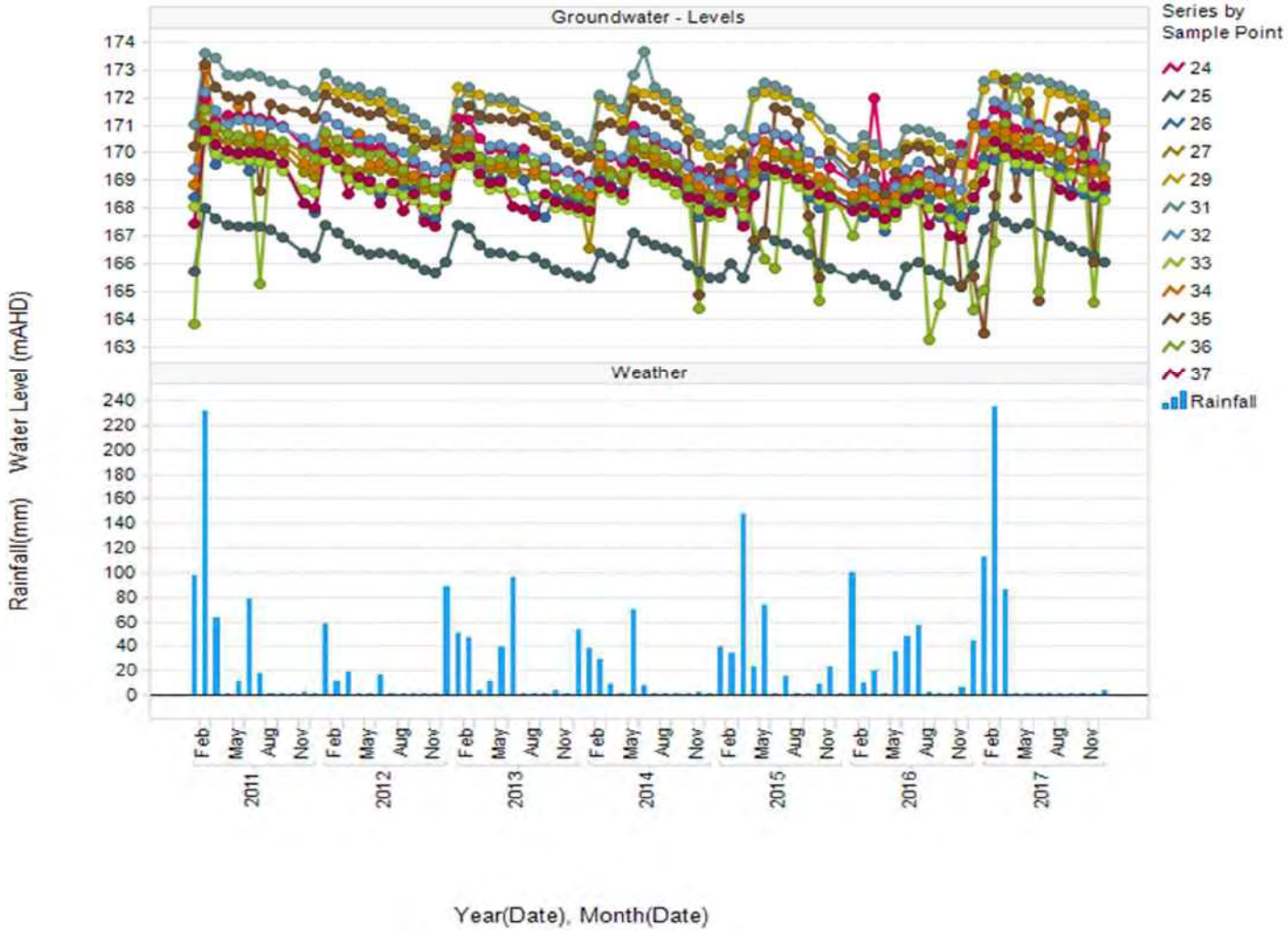


Figure 27: Mesa J Rainfall Vs Water Level hydrographs

4.3 Coastal Water Supply

The Bungaroo Coastal Water Supply (CWS) borefield is located 35 km south-east of Pannawonica and approximately 20 km south-east of Mesa H. The borefield consist of nine supply bores that have been abstracting groundwater from the Bungaroo Valley aquifers and conveying it to the Millstream Water Corporation facilities to supplement the West Pilbara Water Scheme.

The Bungaroo Borefield is licensed under GWL No. 171733 (5), which permits annual abstraction of up to 10,000,000kL. The borefield was formally introduced into supply in February 2014, and monitored under the Bungaroo Coastal Water Supply Borefield Water Resources Management Operating Strategy (WRMOS) 2013. Total groundwater abstraction for the Bungaroo Borefield was 7,586,167kL in 2016.

Figure 28 and Figure 29 shows the CWS groundwater abstraction, rainfall and hydrographs from selected bores.

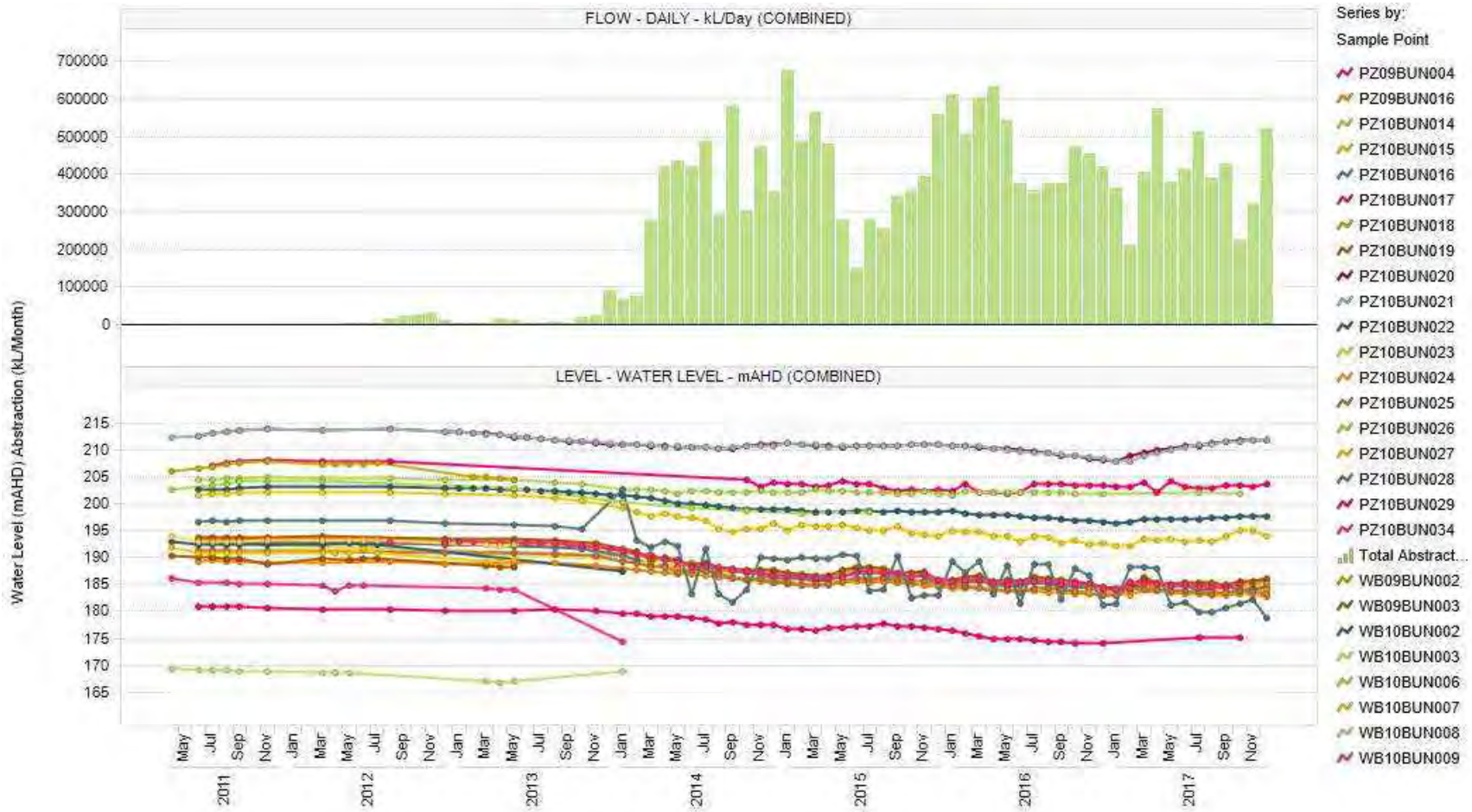


Figure 28: CWS Abstraction Vs Water Level hydrographs

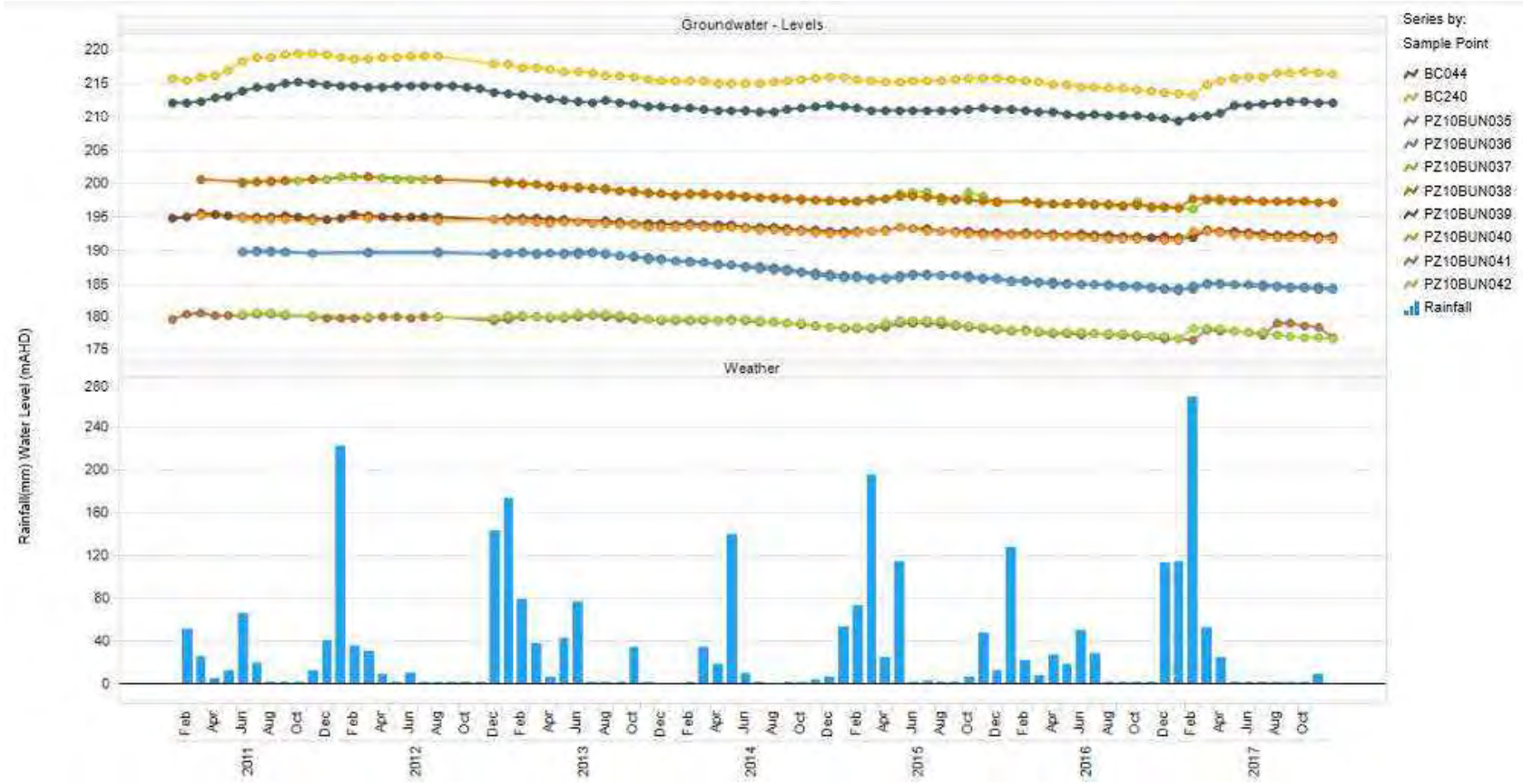


Figure 29: CWS Rainfall Vs Water Level hydrographs

Section 5 - Groundwater Investigation

Three hydrogeological investigations of the Mesa H deposit were completed to support this study. However, investigations to support water supply and dewatering for mine operations have been ongoing at the adjacent Mesa J site since 1987. These investigations were determined to be relevant, given the Mesa J hydrogeological setting is considered to be analogous to Mesa H:

- In total, 18 water bores and 61 monitoring bores have been installed at Mesa J to support mine dewatering and water supply; these bores are operated and monitored according to the Mesa J groundwater operating strategy with many of them decommissioned over the years.
- In 2015, 14 reverse circulation (RC) drill holes in the Mesa H deposit were converted to monitoring bores. The monitoring bores were designed specifically to support stygofauna sampling, and aim to improve the understanding of the extent of Mesa J's dewatering impact on the water table at Mesa H.
- In 2016, 4 water bores and 18 monitoring bores were installed in the Mesa H deposit to support the aquifer assessment and the development of a groundwater numerical model to assess dewatering requirements and potential dewatering impacts in the Robe River pools as part of a Pre-Feasibility Study (Appendix A).
- In 2017, 5 water bores, 15 monitoring bores and 2 vibrating wire piezometers were installed in the Mesa H deposit and surroundings to close conceptual uncertainties identified during the Pre-Feasibility Study (Appendix A).

5.1 Aquifer testing

A total of 26 production bores were pump tested in the Mesa H and Mesa J areas for hydraulic parameters and bore efficiency. Tests were conducted in 2004, 2013, 2015, 2016 and 2017 after the completion of different hydrogeological drilling programs. Production bores were constructed with screens over multiple lithological units including alluvium, CID, conglomerate and basement formations (Wittenoom or Marra Mamba). Aquifer parameters therefore are a combination of all the identified hydro-stratigraphic units (alluvium, CID and basement aquifers). For the majority of tests, aquifer analysis assumed semi-confined to confined conditions due to the presence of prominent clay content in the CID and at the base of the CID. Pump testing is summarised below:

- Bores screened across CID, Conglomerate and Basement Formations (Wittenoom or Marra Mamba) were tested between 6 and 70L/s;
- Bores screened in CID and Wittenoom Formation (Paraburdoo Member) were tested between 2.5 and 35L/s;

- Bores screened in CID and BIF (Marra Mamba Formation) were tested between 7 and 85L/s;
- One bore was screened in Dolerite and tested at 14L/s.
- Bore screened in the Robe River alluvium were tested between 5.5 and 18 L/s.

Drawdown analysis indicates a combination of unconfined, leaky and confined aquifer systems. Interpreted hydraulic conductivity and specific yield / storage of each test is summarised in Table 6.

Table 6: Mesa H / J water bore pumping test summary

Site	Bore Name	Cased Depth (mbgl)	Date	Casing Diameter (mm)	CRT duration (hrs)	CRT (L/s)	Max Drawdown (m)
Mesa J	WB12MEJ002	102	2013	323	72	15	36
	WB12MEJ003	110	2013	323	8	47	3
	WB12MEJ004	70	2013	323	72	14	0.8
	WB13MEJ001	90	2013	305	96	70	6
	WB13MEJ002	72	2013	305	88	85	10
	WB13MEJ003	113	2013	305	96	70	20
	WB13MEJ004	107	2013	305	72	38	28
	WB13MEJ005	86	2013	305	72	23	19
	WB15MEJ001	133	2015	305	72	7	10
	DWB11	64	2004	203	72	30	40
	DWB13	66	2004	203	48	6	40
	DWB14	70	2004	305	168	17	40
	DWB15	82	2004	305	72	30	40
	DWB16	82	2004	305	72	35	40
	DWB17	78	2004	315	72	30	50
	DWB18	66	2004	315	72	28	38
	DWB19	71	2004	315	72	10	45
	DWB20	63	2004	322	48	30	40
Mesa H	WB16MEH0001	84	2016	305	72	18	21
	WB16MEH0002	56	2016	305	24	2.5	11
	WB16MEH0004	76	2016	305	191	3.5	17
	WB17MEH0001	40	2017	305	72	16-18	6.8
	WB17MEH0002	40	2017	305	24	5.5	16.8
	WB17MEH0003	36	2017	305	24	10	8.9
	WB17MEH0004	46	2017	305	24	15	10.8
	WB17MEH0005	104	2017	305	24	45	4.2

Table 7 Indicates a summary of the hydraulic conductivity and specific yield / storage capacity interpreted from the pumping test in each bore.

Table 7: Pumping test results for Mesa H and J

Site	Bore ID	Screened Formation/ Member	Aquifer Type	Hydraulic Conductivity (m/day)	Storage Coefficient
Mesa J	WB12MEJ002	Conglomerate and Dolomite (WF)	Leaky	0.3	5.02E-05
	WB12MEJ003	CID and Conglomerate	Leaky	17.2	1.80E-02
	WB12MEJ004	Dolerite	Confined	12.4	5.35E-02
	WB13MEJ001	CID, Conglomerate and BIF (MM)	Confined	12.3	1.02E-06
	WB13MEJ002	CID and BIF (MM)	Confined	36.6	9.41E-05
	WB13MEJ003	No sample (MM?)	Leaky	4.1	3.86E-02
	WB13MEJ004	BIF (MM)	Confined	6.1	2.00E-03
	WB13MEJ005	No sample (MM?)	Confined	6.1	1.90E-03
	WB15MEJ001	CID and BIF	Confined	5.7	2.00E-03
	DWB11	CID, conglomerate and WF	Unconfined	10.9	*
	DWB13	CID, conglomerate and WF	Unconfined	0.7	*
	DWB14	CID, conglomerate and WF	Unconfined	0.8	*
	DWB15	CID, conglomerate and BIF/WF	Unconfined	4.4	*
	DWB16	CID and WF/ BIF	Unconfined	2.9	*
	DWB17	CID , BIF, WF	Unconfined	1.6	*
	DWB18	CID, conglomerate and WF	Unconfined	5.9	*
	DWB19	CID, conglomerate and WF	Unconfined	0.8	*
	DWB20	CID, conglomerate and WF	Unconfined	4.3	*
Mesa H	WB16MEH0001	CID and WF	Leaky	1.6-20.2	7.32E-04
	WB16MEH0002	CID and WF	Leaky	1.2-4.1	5.84E-05
	WB16MEH0004	CID and WF	Leaky	0.4-3.7	2.66E-03
	WB17MEH0001	Alluvium	Unconfined	36-109	0.33 (Sy)
	WB17MEH0002	Alluvium	Leaky	0.5-6.5	6.4E-03
	WB17MEH0003	Alluvium	Unconfined	10.5-71.5	1E-03 (Sy)
	WB17MEH0004	WF	Unconfined	1.3	6.4E-05
	WB17MEH0005	BIF	Unconfined	17.14	6.2E-05

*No Storage coefficient available from 2004 Aquaterra reports for individual tests however modelling has lumped the confined storage of various aquifer types as 0.0001.

Aquifer testing analyses of results are as follows:

- The CID aquifer hydraulic conductivity ranges between 0.5 and 4 m/day with a storage coefficient ranging between 0.01 and 0.0001.
- The Wittenoom aquifer hydraulic conductivity ranges between 0.5 and 20 m/day with a storage coefficient between 0.002 and 0.00005.

- The bulk hydraulic conductivity of the CID and Wittenoom Aquifers ranges between 5 and 20 m/day with a storage coefficient in the order of 0.002.
- Broadly, higher drawdown in the basement formation in comparison to the CID were observed, suggesting the confinement of the weathered Wittenoom and Marra Mamba Iron Formations in areas of limited vertical extension.
- The Robe River alluvium aquifer hydraulic conductivity ranges between 0.5 and 109 m/day with a specific yield ranging between 0.3 and 0.001.
- There has not been any local testing of the Jimmawurrada alluvium aquifer to date.

The Pannawonica town borefield is located approximately 10 northwest of Mesa H, abstracts water from the Robe River Aquifer for the purpose of dust suppression and potable water supply to Pannawonica Township, and has been in operation since 1981 abstracting approximately 700ML/year. An assessment of the long term abstraction data to estimate aquifer parameters was developed and presented in RTIO-PDE-0143871, aiming to assist in characterising the Robe River Alluvial Aquifer. Data analysis suggests specific yield of up to 0.25 and hydraulic conductivity ranging from 60 to 380 m/day.

Section 6 - Groundwater chemistry

Groundwater and surface water samples have been collected from Mesa J mine site since 1993 as part of the site Groundwater Operating Strategy (GWOS), additionally, to support the Mesa H development, several pools up gradient and down gradient from Mesa H were collected on a fortnightly basis during 12 months, including isotopes, to assess the potential contribution of local aquifer (CID and Wittenoom aquifers) to the Robe River Alluvium aquifer.

A total of 43 bores from Mesa H, Mesa J, Pannawonica and Jimmawurrada Creek were analysed, together with surface water chemistry data from seven pools along the Robe River including Yeera bluff, Medawandy and Japanese Pool (Figure 16). Although available data represent a good spatial coverage of the Mesa H area, temporally the data, particularly from groundwater, are limited to only one or two data points per bore (RTIO-PDE-0144245).

Available chemistry and isotope data indicate, as expected, that the pools are largely connected to the Robe River alluvium aquifer, and that the CID and Wittenoom aquifers are mainly comprised of fresh recharge. However, the latter aquifers appear to be receiving unusually high saline recharge at different locations particularly along the topographically low part of the mesa located to the west of Mesa H and down-gradient of the tailings pond. It is unclear whether the high salinity recharge observed in outlier CID/Wittenoom bores results from diffuse recharge due to local topography or leakage from the Robe River alluvium recharging the basement. Because these high salinity recharge areas extend from the Mesa J mine to the Robe River near Yeera Bluff pool, interactions between the Robe River pools, the alluvial aquifer and CID/Wittenoom aquifers cannot be ruled out at this point.

The groundwater within the local catchment is described as fresh, with recorded salinities typically around 64 mg/L, though readings up to 2,800 mg/L have been recorded; and circum-neutral pH between 6 – 8. The CID and Wittenoom aquifers generally comprise fresher water than the alluvial aquifer and the Mesa H pools.

In order to chemically characterise the three aquifers identified at Mesa H, bores have been grouped based on the geological formation they have been screened against. Bores screened across multiple aquifers have been grouped separately. Additionally, bores outside Mesa H including those from Pannawonica and Mesa K have been removed from the major and minor ion analysis as their chemistry was found to be very different from that of Mesa H bores.

6.1 Major ion data

The analysis of chemical signatures based on major ions suggests the following:

- Except for the Medawandy pool, chemical compositions of Robe River pools are homogeneous.

- All aquifers and pools show similar cation composition while significantly differing in anion composition. This appears to be due to the increasing chloride predominance in pools, alluvial bores and some Wittenoom bores. This trend is typically observed for waters that have undergone varying degrees of evaporation.
- While the CID and Wittenoom aquifers appear to have much fresher water than the alluvial aquifer and the Mesa H pools, outliers to this general trend exist (see bores plotting within the blue circle or above it on Figure 30).

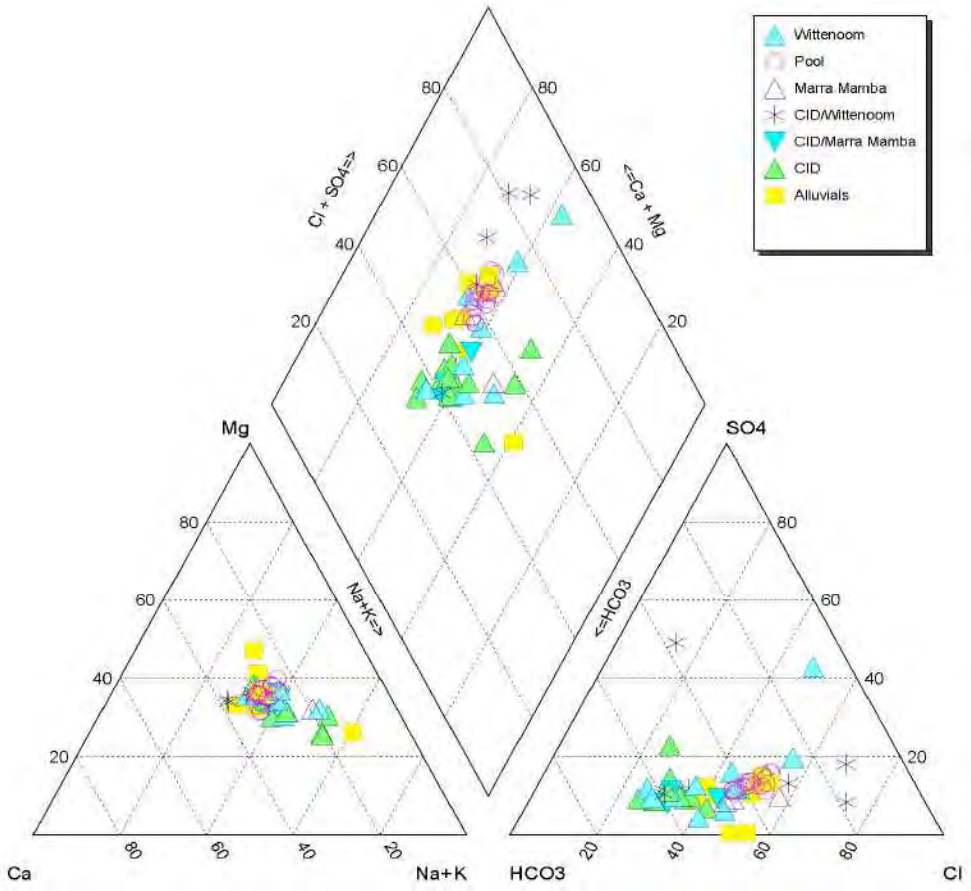


Figure 30: Piper plot of major ions. Encircled are data from those aquifers considered closely related to Mesa H pools and/or located in the Robe River floodplain

6.2 Minor ion data

Though Robe River pools have not been consistently analysed for minor ions including F, Br, and B, these parameters tend to be ubiquitous in Pilbara groundwater and their relative proportions can be useful in assessing connectivity between different aquifers, mainly because some of these anions tend to be very conservative in the environment and thus can be used as tracers.

As indicated in Figure 31, the pools are more closely related to the alluvial aquifer; and show in general greater bromide predominance than the CID or Wittenoom aquifers. However, here again there are outliers to the CID and Wittenoom aquifers, all of which had already been identified as having chemical compositions different than the bulk of the CID or Wittenoom bores and closer to the alluvial bores and pool`s. Thus, the minor ion data would confirm that along the topographically low part of the mesa located to the west of Mesa H the CID and Wittenoom aquifers appear to be receiving high salinity water from diffuse surface water recharge and recharged by the Robe River alluvium.

Additionally, the minor ion data do not align with most CID/Wittenoom outliers (depicted in green on Figure 32) are indeed outliers to the CID and Witttenoom aquifers and appear to be unusually enriched in bromide. Bores located close to the Robe River have water with salinity and bromide values even higher than those seen in Mesa H pools (see Figure 31) possibly caused by the pools getting periodically flushed with spikes in chloride.

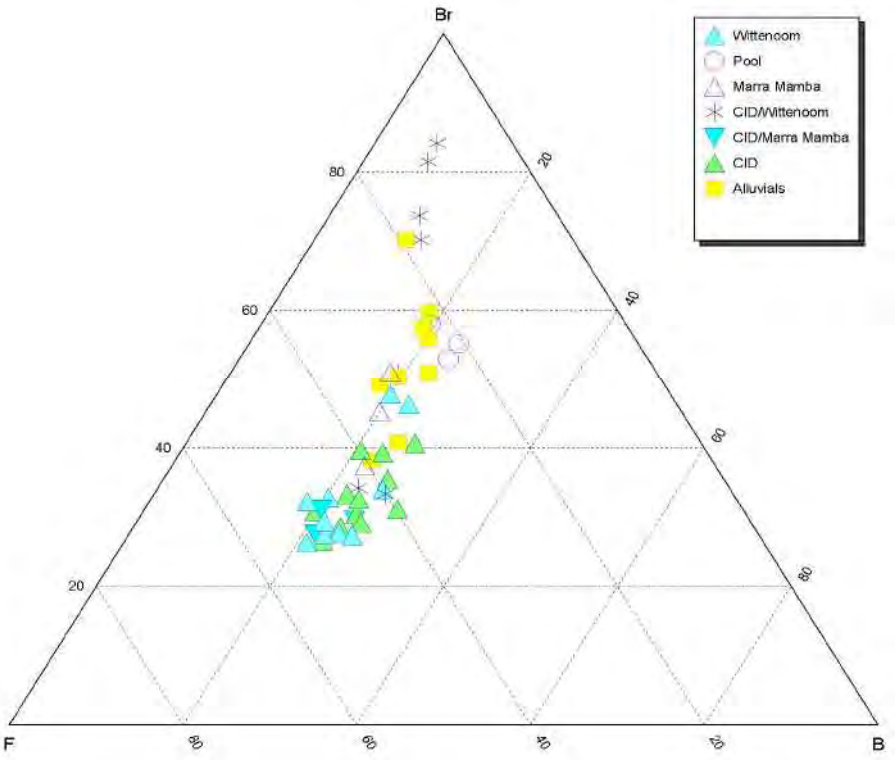


Figure 31: Ternary plot of minor anions. Encircled are data for those aquifers considered closely related to Mesa H pools

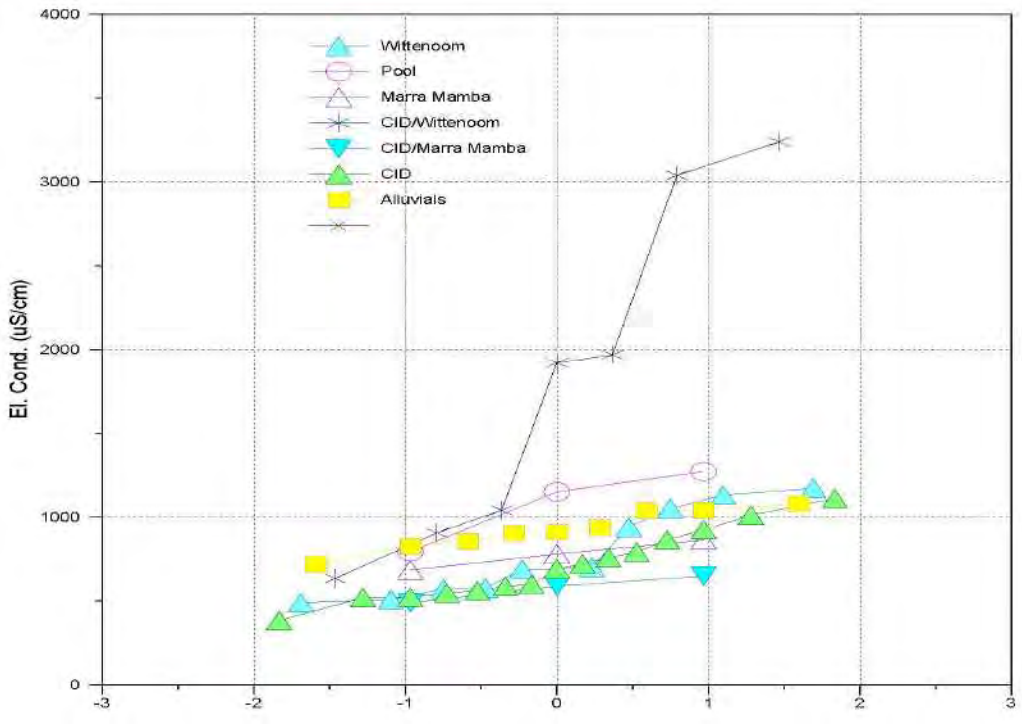


Figure 32: Distribution of electrical conductivity among different aquifers/formations

6.3 Isotope data

Isotope data have been collected from the Robe River pools and Mesa H bores. Figure 33 shows these data along with the Local Meteoric Water Line (LMWL) for the Hamersley Basin obtained from Dogramaci, et al., 2012; while Figure 34 and Figure 35 show isotopic data plotted against chloride concentrations. Isotopic data indicate the following:

- Robe River pools and groundwater at Mesa H plot below and to the right of the LMWL indicating a general heavier ^{18}O isotopic composition but lighter deuterium composition than the Hamersley Basin precipitation. This is consistent with isotopic fractionation that occurs when meteoric waters undergo different degrees of evaporation (Mazor, E. 2004).
- In general, Robe River pools and alluvial bores have heavier isotopic composition than CID and Wittenoom bores, (plot above $d^{18}O$ of -6.5 and $d^{2}H$ -42; while most CID and Wittenoom bores plot below these cut-off values). This is expected as both pools and alluvial bores undergo a greater degree of evaporation than the CID or Wittenoom bores.
- Bores within the CID and Wittenoom aquifers have water samples showing lighter isotopic composition than the Robe River pools or bores slotted in the Robe River alluvium aquifer, indicating that these aquifers may be comprised of fresh recharge. Outlier bores plotting close to pools and alluvial bores may indicate that at some locations, the CID and Wittenoom aquifers may be receiving diffuse surface water recharge or seepage,

corroborating the theory that higher salinity water, periodically, recharges the CID/Wittenoom aquifers at these locations.

- Isotope data plotted against chloride on Figure 34 and Figure 35 suggest water within the Robe River pools and alluvial aquifer originate from the same water source as the CID and Wittenoom aquifers, and that later fractionation occurs in pools and the alluvial aquifer due to evaporation. This conclusion is reached because both datasets (i.e: alluvium and basement aquifers) meet (within the instrumental error of +/- 5‰) at the origin (i.e. chloride = 0), which would approximate the composition of rain.

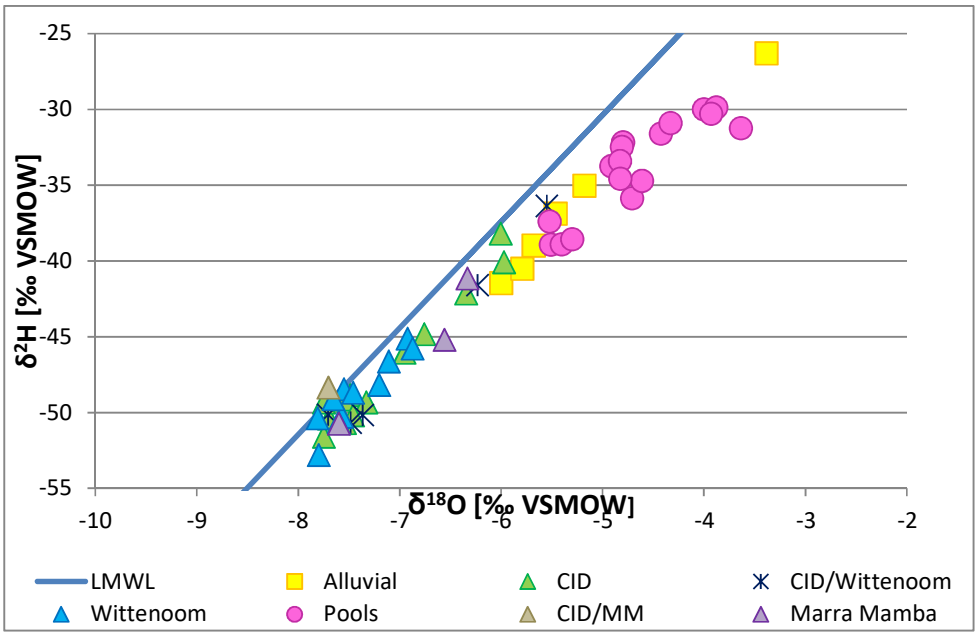


Figure 33: $d^{18}O$ versus $d^{2}H$ for Robe Valley pools and Mesa H bores along with the LMWL.

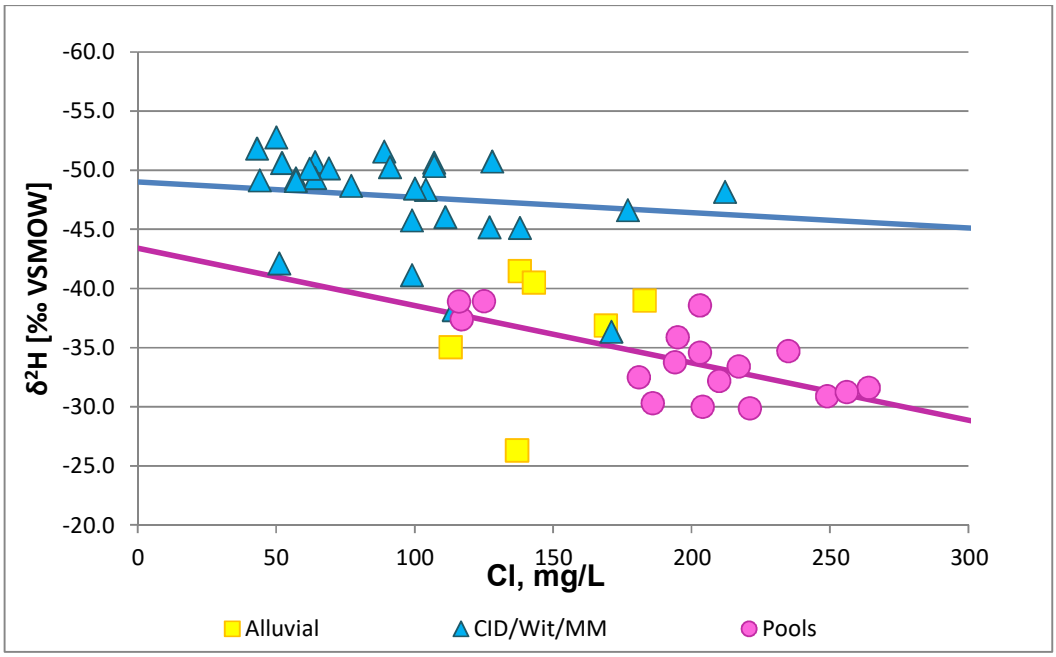


Figure 34: d^{2}H versus chloride for Robe Valley pools and Mesa H bores

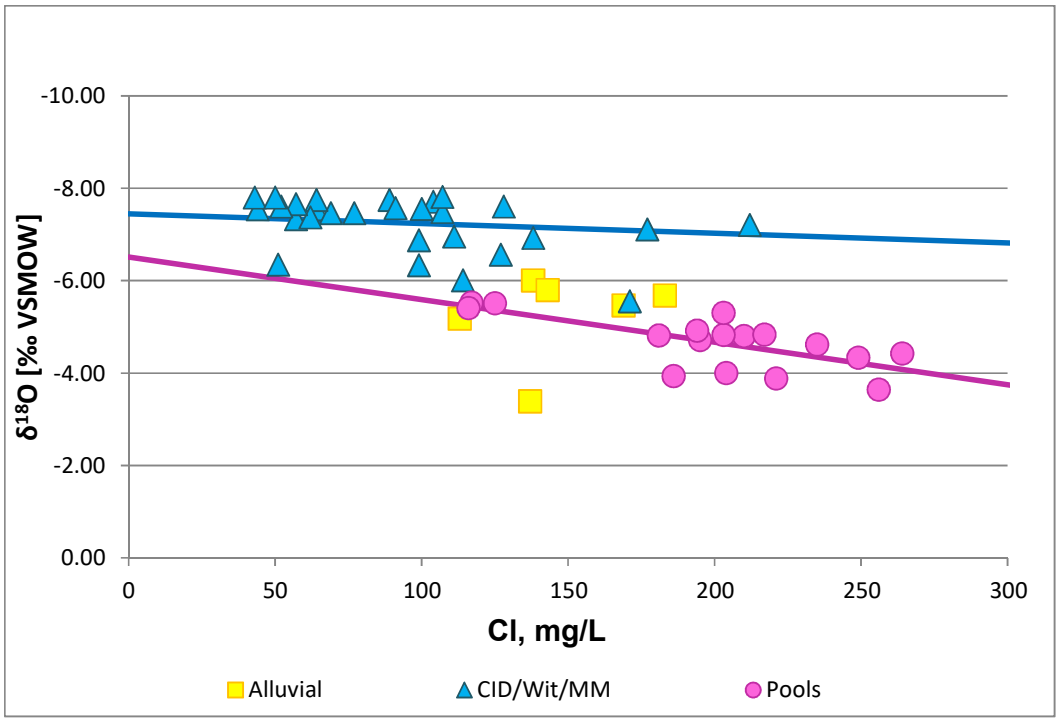


Figure 35: d^{18}O versus chloride for Robe Valley pools and Mesa H bores

Section 7 - Groundwater flow model

A groundwater numerical model was initially developed in 2002 to predict inflows to the open pit workings for the Mesa J mine (Aquaterra 2002a). This model was sequentially updated and refined by Aquaterra in 2003, 2004 and 2006. As part of the 2016 dewatering and impact assessment of the proposed Mesa H mine, RTIO developed a new model which incorporated both Mesa H and Mesa J mines for the first time; results from this model have been peer reviewed by RPS, which prompted the development of a new numerical model to address identified issues with the model build.

The foundation of the current numerical groundwater model (Appendix B), presented in this H3 level assessment, is based on the latest conceptual hydrogeological model, and utilises the results and setups of previous models (RPS 2016/17 model), and further updated based on the Base Case conceptualisation presented in this report.

7.1 Numerical Model Set-up

The numerical groundwater flow modelling package Modflow-Surfact (Version 4.0, Hydrogeologic Inc 1996) has been used to develop the model operating under the Groundwater Vistas graphical user interface (Version 6.52, Rumbaugh and Rumbaugh 1996–2011). The Modflow-Surfact numerical code was chosen to allow simulation of shallow water tables, reduction of water levels in mining areas and subsequent groundwater recovery.

The model confidence level classification (as per the National Water Commission 2012) is Class 2 due to the spatial and temporal coverage of the monitoring data not being extensive in some areas of the model domain.

7.1.1 Boundary Conditions

Figure 36 shows the model is bounded in the east and west by the basement outcrops, represented by no flow boundaries. The Stream Package (STR1 package) of Modflow Surfact is used to represent the Robe River and its tributaries (Jimmawurrada Creek and West Creek) within the model domain. The stream stages of the Robe River were set 2 m above the derived streambed elevations and 0.5 m in the Jimmawurrada Creek and the West Creek, adopting a conductance of 100 m^2/d, roughness of 0.045 and slope of 0.00245.

The Robe River also carries a significant underflow in its alluvial bed. This subsurface inflow and outflow are simulated using the GHB package in Modflow-Surfact with the underflow boundaries assigned to the Robe River valley at the model edges.

In the south, the groundwater inflow from the Bungaroo Creek palaeo-valley is represented by a general head boundary. In the north, the groundwater outflow from the Wittenoom aquifer to the north is also represented by a general head boundary.

Inflow to the Robe River was based on recorded flows at Ngalooin Pool Station 707004, located approximately 18 km upstream from the Mesa J mine site (Figure 5). Flow records are available from 1977 until 1999. From 1999 onwards for the remainder of the calibration period historical flow data was replicated to simulate variable annual Robe River flows.

Due to a lack of gauging stations along the Jimmawurrada Creek, it was assumed that each time the Robe River was flowing, that Jimmawurrada Creek also had surface flow. With an approximate area of 1,270 Km^2 the Bungaroo / Jimmawurrada catchment represents about 20% of Robe catchment, thus an assumed 20% of the Ngalooin Pool recorded data was used to simulate stream flows along the Jimmawurrada Creek. No natural flow was assigned to the West Creek.

Recharge to the groundwater system is assumed to occur via rainfall recharge over the model domain using gridded rainfall data (BOM, 2009). It is specified as a percentage of the recorded annual rainfall, distributed as follows:

- 0% BIF outcrop
- 15% Robe River alluvium
- 2% Jimmawurrada Creek alluvium
- 1% CID outcrop

Evapotranspiration occurs from the shallow water table (between 2 and 5 mbgl) within the Robe River and Jimmawurrada Creek where surface pools and vegetation occur. Elsewhere, the water table is generally substantially more than 10 m below the surface and losses from the water table to the atmosphere are negligible. Evaporation from riparian vegetation and from the shallow or near surface water table was modelled using the Evapotranspiration package (EVT) in Modflow-Surfact. The ET surface was set consistent with topographic (1m contour) with extinction depth of 5m. Evapotranspiration was assigned a constant value of 0.0065 m/d or 70% of long term measured average pan evaporation of 3,400 mm/year.

During mining at Mesa J surplus dewatering was historically discharged at two locations (Jimmawurrada Creek and West Creek) and the transient model includes both. Discharge to the creeks is applied as stream inflow at designated locations based on the recorded discharge data.

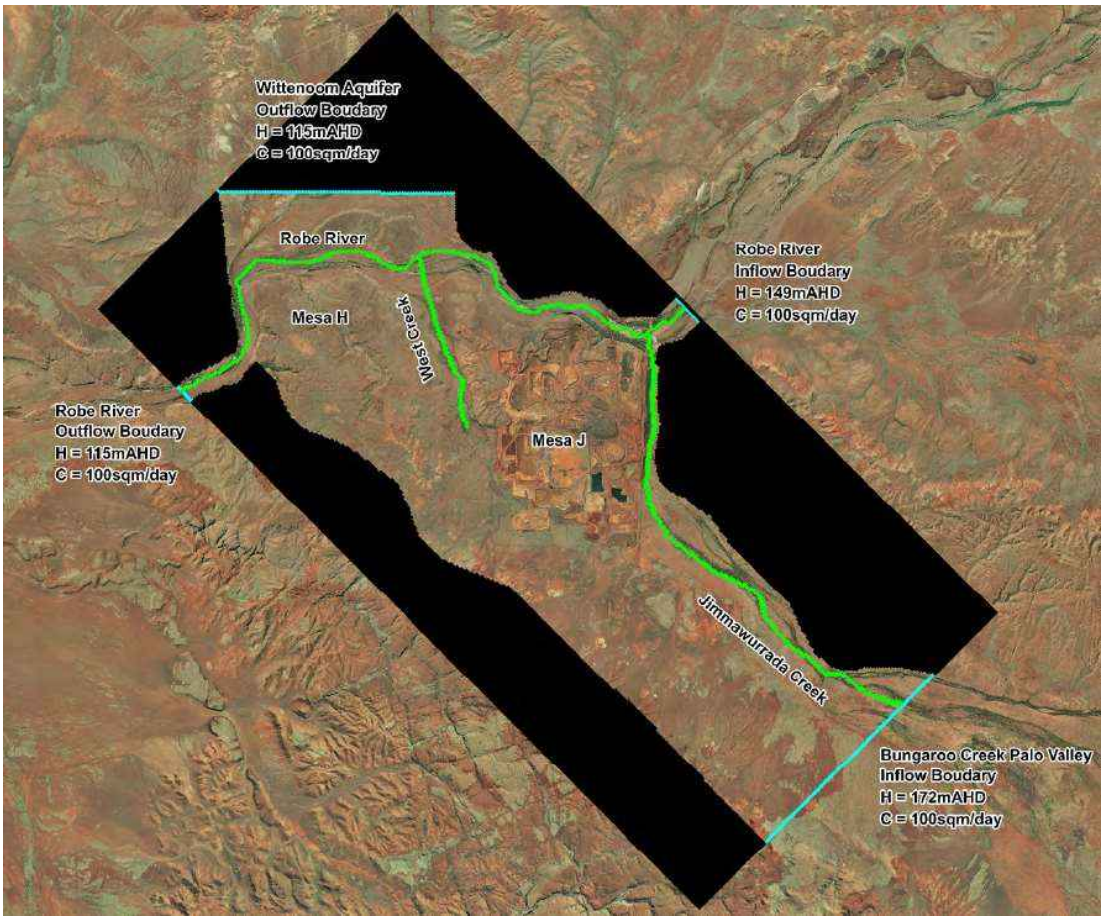


Figure 36: Numerical model domain and boundary conditions

7.2 Model Calibration

The focus of the steady state calibration was to calibrate the model to interpreted pre-development groundwater levels and flows across the catchment. However, the time variant monitoring data covering the period 1990 to 2016 indicates a seasonal trend in water levels, in the order of several meters resulting from the wet and dry season recharge pattern. Thus the groundwater conditions within the catchment are not readily described by an average or steady state set of water level conditions. To accommodate this, a set of initial conditions was generated using a dynamic calibration process. This process involved going back and forth between the steady state and transient models, fine tuning model parameters until a set of conditions were generated that closely matched the start of the calibration period and satisfied the time variant trends.

The steady state water balance is presented in Table 8.

Table 8: Numerical vs conceptual water balance

Flow Component	RTIO Water Balance (ML/year)	Numerical Model (ML/year)
Inflow from the Bungaroo paleo-valley	~1,500	Inflow from the GHB = 800 Inflow from the Jimmawurrada Creek = 700 TOTAL = 1,500
Robe River underflow (inflow from the upstream)	>900	Inflow from the GHB = 430 Inflow from the stream leakage = 420 TOTAL = 850
Robe River underflow (outflow to the downstream)	>900	Outflow through the GHB = 290 Inflow from the stream leakage = 330 TOTAL = 630
Robe River flow (inflow from the upstream)	-	43,860 ML/year
Jimmawurrada Creek flow (inflow from the upstream)	-	8,770 ML/year
Robe River flow (outflow to the downstream)	-	51,100 ML/year

As presented above the conceptual and model inflows from the Bungaroo paleo-valley and outflow through the Wittenoom aquifer are very well matched.

Model performance was tested (transient calibration) by comparing predicted and observed time variant groundwater levels over the period 1990 to 2016. The model calibration includes annual time increments from 1990 to 2016. This encompasses:

- Mesa J mine dewatering to date
- historical mine water supply pumping in the area
- discharge to Dan's Dam, Jimmawurrada Creek and West Creek.

In total 37 bores with long term monitoring records and 33 bores with recent monitoring records (both regional bores and Mesa J mine monitoring bores) were used as a representative calibration dataset. Measured groundwater levels and trends are generally well matched by the model. In the immediate vicinity of the Mesa J mine the decreasing water level trend associated with dewatering is well replicated by the model.

Long term monitoring records in the Mesa H area or along the Robe River are not available at this time. Model performance was tested against the short term monitoring records at 33 recently installed monitoring bores. There is a good match to the measured groundwater levels at these bores especially to the bores closest to the Robe River and to the north of the Robe River.

The aquifer parameters adopted for the calibrated model are summarised in Table 9. Assigned aquifer parameters are consistent with available hydraulic testing data, previous groundwater models, published data and similar hydrogeological environments.

Table 9: Calibrated Aquifer Parameters

Formation	Kh (m/d)	Kv (m/d)	Specific Yield (%)	Confined Storage
Robe River Alluvium	100	50	30	0.0001
Jimmawurrada Creek Alluvium	5	0.5	20	0.0001
CID	4	2	10	0.0001
Tertiary Pisolite TPB	1	0.1	6	0.0001
Weathered Basement	8	8	1-10	0.0001
Fresh basement	0.0001	0.0001	0.1	-

The predicted groundwater balance for December 2016 (i.e. the end of the calibration) is presented in Table 10. The water balance shows that inflow from upstream (Robe River) dominates the inputs to the modelled catchment. Besides replenishing the surface water pools along its path, the Robe River also feeds the partially dewatered aquifers which are in direct hydraulic connection with the river. Inflow from the Robe River into the model (modelled aquifers) is 51% of the overall water balance. Dewatering and borefield pumping combined provide the greatest outputs (35% of the overall water balance).

Table 10: Modelled Water Balance

Flow Component	Inflow (ML/y)	Outflow (ML/y)
Storage	3,515	900
Borefield Pumping		1,170
Dewatering		4,640
Rainfall Recharge	695	
Discharge to Dan's Dam	510	
Evapotranspiration		2,880
Groundwater Inflow / Outflow	1,430	290
Stream Leakage	5,900	2,170
Total	**12,050**	**12,050**

Zone budget analysis indicates the interaction between the Robe River and Jimmawurrada Creek depends on the assigned stream flows where during periods of low flows Robe River alluvium feeds the alluvium associated with Jimmawurrada Creek at a minimal rate. However when river and creek are flowing the Robe River alluvium gains ~1 ML/day from the Jimmawurrada Creek alluvium.

The Robe River alluvium loses water to the undelaying CID (TPB unit). Predicted inflow from the alluvium to the TPB ranges between 1.5 and 4 ML/d, additionally the Robe River also loses water to the north along the weathered Wittenoom Formation (~ 1ML/d).

7.3 Model Predictions

The calibrated model was used to complete dewatering predictions for Mesa J and Mesa H and to predict mine dewatering and drawdown along the Robe River alluvium. The predictions were completed as outlined below:

- Initial groundwater level/flow conditions were derived from the end of the transient calibration (December 2016).
- The prediction period starts in January 2019.
- The model was run for a period of 19 years (January 2019 to December 2037).
- The model predictions were run using annual time increments (stress periods). Steady state evapotranspiration rates were used in the prediction model.
- As mentioned in the model setup sections Robe River flow records exist until 1999. For the 19 year prediction period, the last 19 years of recorded Robe River flows were used (from 1981 to 1999). Consistent with that, rainfall recharge data from 1981-1999 was used in the prediction model.

- Dewatering at Mesa J and Mesa H was simulated using the Drain Package (DRN) in Modflow Surfact. Drain elevations were set consistent with the proposed mine plan. Drain bed conductance was set consistent with the calibrated model (i.e. 1,000 m^2/d).
- Discharge to Dan's Dam was applied using the Recharge Package (RCH) in Modflow Surfact at average recorded discharge rates from the calibration period.
- Surface water discharge to Jimmawurrada Creek and West Creek was assumed to cease and resume only if required for seasonal surplus water management.
- The impact of the Costal Water Supply system, proposed to take place in the Bungaroo Creek valley, was taken into account based on the results of separate groundwater modelling undertaken by Rio Tinto to support the CWS project and approvals process. Predicted drawdown impacts were accounted in the prediction model by lowering the southern inflow General Head Boundary consistent with the predicted drawdown impact. The Bungaroo model predicts 6 m of drawdown after five years, 8 m after 10 years, 9 m after 15 years and 11 m after 30 years of water supply pumping from the CWS. The GHB was lowered linearly to account for the predicted impact.
- The volume of abstraction for water supply required was calculated as the difference between the projected water demand and the predicted total dewatering. The pumping rates required were calculated using an iterative process and the prediction model was re-run until the assigned borefield pumping and predicted dewatering satisfied the water demands. Seven existing and nine nominal bores were used to simulate water supply pumping when required.

Two predictions were simulated:

- Scenario 1: No water return from TSFs due to the commissioning of a thickener plant (82.8 GL total demand)
- Scenario 2: higher water demand (no thickener plant) (141.5 GL total demand)

Due to the fact the inclusion of a thickener plant is the base case to avoid significant impacts to environmental and heritage values, this H3 update only describes the Scenario 1 results. However, for comparative purposes, results of both predictions are depicted in the model report (Appendix B).

In order to simplify the computational prediction (Scenario 1), the water demand was averaged at 5 GL/y between 2020 and 2033 and reduced to 4 GL/y until 2037, totalling 86 GL.

Prediction runs have been completed using a conservative approach (i.e. reduced inflow from the southern model boundary, no surface water discharge to creeks when dewatering exceeds water supply requirements, and no seepage from the TSFs) to allow prediction of maximum potential groundwater drawdown throughout the modelled catchment

7.3.1 Mesa J Dewatering

BWT mining at Mesa J is ongoing and planned to continue until 2029. Dewatering from 2019 was simulated using drains cells set accordingly with the proposed mine plan (Table 11), as a result, predicted water levels closely follow the mining schedule.

Dewatering at Mesa J is predicted to peak at 8.2 GL/y in 2023 (with pumping from pits 6, 12 and 15), with another peak of up to 7.2 GL/y in 2027 (with pumping from pits 7, 12, 14 and 15). Mining at Mesa J is scheduled to end in December 2029, with the model drains associated with dewatering at Mesa J set as 'inactive' from January 2030 onwards. The simulation also predicts a total of approximately 54 GL will be required to be removed between 2020 and 2029. Figure 37 shows the simulated dewatering annual average rates the drain package took out over the simulation period

Table 11: Mesa J BWT Mine schedule

End of year	Pit 3	Pit 5	Pit 6	Pit 7	Pit 8	Pit 9	Pit 11	Pit 12	Pit 14	Pit 15
2019	146		182	138	126	158				142
2020	146		174	134		158				134
2021			174	134		158		138		130
2022			134	134		158		138		
2023			134	134		158		130		
2024			130	134		154		130	162	
2025				134		154		130	146	
2026				134		142	146	130	134	
2027		170		130			138	130	120	
2028		170		130			130	110		
2029		154					114			

**cells highlighted blue denote benches below pre-mining water level*

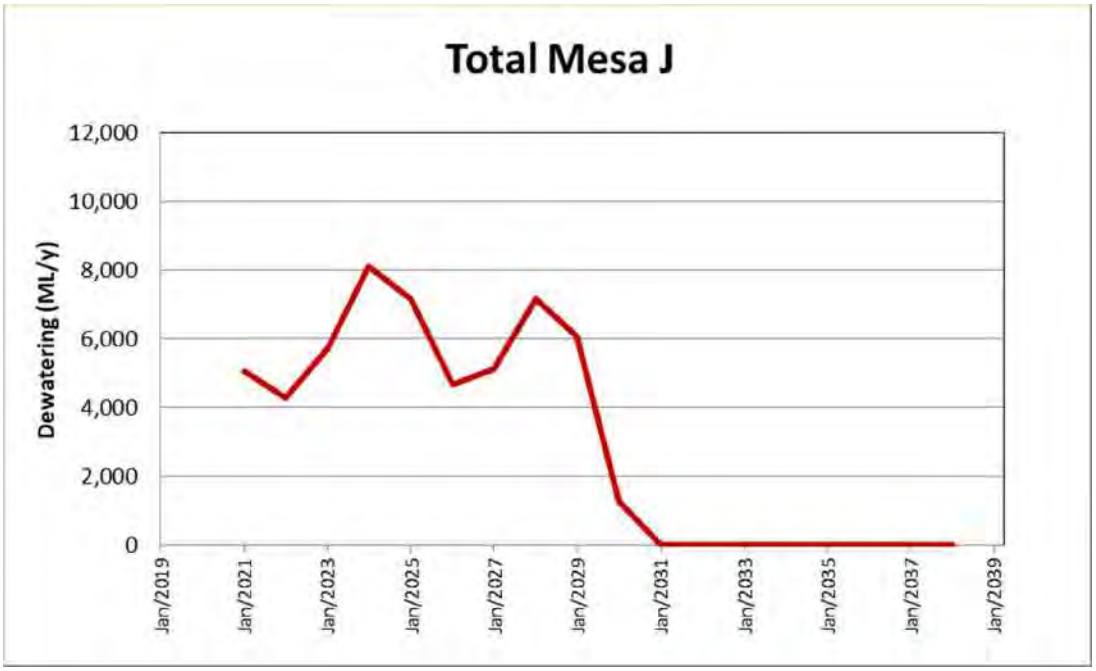


Figure 37: Dewatering rates and cumulative volumes

7.3.2 Mesa H Dewatering

BWT mining at Mesa J is expected to start in 2024 at Pit 6. Dewatering was simulated using drains cells set accordingly with the proposed mine plan (Table 12), as a result, predicted water levels closely follow the mining schedule.

Dewatering rates from Mesa H are predicted to reach a maximum of ~3 GL/y in 2033 mostly as a result of mining and dewatering at Pit 2. Dewatering is predicted to decrease to 2.5 GL/y by 2035. After 2035 dewatering is predicted to decrease to 1.3 GL/y in 2037 with no further declines before the end of mining. The simulation also predicts a total of approximately 15 GL will be required to be abstracted to achieve the LoM. Figure 38 shows the simulated dewatering annual average rates the drain package took out over the simulation period.

Table 12: Mesa H Mine schedule

End of year	Pit 1	Pit 2	Pit 3	Pit 4	Pit 5	Pit 6	Pit 7	Pit 8
2019								
2020						162		
2021						158		
2022						154		
2023						134		
2024						114	162	166
2025							162	166
2026							162	162
2027							150	162
2028	150						150	158
2029	134						150	150
2030	134						122	122
2031	122	166					122	
2032		126	166				118	
2033		114	126	150			118	
2034			114	130	166		118	
2035				118	150		114	
2036					130		110	
2037					122			

**cells highlighted blue denote benches below pre-mining water level*

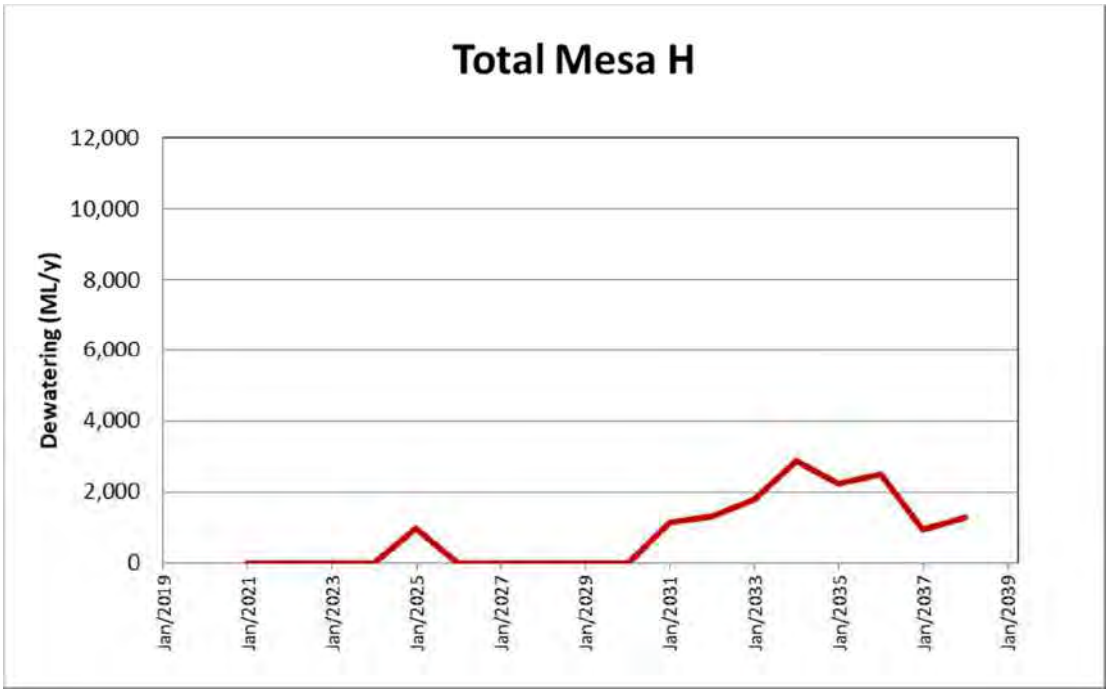


Figure 38: Dewatering rates and cumulative volumes

7.3.3 Water Supply

To sustain the water requirement of the Mesa J / H dry and wet plants, the estimated water demand is required to be consistent with the implementation of the thickener plant. The Southern Cutback Borefield (SCB) is predicted to successfully meet shortfalls in predicted surplus water availability from mine pit dewatering. Assigned SCB pumping rates in conjunction with mine pit dewatering surplus volumes are predicted to meet the projected J / H operational water demand of up to 7 GL/year.

7.3.4 Model Water Balance

The model predicted water balance (average inflows and outflows over the life of mine) is presented in Table 13. Consistent with the calibrated model the sources of inflow are depletion of aquifer storage (by dewatering) and borefield pumping, replenished by the stream leakage (from the Robe River and Jimmawuarrada Creek). Major outflow components are pumping from the water supply borefield and mine dewatering.

It should be noted that changes made to the prediction model to account for the impact of Coastal Water Supply pumping reversed the boundary fluxes at southern inflow boundary, making it an outflow boundary from 2021 onwards. In addition, some of the stream leakage from the Jimmawurrada Creek predicted to flow to the south, toward the CWS rather than downstream towards the Robe River, which is considered to be a conservative assumption.

Figure 39 shows the predicted cumulative Mesa H and Mesa J dewatering volumes, water supply abstraction rates vs predicted water demand. The simulation predicts a cumulative total of approximately 100 GL will be required to be abstracted between 2020 and 2037.

Figure 39 also indicates the direct rainfall plus surface water run-off, and seepage recirculation from waste fine storage facilities and water reservoir into active pits; these volumes will be abstracted through the same sump-pumping system used to measure pit dewatering rates, hence the total volumes to be abstracted, as measured via dewatering flow metres, will potentially be higher than the volumes indicated in the numerical model predictions.

Based on current and previous volumes, direct rainfall and surface run-off can increase water abstraction by up to 4 GL/a (depending on size and frequency of rainfall events) and seepage recirculation an estimated 3 GL/a (depending on location and depth of the surrounding pits and level of the waste fines storage facility), with up to 15 GL/year abstracted from the Mesa J hub.

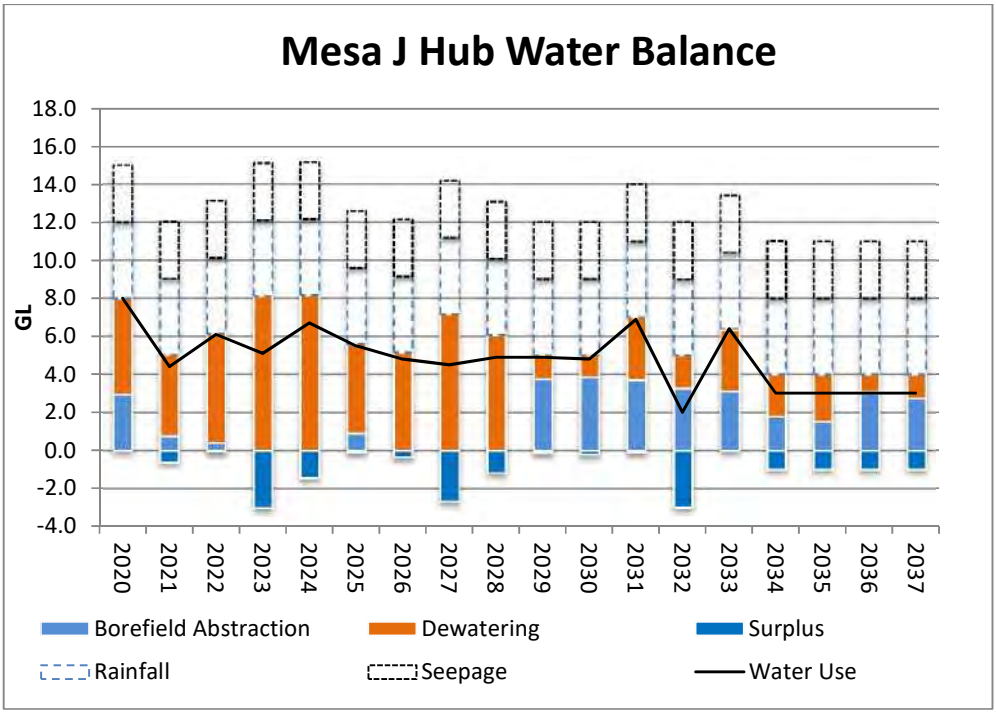


Figure 39: Cumulative Mesa H, J and Borefield groundwater abstraction rates

Table 13: Average Predicted Inflows and Outflows over Life of Mine

Flow Component	Inflow (GL/y)	Outflow (GL/y)
Storage	3.9	3.8
Borefield Pumping	-	1.9
Dewatering	-	3.9
Rainfall Recharge	0.6	-
Discharge to Dan's Dam	1.3	-
Evapotranspiration	-	2.1
Groundwater Inflow / Outflow	0.8	0.8
Stream Leakage	7.5	1.6
TOTAL	**14.1**	**14.1**

7.4 Surplus Discharge

Surplus water from mine pit dewatering to access the BWT resources is proposed to be discharged from the existing licensed discharge point in the Jimmawuarrada Creek. This water management option has been determined to be the most appropriate method of surplus site water management, mostly required during and directly post wet season for surface water management purposes. This option was selected on the basis of its potential to provide supplementary water along zones that will potentially have the biggest drawdown along the Jimmawurrada Creek. These locations are also supported by the ongoing monitoring of the current discharge currently indicating no discernible environmental impact.

The Proponent developed a model to estimate the extent of impact of surplus water discharge along the Jimmawuarrada Creek (Appendix C). Table 14 shows the estimated extent of the discharge footprint along the Robe River adopting six discharge rates scenarios.

Table 14: Estimated discharge extent from discharge location for various discharge rates

Discharge Rate	Maximum Distance Travelled (km)
5 ML/d	3.5
10 ML/d	5.2
15 ML/d	5.2
20 ML/d	5.9
25 ML/d	9.3
30 ML/d	11.8

Based on BWT mine schedule for Mesa H and J, it is predicted that between 2021 and 2030 the totality of the dewatering volumes will be used for ore processing and an increase abstraction from the SCB will be required to meet site water demand. Surplus discharge is only expected during this period for the management of direct rainfall and surface run-off. Between 2030 and 2037, BWT mining will progress more consistently and surplus discharge may occur more often in order to maintain the site water reservoir at a manageable level.

7.5 Prediction Uncertainty

While a reasonable calibration to steady state and time-varying conditions has been achieved for the groundwater flow model, there remains inherent uncertainty in the parameters and setups adopted to describe the hydrogeological system with consequent risks in the prediction of dewatering impacts owing, mostly, to the absence of historical monitoring data for calibration.

To assess the potential impact of these uncertainties, uncertainty predictions have been conducted on the base case model dewatering prediction. Details of the uncertainty runs, focusing mainly on the potential impacts on the Robe River pools, are outlined in Table 15.

Normally, uncertainty analysis is limited to varying input parameters within reasonable limits which are not necessarily supported by the model calibration. However as part of this investigation the uncertainty analysis also included combinations of parameters to assess what conditions might be required to produce dewatering impacts that would trigger necessary mitigation measures to maintain surface water pools along the Robe River. The uncertainty runs were grouped as:

- Conceptual Model Uncertainties: These runs were designed to investigate the impact that hydrogeological changes, that are not supported by the current conceptualisation or the

model calibration, may have on predicted drawdown impacts on surface water pools along the Robe River. These include Runs 8, 10, 11 and 12.

- Climatic Uncertainties: These runs were designed to assess what hydrological conditions might be required to produce worst case drawdown impacts on surface water pools along the Robe River. These include Runs 2, 3, 4, 6 and 9.
- Extreme /Stress Uncertainties: These runs included extreme changes in the model set or operating conditions to assess the drawdown impact on surface water pools along the Robe River. These included Runs 1, 5, 7 and 13.

Table 15: Summary of Uncertainty Runs

Run	Description	Type of Uncertainty
1	Natural inflows to the Robe River and Jimmawurrada Creek not simulated (set to zero)	Stress
2	Natural inflows to the Robe River and Jimmawurrada Creek reduced by 50%	Climate
3	Natural inflows to the Robe River reduced by 50%. Inflows to the Jimmawurrada Creek not simulated (set to zero)	Climate
4	Natural inflows to the Robe River not simulated. Inflows to the Jimmawurrada Creek reduced by 50%	Climate
5	Steady state rainfall recharge and stream flows. Impact associated with CWS not included.	Stress
6	Rainfall recharge reduced by 50% everywhere	Climate
7	Rainfall recharge reduced by 50% everywhere and discharge to Dan's Dam not simulated (set to zero)	Stress
8	General head inflow boundary associated with Robe River not simulated (removed from the model)	Stress
9	Rainfall recharge increased by 50% everywhere. Robe River and Jimmawurrada flows increased by 50%.	Climate
10	Unconfined storage (Sy) of the Robe River alluvium increased by 10% (from 30 to 40%)	Conceptual
11	Hydraulic conductivity of the outcropping Brockman Formation increased to 5 m/d	Conceptual
12	Outflow from the Wittenoom Formation included (General Head Boundary included across the northern model boundary at 115 mAHD)	Conceptual
13	No dewatering from Mesa H and J. All water demand supplied from proposed borefield	Stress

Uncertainty Runs 1, 4 and 8 are predicted to result in the greatest increase in predicted drawdown across the modelled catchment. The total drawdown at tracking points for these three Uncertainty Runs is at least double the total drawdown predicted for the other Uncertainty Runs (and the Base Cases). The next greatest impact on drawdown is predicted by Uncertainty Run 12, however it is less than half of the total drawdown predicted for Uncertainty Runs 1, 4 and 8. Overall however, Uncertainty Runs 1, 2, 3, 4, 6, 7, 8 and 12 predict more drawdown at tracking points compared to the Base Cases.

Uncertainty Runs 5, 9, 10, 11 and 13 all predict less combined drawdown at tracking points than the Bases Cases. As would be expected, Uncertainty Runs 5 and 13 predict less drawdown at

tracking points along the Robe River due to the inclusion of constant recharge and stream flow and moving all pumping to the water supply borefield.

Considering the predicted drawdown at TP7 (along the Jimmawurrada Creek, east of the Southern Cutback borefield), Uncertainty Runs 1 and 3, are predicted to result in the greatest increase in predicted drawdown. As would be expected, simulating all water demand drawn from the borefield (Uncertainty Run 13) predicted the next greatest impact on predicted drawdown at TP7 as TP7 is closest to the water supply borefield; as would be expected, this Uncertainty Run reduced the predicted drawdown at all other tracking points.

A reduction of 50% of the natural inflow in Jimmawurrada Creek (Uncertainty run 2), increased predicted drawdown by ~3m, however, the same uncertainty run showed no significant increase in the drawdown along the Robe River, with max drawdown remaining less than 1m.

Section 8 - Assessment of Potential Impacts

8.1 Groundwater Levels

Predicted drawdown by 2037 (end of mining at Mesa H) is reflected in groundwater level contours provided in Figure 41. Maximum drawdown at the end of mining at Mesa H (end of 2037) is predicted in the immediate area of Pits 4 and 5 at Mesa H, with predicted drawdowns of around 25 m. As dewatering at Mesa J finishes at the end of 2029, borefield pumping is required to meet the projected water demand and drawdown of 15 m is predicted in the borefield area at the end of mining.

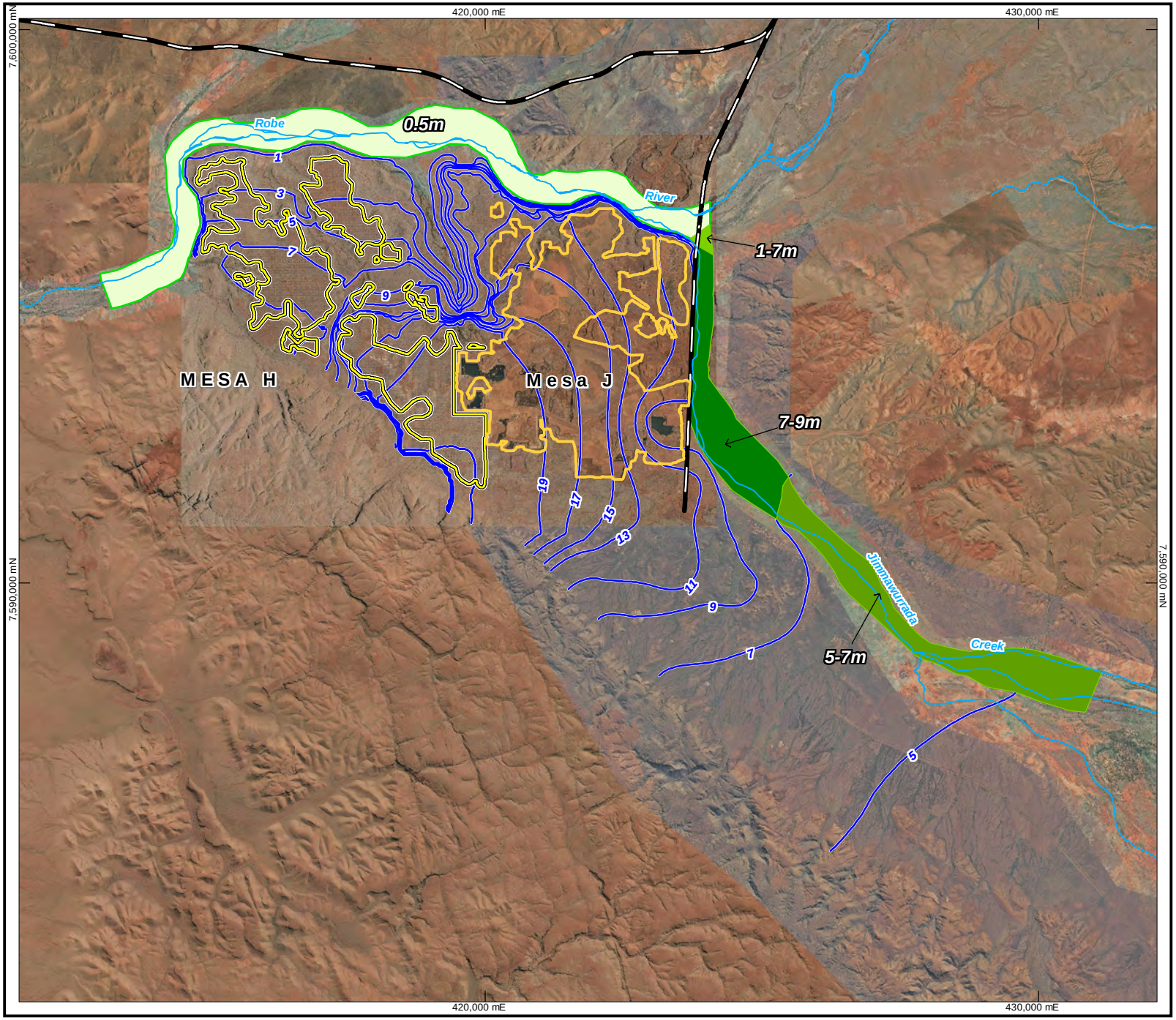
Figure 40 40 and Figure 41 shows a visual representation of the zones of maximum drawdown predicted along the Robe River and the Jimmawurrada Creek by Dec 2030 and 2037, respectively.

The drawdown along the Jimmawurrada Creek is predicted to lower the water level up to 9 m by 2030 mostly caused by Mesa J BWT mining, with the water table ranging between approximately 140 and 165 mRL along the zones of drawdown in Figure 41.

However, the drawdown will reduce to 2.3m by 2037 (Figure 42) due to the end of BWT mining at Mesa J and overall reduction in groundwater abstraction from Southern Cutback Borefield from 2034 to 2037 with the water table ranging between approximately 145 and 165 mRL.

The maximum rate of drawdown along the creek is predicted to happen between 2027 and 2030 with a drawdown rate of approximately 2.5 m/year. However, drawdown and aquifer recovery rates of 2m/year will happen frequently depending on duration of dry season and frequency of rainfall events (Figure 42). Between 2023 and 2036 the average rate of drawdown during this entire period is predicted to be approximately 0.2 m/year.

Due to the fact only intermittent / ephemeral pools (no permanent or semi-permanent pools), have been identified along the 12 km section of Jimmawurrada Creek nearest to Mesa J, the predicted drawdown will not have a direct impact to these intermittent pools; these pools are surface water driven - formed immediately after rainfall / streamflow events, and are preserved only for a short period of time until they naturally disappear due to infiltration and evaporation. The intermittent pools are disconnected from the alluvium aquifer due the depth to water along the creek.



LEGEND

- Drawdown contour
- Mesa H proposed pit
- Mesa J Pit
- Railway
- Major Watercourse

Groundwater drawdown contours

- 0.5m
- 1-7m
- 5-7m
- 7-9m

N

SCALE

0 2 4km

1:100 000 @ A4

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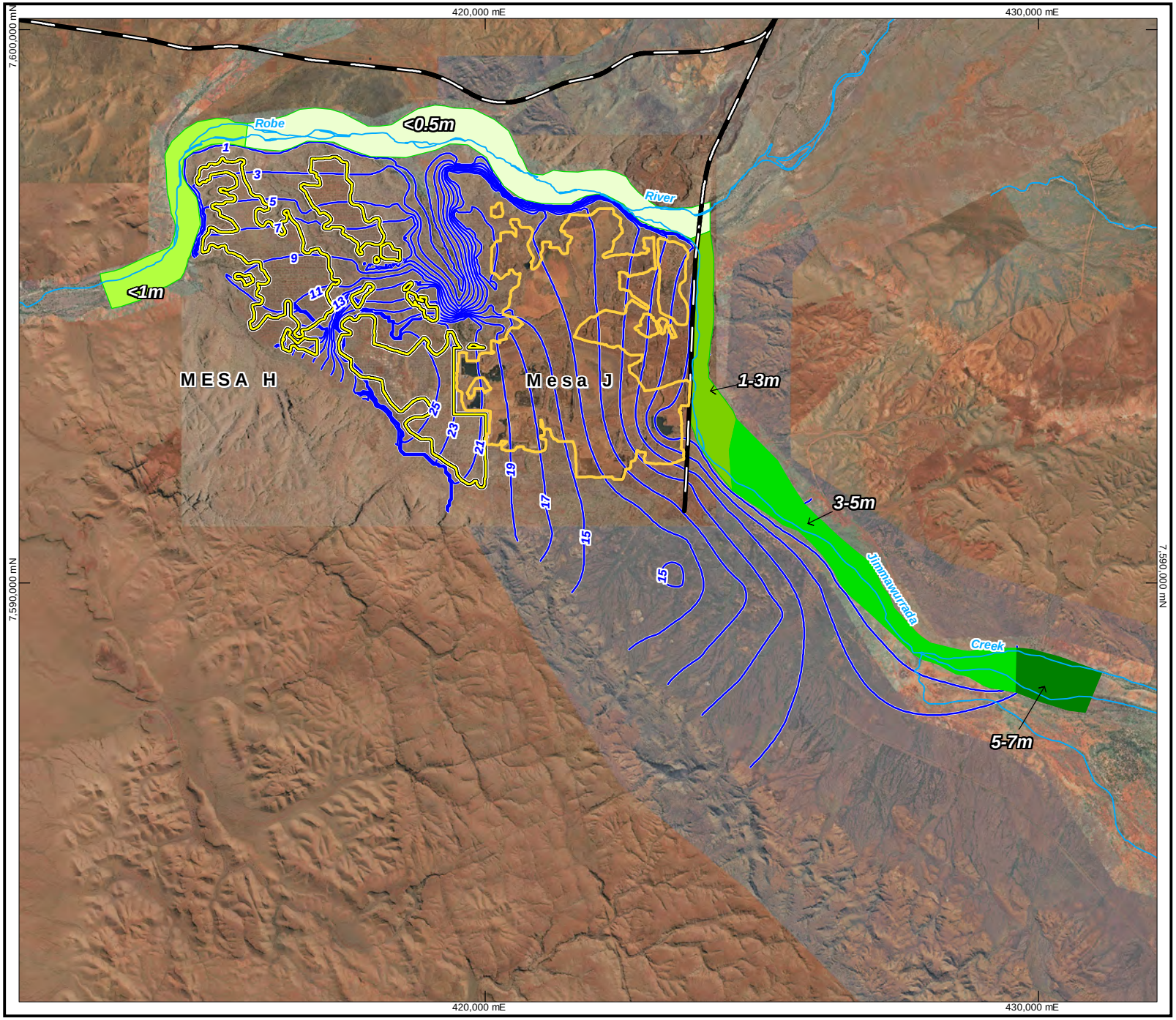
Iron Ore (WA)

Figure 40: Groundwater drawdown contours and zone of maximum drawdown along Robe River and Jimmawurrada Creek by December 2030

Drawn: T.M
Date: Aug, 2018

Plan No: PDE0162442v1
Proj: MGA94 Zone50



LEGEND

- Drawdown contour
- Mesa H proposed pit
- Mesa J Pit
- Railway
- Major Watercourse

Groundwater drawdown contours

- <0.5m
- <1m
- 1-3m
- 3-5m
- 5-7m

N

SCALE

0 2 4km

1:100 000 @ A4

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Iron Ore (WA)

Figure 41: Groundwater drawdown contours and zone of maximum drawdown along Robe River and Jimmawurrada Creek by December 2037

Drawn: T.M
Date: Aug, 2018

Plan No: PDE0162442v1
Proj: MGA94 Zone50

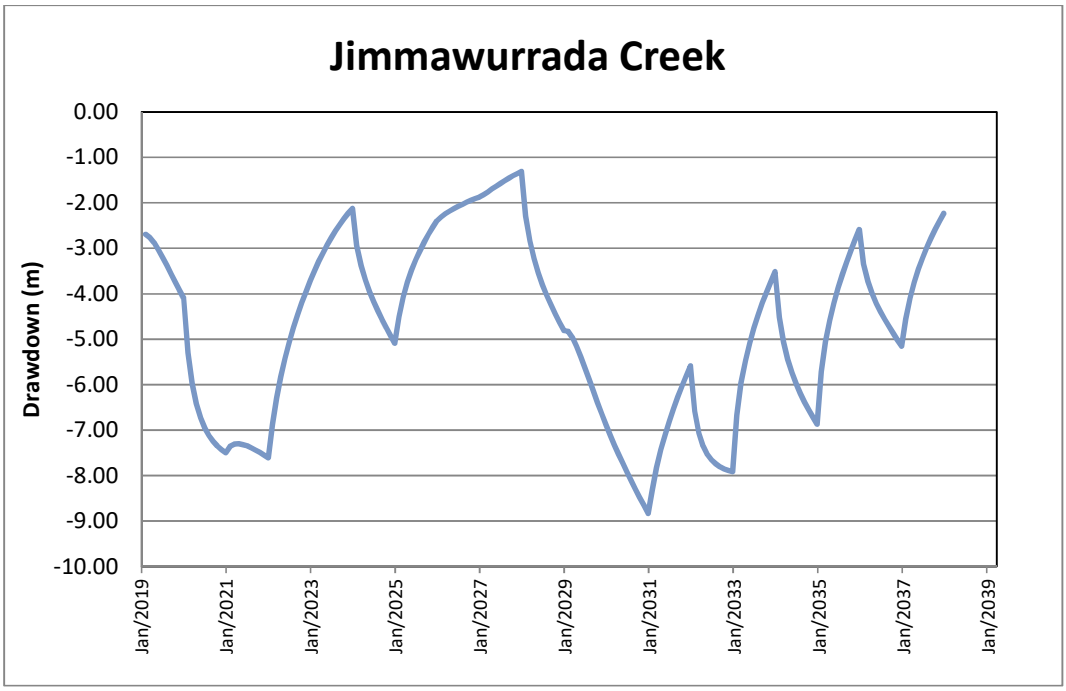


Figure 42: Groundwater drawdown to the east of the southern cutback borefield

Although long term monitoring data in the immediate area of the surface water pools or in Robe River alluvium are not available, monitoring records from the nearby bores close to the river suggest seasonal variation of groundwater levels approximately 3m (Figure 43), this natural fluctuation of the water table in the Robe River alluvium is consistent to what has been observed in the lower Robe River (DoW, 2010).

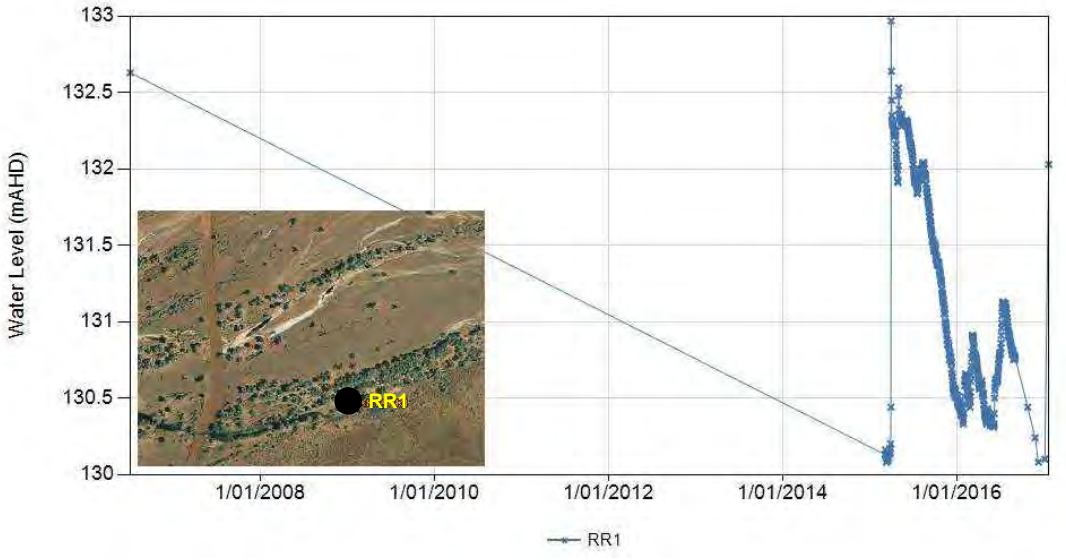


Figure 43: RR1 Hydrograph

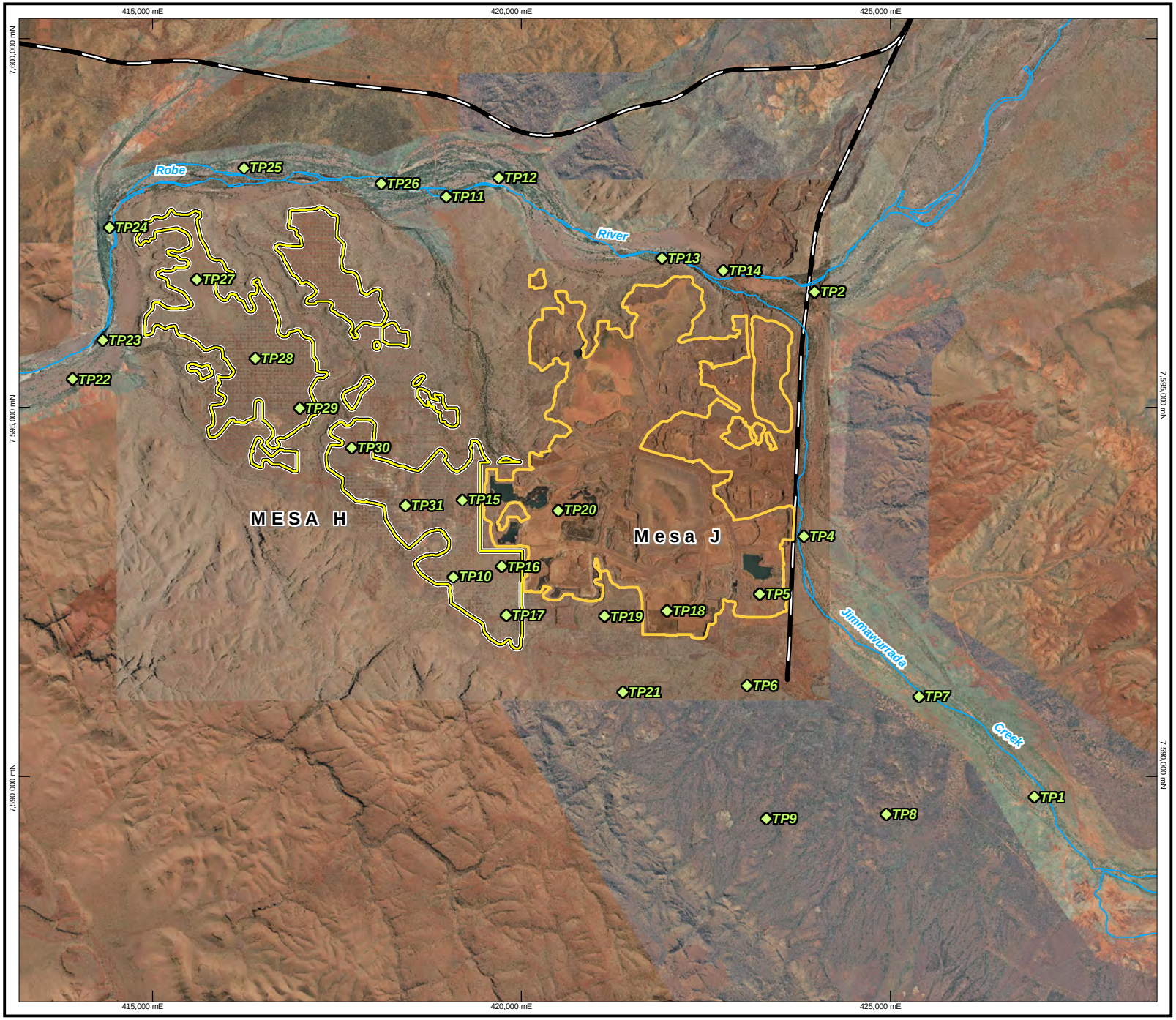
There are five main areas where the proposed mining area would be adjacent to the surface water pools and phreatophytic vegetation that could use the groundwater (model tracking points are indicated in Figure 44):

- Tracking point TP2, at the confluence of Robe River and Jimmawurrada Creek, where dewatering at Mesa J and borefield pumping could potentially create extensive drawdown in the Jimmawurrada Creek alluvium extending to the north towards the Robe River. Maximum predicted drawdown at TP2 is 0.26 m.
- Tracking points TP11, 12, 13 and 14 (between Jimmawurrada and West Creek) adjacent to Mesa J mining areas. Maximum predicted drawdown in this area is 0.44 m at TP14.
- Tracking points TP25 and 26, adjacent to the outflow boundary associated with the Wittenoom aquifer. This area is not only in direct hydraulic connection with the orebody aquifers via TPB but is also underlain by high k Wittenoom aquifer. Maximum predicted drawdown in this area is up to 0.68 m at TP25.
- Tracking points TP22, 23 and 24, in the Robe River alluvium west of TP25. This area is in direct hydraulic connection with the CID aquifer via bounded by fresh Brockman Formation. Maximum predicted drawdown in this area is 0.28 m at TP23.
- Tracking point TP7 is located near the Jimmawurrada Creek in the vicinity of the proposed water supply borefield. Maximum predicted drawdown at TP7 is 8.81 m.

In summary, the potential impacts of mining and dewatering at Mesa J and Mesa H on the surface water pools along the Robe River are predicted to be localised, temporary in duration and relatively small, and fall within the natural fluctuation of the Robe River water level (2-3 m). Permanent and semi-permanent pools with more than 0.5 m depth should not be severely impacted, however shallower semi-permanent or seasonal pools, immediately to the north of Mesa H, could potentially seasonally dry out during periods of low rainfall or periods of drought.

The drawdown along the Jimmawurrada Creek is predicted to lower the water table up to 9 m by 2030. This drawdown is caused mostly by the SCB water supply abstraction (bores slotted against the CID and Basement aquifers) and by the Mesa J dewatering scheduled to be finalised by 2029, but also partially attributed to the CWS, which will lower the water table ~10m by 2037 along the inflow boundary of the Mesa H model. However, with the end of dewatering at Mesa J and natural rebound of the water level during wet season, the drawdown at the end of life of mine (Dec 2037) is expected to be between 1 and 5 m along a 11 Km section of Jimmawurrada Creek, and up to 7m from that point due to the overlap with the Coastal Water Supply drawdown cone of depression.

As indicated in Figure 22, extended dry period and lack of cyclonic events simulated by a 50% reduction of natural recharge could further lower the water table along the Jimmawurrada Creek, with a low seasonal level predicted to drop to a maximum depth of 18 m bgl east of SCB (cross section 1).



LEGEND

- Tracking points
- Mesa H proposed pit
- Mesa J Pit
- Railway
- Major Watercourse

N

SCALE

1 0 1 2km

1:75 000 @ A4

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Figure 44: Model tracking points

Drawn: T.M
Date: Aug, 2018

Plan No: PDE0162442v1
Proj: MGA94 Zone50

8.2 Other Users

The Pannawonica town borefield is up gradient from the mine site and impact to the local aquifer and associated borefield is not expected.

The CWS borefield is not expected to impact on or be impacted (yield reduction) by Mesa H and Mesa J dewatering and water supply abstraction, however, groundwater trigger levels set for the CWS in the respective GWOS, along the Jimmawuarrada Creek, could potentially be impacted due to cumulative localized lowering of the water table.

8.3 The Environment

The environmental systems identified which are likely to be sensitive to changes in the hydrogeological regime at Mesa J and H (as identified in DoW 2010) include:

- Riverine ecosystems – particularly semi-permanent and permanent pools
- Riparian ecosystems – particularly phreatophytic vegetation
- Aquifer ecosystems – particularly stygofauna assemblages

8.3.1 Riverine Ecosystems

The Riverine habitat is considered to be of high importance to fauna species providing a range of ecological values to a wide suite of species. A number of semi-permanent to permanent pools have been recorded within the locality (Figure 16). These pools are considered to provide significant fauna habitat due to the refuge they provide to fish, amphibians and water fowl together with foraging habitat for terrestrial fauna (including conservation significant fauna – Northern Quoll, Pilbara Olive Python, Ghost Bats and Pilbara Leaf-nosed Bats during dry times and the vegetation assemblages that they support.

Permanent and semi-permanent pools on the Robe River support “River Pool Ecosystem” type groundwater dependant ecosystems (GDE’s). These ecosystems rely on consistent surface expressions of groundwater, and are often characterised by a specific assemblage of phreatophytes, macrophytes, mesic shrubs and ephemeral taxa. The pools are typically fringed by vegetation association EcMaCv dominated by *M. argentea* and *E. camaldulensis* var. *refulgens*. (Astron 2016). These vegetation associations are consistent with the vegetation that typically occurs along minor and major channels within the River land system.

Vegetation association EcMaCv is considered to represent groundwater dependant vegetation due to the dominant species being *M. argentea* (obligate phreatophyte) and therefore likely to be sensitive to changes in water depth and availability.

Results of the groundwater modelling indicate that the groundwater drawdown from mine pit dewatering at Mesa H may potentially result in a minor change to the water levels in the pools of

the Robe River of <1m. Whilst this may result in changes to the depth and lateral extent of the pools, potential drawdown impacts on riparian vegetation (particularly the woodland community) are predicted to be localised, temporary in duration, relatively small, and within the natural fluctuation range of the Robe river water levels (measured to be in the order of 2-3 m).

8.3.2 Riparian ecosystems

The riparian ecosystems within the Robe Valley are dominated by mixed woodlands of Cajeput (*Melaleuca argentea*), River Red Gum (*Eucalyptus camaldulensis*) and Coolibah (*Eucalyptus victrix*). Major disturbances to vegetation associated with river beds and pools have resulted from variation in the pattern and volume of rainfall. The local topography, and resultant force of floodwaters can uproot young to semi-mature vegetation and other vegetation may die from being submerged under floodwaters for extended periods. Qualitative assessments of riparian vegetation have shown significant physical uprooting evident in both riparian and floodplain vegetation. These changes were a direct result of the high flows and widespread flooding associated with high flow events.

Robe River

The Robe River riverine habitat is dominated by moderately-dense to dense mixed woodlands to open forests of Cajeput (*Melaleuca argentea*), River Red Gum (*Eucalyptus camaldulensis*) and Coolibah (*Eucalyptus victrix*). The open understorey of tall shrubs is dominated by *Petalostylis labicheoides* and *Acacia trachycarpa* with scattered *Sesbania formosa* and *Gossypium robinsonii* over sedges and mixed herbs. Filamentous green algae are common in the waterways, together with emergent macrophytes, such as *Typha domingensis*, *Potamogeton* and *Vallisneria* species, and fringing rushes such as *Schoenoplectus* sp. and *Eleocharis* sp. (Rio Tinto 2017).

Similar to the pools of the Robe River, results of the groundwater modelling indicate that the groundwater drawdown from mine pit dewatering may potentially result in a minor change to the water levels of <1m and thus potential drawdown impacts on riparian vegetation (particularly the woodland community) are within the natural fluctuation range of the Robe river water levels. Therefore, impacts to phreatophytic vegetation in the Robe River are predicted to be negligible.

Jimmawurrada Creek

Jimmawurrada Creek supports moderate-risk facultative phreatophytic vegetation (i.e. species that utilise groundwater for a portion of their water requirements). The dominant phreatophytic species recorded from Jimmawurrada Creek are *Eucalyptus camaldulensis* subsp. *refulgens* and *Eucalyptus victrix* (RTIO 2017). The pre-mining depth to groundwater along Jimmawurrada Creek, throughout the modelled zone of drawdown, has historically occurred around 4-12 mbgl. This spectrum of depth to groundwater represents both a depth where groundwater is likely to have been accessible to root systems, but unlikely to contribute a significant proportion of phreatophytic Environmental Water Requirements (EWR), and the potential outer limits of depth from which mature facultative phreatophytes might successfully supplement their EWR with groundwater.

The groundwater drawdown predicted is unlikely to be represent a significant proportion of EWR and this is supported by the general absence of such species (i.e Melaleuca's) on Jimmawurrada creek. For phreatophytes occurring on Jimmawurrada Creek, the likely reliance on access to groundwater is inferred to be more closely linked to surface and stored soil water availability.

The phreatophytic species (particularly *E. camaldulensis*) along Jimmawurrada Creek are, therefore, unlikely to be wholly dependent on groundwater access. Experience in other parts of the Pilbara shows that *E. victrix* in woodland/open woodland communities (as present along Jimmawurrada Creek) are less likely to be significantly impacted by the predicted drawdown. The key potential impact to phreatophytic vegetation may, therefore be more general changes in the vigour and canopy stature/reach of *E. camaldulensis* subsp. *refulgens* populations along sections of Jimmawurrada Creek.

An approximately 12 Km section of Jimmawurrada Creek is expected to be inside the estimated cumulative drawdown cone of depression. The maximum modelled drawdown of up to 9m (equating to ~14mbgl) over a 6.5km stretch) is likely to alter the water table beyond the reach of most phreatophytic vegetation root systems, and therefore likely to result in drought stress impacts, particularly during extended dry periods. Impacts to overstorey vegetation, especially *E. camaldulensis* subsp. *refulgens* populations are likely to be in the order of a 15-50% canopy decline and 5-15% increased mortality, particularly on the southern channel and terrace zones away from the direct/indirect influence of surface water and discharge. Understorey changes are also likely; mainly in the form of reduced abundance of mesic understorey species. However, overstorey changes are likely to be more discrete, with overstory species gradually reducing canopy cover to match the reduced water availability.

Some intermittent pools appear during high rainfall events, however no permanent or semi-permanent pools have been identified within in this section of Jimmawurrada creekline.

Monitoring

An aquatic ecosystems monitoring program (undertaken by Stremtec) has been in place since 1991 in order to detect any mining related impacts from drawdown and discharge at Mesa J and includes monitoring of aquatic fauna, channel/pool morphology, riparian/bank condition, weeds, water flows and water quality. To date, there have been no detectable changes in the aquatic ecology of the Robe River that could be attributed to mining operations alone (Streamtec 2017). Additional aquatic fauna sampling baseline data has also been collected seasonally since 2017, providing a detailed, quantitative, and systematic analysis of aquatic fauna assemblages and water chemistry, prior to the development of Mesa H, which will support the proposed updated environmental monitoring and management program.

In addition to the existing monitoring program, riparian vegetation transects have been established in 2016 across discharge and reference sites to capture floristic data, population structure, vegetation and crown condition of phreatophytic species. Worldview Lansat imagery has also been acquired to enable vegetation condition to be assessed on a catchment scale. Leaf-water potential measurements are also undertaken as part of the analysis to understand tree-water usage and

stress. Ongoing data capture and analysis will enable vegetation changes to be assessed over time and compared to pre-Mesa H development.

8.3.3 Aquifer ecosystems

The primary habitat for stygofauna in the locality is considered to be the alluvial aquifers and the CID aquifer, the latter underlies the alluvial aquifer along Jimmawurrada Creek. The Southern Cutback Borefield and modelled cumulative groundwater drawdown cone of depression falls within the Priority Ecological Community (Priority 1) *Stygofauna Community of the Bungaroo Aquifer.*

Three stygofauna of conservation significance have been recorded within the cumulative drawdown impact area within two of the main aquifer systems:

- CID aquifer (Mesa H pit area) :
    - Amphipoda species: *Nedsia hurlberti* and *Nedsia sculptilis*, both of which are Schedule 3 species. More sampling and molecular work is being undertaken to gain a better understanding of the local distribution of this species.
- Alluvial aquifers:
    - Nine records of the Commonwealth listed subterranean fauna: Blind Cave Eel (*Ophisternon candidum)* (Vulnerable; Schedule 3) has been recorded in within the alluvial aquifers associated with Bungaroo Creek, Jimmawurrada Creek, and the Robe River and currently represent the only inland Pilbara records of this species.

The Blind Cave Eel records comprise both physical samples and environmental DNA (eDNA) samples, both upstream and downstream of the modelled extent of groundwater drawdown, and have been recorded within the hyporheic zone of the Robe River (Biota 2018, WRM 2019).

The modelled groundwater drawdown is predicted to result in a temporal and localised loss of stygofauna habitat, which has the ability to be recover during rainfall – recharge events. Habitat parameters including groundwater levels and groundwater and surface water quality will be monitored as part of the broader catchment environmental and hydrogeological monitoring program.

8.4 The Aquifer

Once mining is complete and dewatering ceases, groundwater levels in the Mesa J and Mesa H mining areas will recover until a balance is reached between groundwater inflows and groundwater outflows. In the event that pit voids are infilled with waste / waste fines storage facility, groundwater levels will eventually recover to pre-development levels. Aquifer recovery in the pit areas (i.e. the CID aquifer) is expected to take up to 50-60 years to recover to pre-mining level.

The large majority of the drawdown along the Robe River and Jimmawurrada Creek is expected to recover 90% of the drawdown after the first or second significant rainfall events The drawdown in

the Yeera Bluff permanent pool area is estimated to take the longest to recover, with the last 20cm of drawdown taking up to 40 years to recover (Figure 45). Details of the mine closure modelling are outlined below:

- Initial conditions for the prediction were taken from the end of dewatering (December 2037);
- The model was run for a period of 190 years (January 2038 to December 2137);
- The model predictions were run using annual time increments (stress periods);
- Infilling of all mine voids is completed prior to any groundwater recovery;
- The hydraulic conductivity of the infill material will be similar to the material of the original formations excavated during mining;
- The mined out void will be infilled to a level above the pre-development groundwater table and the final land form will be designed such that there will be no increase or decrease in recharge to the infilled mine void;
- The ET setup is identical to that used for the predictions. No ET was included for the infilled void because water levels in the infilled pits are not expected to exceed the top of the infill for extended periods of time;
- Recharge rates as a percentage of annual rainfall as well as stream flows are identical to those used for the model predictions. Annual rainfall and stream flow data from the prediction period is repeated to simulate variable annual recharge and flows for the closure predictions;
- The prediction does not include any further pumping, dewatering or discharge from any other area in the modelled catchment or impacts associated with the Coastal Water Supply Project; and
- All other model parameters were set consistent with the steady state model.

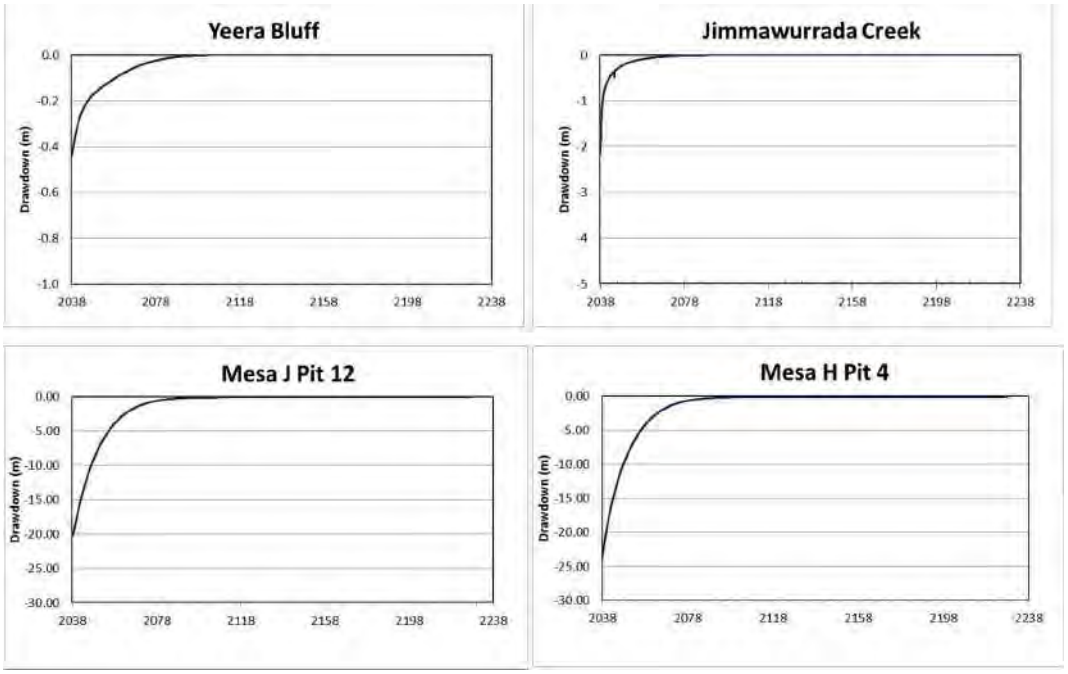

Figure 45: Predicted water level post closure

Section 9 - Site Water Balance

Water respects no boundaries, and drought and floods are events beyond our direct control. Rio Tinto's role in water management is one of stewardship, not ownership, and therefore our operating philosophy is based on the following concepts:

- efficient use of water;
- implementation of the reduce, re-use, recycle concepts;
- avoid or minimise contamination of clean streams and catchments; and
- recognise and protect downstream beneficial uses (for both surface and groundwater).

Implementing these concepts requires considerable planning, based on a clear understanding of the project and the hydrological, geochemical and processing regimes in which it operates.

The hydrologic cycle is the primary model for the input and output water management elements in any site development. These elements include:

- Rainfall: an estimated sum of areas of operational pits times a twice a year 150mm event occurring over a 1-5 day period.
- Evaporation: an estimated sum of areas of the waste fines storage facility, the water reservoir and sumps times the average yearly pan evaporation.
- Dewatering and groundwater abstraction: extracted from the groundwater numerical model.
- Seepage: based on observed volumes seeping through pit walls close to operational waste fines storage facility and Dan's Dam.
- Discharge: excess volume that can't be managed / used on site and will be discharged in the Jimmawurrada Creek.

Site water demand has been defined as:

- Wet Plant processing: estimated based on current site water demand and secondary screening plant design and mine schedule.
- Non-processing infrastructure: based on current site water demand.
- Dust suppression: estimated as 17 litres per ton of moved material based on mine schedule.

Table 16 presents the estimated water demand for Scenario 1 (thickener plant) and Scenario 2 (without thickener plant) used to estimate water demand for the model prediction.

Table 16: Site Water Balance

Description	Unit	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037
PP1 and PP2 water supply based on crusher feed rates (Scenario 1)	GL	2.8	3.3	5.3	3.7	5.8	4.4	3.7	3.5	3.6	3.7	3.6	5.6	0.8	5.2	2.3	2.3	2.3	2.3
PP1 and PP2 water supply based on crusher feed rates (Scenario 2)	GL	9.5	11.5	15.4	12.3	16.4	13.7	12.3	11.8	12.1	12.2	12.0	16.1	3.1	15.1	8.8	8.8	8.8	8.8
Dust suppression	GL	0.7	0.9	0.7	1.2	0.7	0.9	0.9	0.8	1.1	1.1	1.1	1.1	1.0	1.0	0.5	0.5	0.5	0.5
Non-processing infrastructure	GL	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Evaporation loss	GL	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Direct rainfall recharge	GL	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
50% Decant plus seepage recovery from Mesa J's pits (Scenario 1)	GL	4.8	5.7	7.7	6.2	8.2	6.8	6.2	5.9	6.0									
30% Decant water recovery (Scenario 1)	GL										3.7	3.6	4.8	0.9	4.5	2.6	2.6	2.6	2.6
Groundwater Abstraction Demand																			
Scenario 1 – thickener included, no decant return	GL	**3.8**	**4.4**	**6.1**	**5.1**	**6.7**	**5.5**	**4.8**	**4.5**	**4.9**	**4.9**	**4.8**	**6.9**	**2.0**	**6.4**	**3.0**	**3.0**	**3.0**	**3.0**
Scenario 2 – no thickener, decant return	GL	**5.7**	**6.8**	**8.5**	**7.5**	**9.1**	**7.9**	**7.2**	**6.9**	**7.3**	**9.8**	**9.6**	**12.5**	**3.3**	**11.8**	**6.9**	**6.9**	**6.9**	**6.9**

*PP1 and PP2 = processing plants

Section 10 - Groundwater Monitoring

The Proponent's aim is to ensure that the environmental requirements for water quality and sustainability are met. This includes ensuring that water quality does not deteriorate below its current state during mining and post-closure. Potential impacts are currently assessed through the existing groundwater monitoring program at Mesa J and will be expanded to include the Mesa H estimated cone of depression. Based on the site water balance, current combined Mesa J and Mesa H groundwater abstraction (~ 12 GL/year) is expected to be maintained to meet site demand during LoM.

Ongoing monitoring of phreatophytic vegetation, aquatic fauna and pool water quality along the Robe River and Jimmawurrada Creek will continue to be undertaken according to the Mesa J Environmental Management Plan. To manage the potential risk to the environmental values, triggers (biological and water related) will be defined before Mesa H dewatering commences.

Based on the current monitoring schedule for Mesa J, outlined in the current approved site GWOS, Table 17 outlines the preliminary proposed monitoring schedule. Monitoring data is reviewed and evaluated for its validity prior to entry into the licensee's central database (EnviroSys) in readiness for reporting requirements. All data collected through the monitoring programme is included within the externally reported Annual and Triennial Aquifer Reviews.

Monitoring bores will be installed up gradient and down gradient from the planned tailings storage facilities to monitor potential changes in the water quality due to seepage and manage any potential impacts to local receptors in the Robe River.

Table 17: Current Monitoring Schedule

Bore Type	Frequency	Parameter
Production Bores	Monthly	Abstraction volume
	Monthly	Water level
	Monthly	EC, pH, Temperature
	Annually	Field Chemistry (EC, pH, temp, TSS, Colour, Turbidity, Total hardness) Major Ions (CO_3, HCO_3, Ca, Na, K, Mg, SO_4, Si, F, Fe, Al, Cl) Dissolved metals (Ag, As, B, Ba, Cd, Co, Cr, Cu, Hg, Mn, Mo, Ni, Pb, Sb, Se, Sn, U, Zn); Nutrients (Total P, Total N, NO_2, NO_3, NH_4) Microbiological (Thermotolerant Coliforms, *E.coli, Naegleria*)
Monitoring Bores*	Quarterly	Water level

Bore Type	Frequency	Parameter
Sumps	Monthly	Water level
Pools	Monthly	Water level
	Annually	Field Chemistry (EC, pH, temp, TSS, Colour, Turbidity, Total hardness) Major Ions (CO_3, HCO_3, Ca, Na, K, Mg, SO_4, Si, F, Fe, Al, Cl) Dissolved metals (Ag, As, B, Ba, Cd, Co, Cr, Cu, Hg, Mn, Mo, Ni, Pb, Sb, Se, Sn, U, Zn); Nutrients (Total P, Total N, NO_2, NO_3, NH_4) Microbiological (Thermotolerant Coliforms, *E.coli, Naegleria*)
Discharge	Quarterly	Field Chemistry (EC, pH, temp, TSS, Colour, Turbidity, Total hardness) Major Ions (CO_3, HCO_3, Ca, Na, K, Mg, SO_4, Si, F, Fe, Al, Cl) Dissolved metals (Ag, As, B, Ba, Cd, Co, Cr, Cu, Hg, Mn, Mo, Ni, Pb, Sb, Se, Sn, U, Zn); Nutrients (Total P, Total N, NO_2, NO_3, NH_4) Microbiological (Thermotolerant Coliforms, *E.coli, Naegleria*)

Section 11 - Management Approach / Conclusions

The Proponent has a defined Water Strategy that guides water management within the group. This strategy requires an integrated approach to water management that promotes, maintains or improves water quality, minimises fresh water use and maximises reuse and recycling. The water abstracted from the Mesa J hub will be used for mining operations, including irrigation of ore to increase moisture content, potable supply, dust suppression and wet processing.

The inclusion of the thickener to the wet plant at Mesa J will have a significant reduction in the drawdown along the Jimmawurrada Creek, reducing from a predicted 18 m to 9 m maximum drawdown. Although supplemental discharge to the creek is not viable due to the lack of an alternative suitable / sustainable aquifer in the region, the reconfiguration of the existing Mesa J discharge system to a single discharge point approximately 2 Km up-gradient of the SCB will off-set some of the drawdown along the creek through the natural seepage of surplus discharge.

A maintenance schedule will be implemented to ensure water infrastructure is operating optimally. Maintenance personnel will visually check the condition of the pipelines and infrastructure associated with transporting water from the borefield for potential leaks and ruptures.

Monitoring bores will be commissioned with data loggers for continuous monitoring of the water level. Selected bores will have monitoring devices that will also read conductivity and salinity changes over time.

All the production bores will be commissioned with automated telemetry systems to optimise water abstraction and manage drawdown throughout the borefield. The groundwater numerical model will be revised yearly based on transient data viability during LoM.

Ongoing data monitoring and collection will be used to develop a baseline criteria for the water levels in the aquifers, Robe River and Jimmawurrada Creek and used to support the development of water level triggers which will be used for the design and implementation of an impact mitigation strategy. The monitoring data will be integrated with the environmental monitoring and management plan focussed on groundwater dependant ecosystems (riparian vegetation, aquatic fauna and stygofauna).

The water level in the pools, when feasible, will be monitored by automated telemetry systems that will be used to trigger supplemental discharge to specific locations along the Robe River, aiming to mitigate any impact that may be adversely affecting the water levels in the pools. Based on the results of a 30 days discharge trial carried out in the Robe River and the analysis of the Mesa J discharge to the West Creek between 2016 and 2017, supplemental discharge to the pools could be used to reduce the drawdown along the Robe River pools, although the discharge points would need to be located at or immediately adjacent to pools to be protected, hence only a few and selected pools could be protected and this solution will require consultation with the traditional owners due to visual impact of this strategy.

Based on regular monitoring of the pools and water levels, if / when the drawdown in the Yeera Bluff is 0.5 m or more than the average natural variance of pre-defined control points (e.g. Medawandy, monitoring bores in the alluvium) Rio Tinto will cease mining Pit 7 below the water table, until a streamflow event recharges the pool and the water levels have reached a steady state without showing any sign of adverse ecological / cultural impact. Figure 46 shows the drawdown effect of mining Pit 7 BWT to the Yeera Bluff permanent pool.

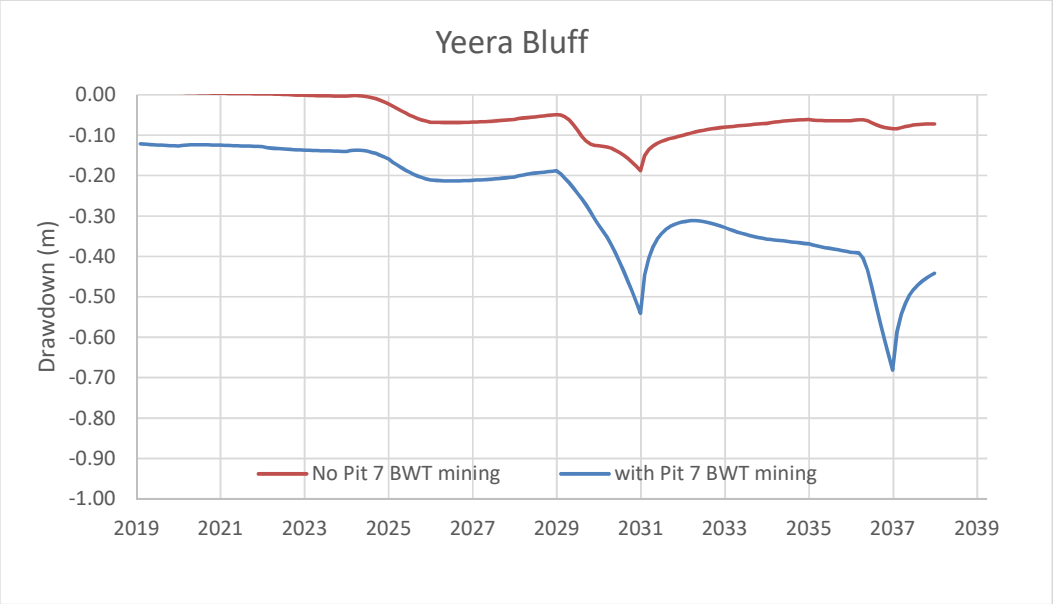

Figure 46: Drawdown caused by Pit 7 BWT to the Yeera bluff permanent pool

The uncertainty run 2 (natural inflows to the Robe River and Jimmawurrada Creek reduced by 50%) was predicted as an appropriate scenario based on climate change, an additional reduction of 2 m as maximum seasonal variation is applied as the worst case scenario. In the worst case scenario, the water table along sections of the Jimmawurrada Creek, east of Mesa J and Southern Cutback, could be lowered down to 18m bgl.

Based on maximum observed alluvium thickness (Figure 22) ranging between 28 and 40m along the channel thalweg, 44% to 64% of saturated alluvium will be preserved below the water table serving as a continuous habitat to the Blind Cave Eel along the Jimmawurrada Creek. Table 18 shows the estimated volume of saturated alluvium in the Jimmawurrada Creek within the numerical model domain for the central case, uncertainty run # 2 and worst case scenarios.

Table 18: Estimated volume of Jimmawurrada Aquifer alluvium preserved by 2030.

Date	Saturated Volume in m^3	% remaining saturated alluvium
Pre-mining	176,900,000	100%
Current	116,650,000	66%
2030 (base case)	113,710,000	64%
2030 (uncertainty run #2)	91,162,000	52%
2030 (uncertainty run #2 + lowest seasonal variation) – worst case scenario	77,526,000	44%

A network of monitoring bores will be installed along the section of the Jimmawurrada Creek that is predicted to be impacted by groundwater abstraction from the SCB and CWS. This network will be used to monitor the water level and trigger mitigation actions (e.g change in the abstraction regime, drill of bores farther away from the creek, direct environmental discharge, aquifer reinjection) during LoM.

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APPENDIX A: BORE COMPLETION REPORTS

Water Resource Evaluation & Services - OKP

Report

Mesa H FS Hydrogeological Field Programme Report 2017

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	Name	**Date**

Stakeholders: Hydrogeologists, Hydrologists, Study and Approvals.

Accountability:

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Executive Summary

This report outlines the hydrogeological drilling and test pumping results completed at Mesa H deposit and surroundings. The purpose of the Mesa H field investigation was primarily to close conceptual uncertainties and increase the hydrogeological understanding of the deposit and surrounding regional aquifers, to support the Mesa H Feasibility Study (FS). Key objectives of this investigation included:

- Assessing the hydraulic connection between the CID Aquifer, regional basement aquifers and Robe River Alluvial Aquifer in key locations where hydrogeological information was previously uncertain;
- Robe River pool mitigation strategy trial through long term test pumping and discharge management along the Robe River within the Mesa H project area;
- Clarify hydraulic boundary at Yeera bluff and aquifer throughflow continuity in the outer reaches of the Mesa H project area and Robe River vicinity;
- Test the aquifer south of the Mesa H deposit for water supply requirements; and
- Investigate water supply sources for the Mesa H provisory construction camp.

As part of the investigation the following works and installations were completed:

- 5 production bores
- 14 monitoring bores (1 nested monitoring bore)
- 1 monitoring bore for environmental sampling
- 2 Vibrating Wire Piezometers (VWPs) grouting and instrument installations
- Short term test pumping of 4 production bores (24 hour Constant Rate Test (CRT))
- 30 day CRT test pumping of 1 production bore

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APPENDICES

Appendix A: Borehole Logs

Appendix B: Pumping Test Analysis

Appendix C: Geophysics Report

Appendix D: Laboratory Certificate of Analysis

Section 1 - Introduction

The Mesa H deposit is the subject of a Feasibility Study (FS) from May 2017 to April 2018. Hydrogeological drilling and test pumping works were undertaken at Mesa H during 2017 as part of the FS investigations. The Mesa H deposit is located adjacent to the Mesa J iron ore mining operation, approximately 17 km southeast of the Pannawonica Township and 110 km southwest of Karratha in the Pilbara region of Western Australia.

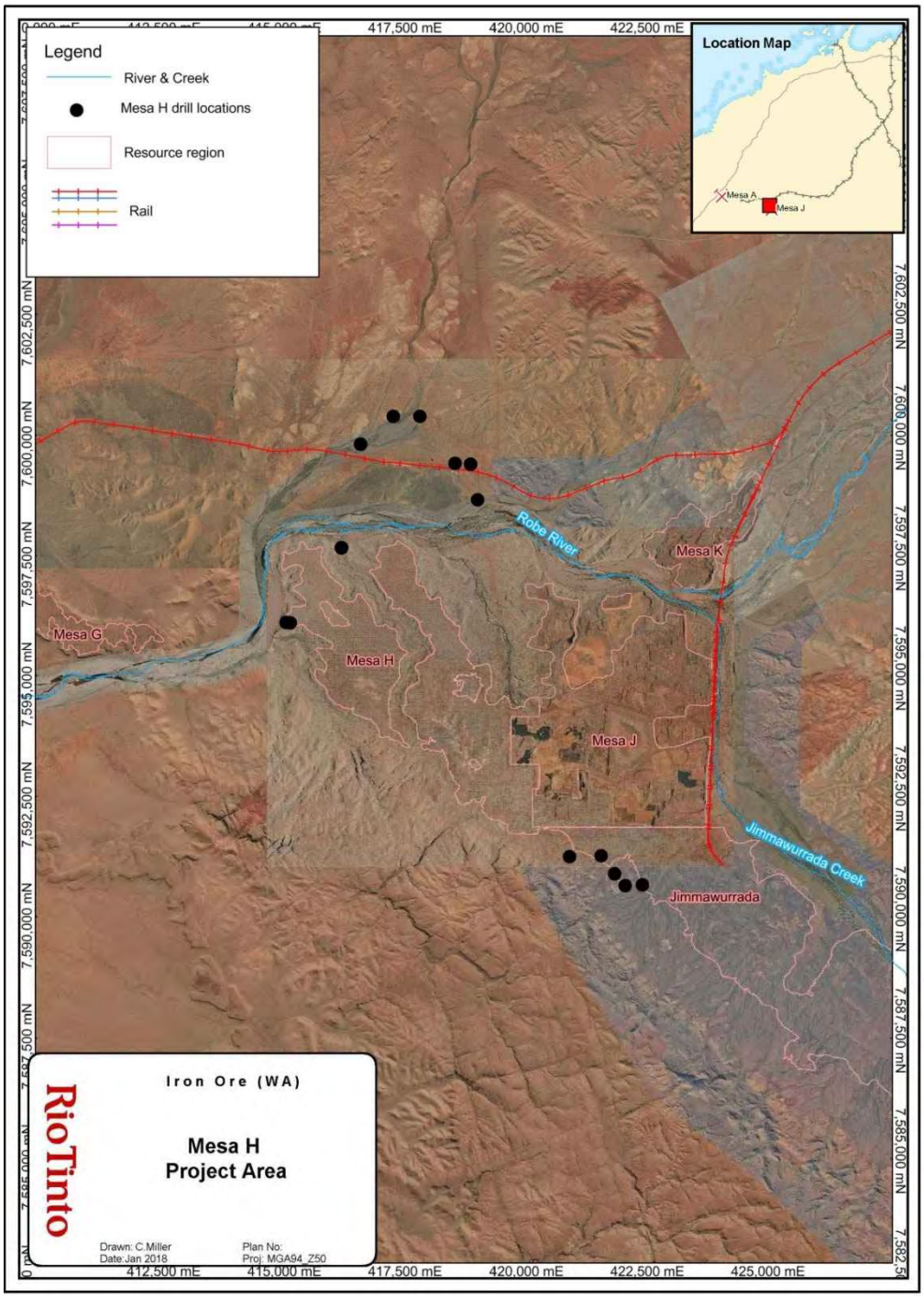

Figure 1 Mesa H project area

1.1 Programme description

The original program scope of works (RTIO-PDE-0152031) comprised of drilling and construction of monitoring bores, production bores and vibrating wire piezometer (VWP) at Mesa H. however due to ground conditions and findings during drilling, changes to the scope have been made during the program. Figure 2 shows the final location of all the installed bores. Test pumping was completed to better understand the aquifer parameters and hydrogeochemical sampling of bore locations was completed for hydro-chemical modelling to support the groundwater potential supply to the Mesa H To address hydrogeological risks identified during early stages of the FS, this program was designed to:

- Assess the hydrogeological characteristics of the basement close to the Yeera Bluff pool;
- Assess the basement continuity north of the Robe River,
- Test the aquifer south of the Mesa H deposit for water supply requirements.
- Perform a discharge trial to support the design of an impact mitigation strategy for the local pools.
- Investigate water supply sources for the Mesa H construction camp

The works included the following:

- 5 production bores and 15 monitoring bores installed at the Mesa H project area
- 2 VWPs installed within the Mesa H project area project area
- 1 Nested piezometer installed within the Mesa H project area
- Complete pumping testing of production bores to assess bore capacities, ascertain aquifer parameters and identify any applicable flow boundaries.
- 30 day discharge trial to assess the hydrogeological characteristics of the basement close to the Yeera Bluff pool;
- Collection of water samples from selected locations to support hydro-chemical modelling.

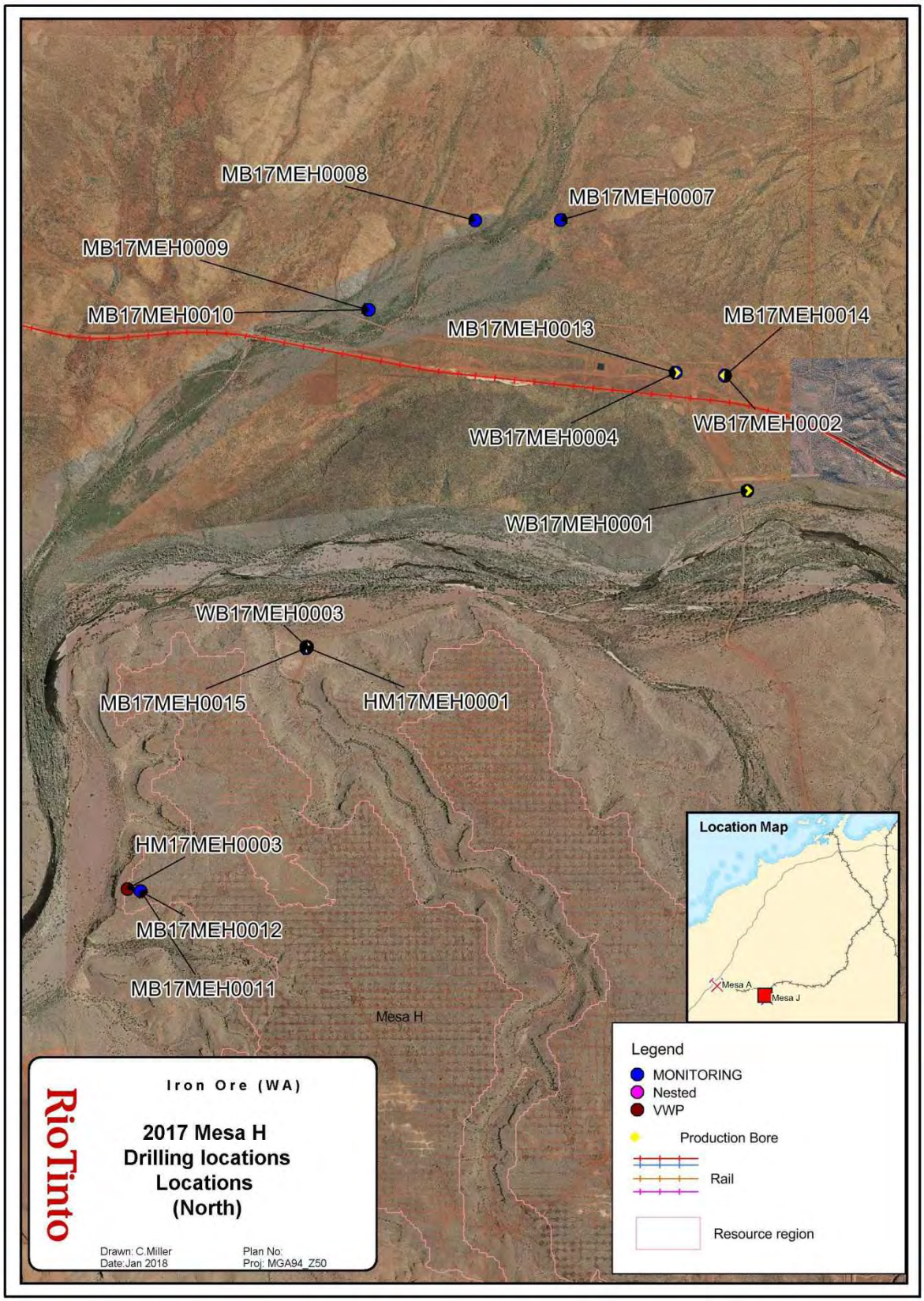

Figure 2 Mesa H Hydrogeological drilling locations north

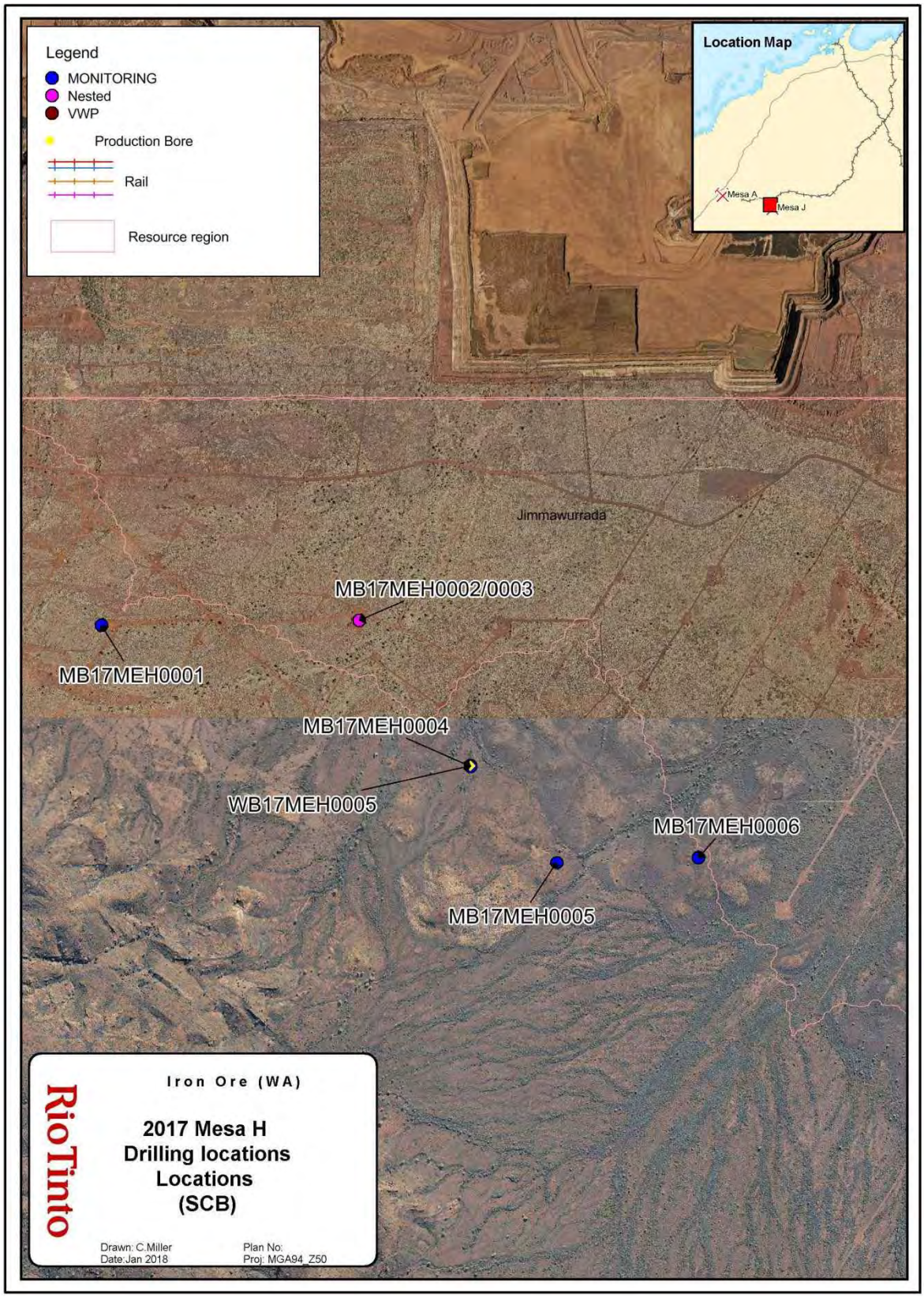

Figure 3 Mesa H Hydrogeological drilling locations Southern Cutback (SCB)

1.2 Approvals

Before earthworks and drilling commenced, the following Approvals Requests (AR) and 26D Licenses were obtained.

Approvals Requests (ARs)

- AR-16-14020 - Mesa H FS Hydrogeological Program (Heritage Areas)
- AR-16-14023 - Mesa H FS Hydro Drilling (Off Mining Lease)
- AR-16-14024 - Mesa H FS Hydro Drilling
- AR-17-14272 - Mesa H Robe River Discharge Trial
- AR-17-14444 -Water Supply Mesa H Construction Camp

26D Licenses

- CAW183351(1)
- CAW183352(1)

Section 2 - Mesa H Project Setting

Mesa H is a channel iron deposit (**CID**) deposit that forms part of a sinuous chain of mesas which define the palaeochannel of the Robe River and its associated tributaries. The deposit contains high grade and low grade mineralisation, with a combined Mineral Resource of 207 Mt at 54.3% Fe. Approximately 34% of the reported resource occurred below the pre-mining water table, however due to the lowering of the water table caused by dewatering activities at the adjacent Mesa J operation, the reported resource at Mesa H is approximately 13% below the present-day water table.

The project site is located downstream from the confluence of the Robe River and Jimmawurrada Creek. Along the river are permanent and semi-permanent pools which support environmental sensitive ecosystems and are of cultural significance in the area. Due to the close proximity of Mesa H to Robe River and a number of significant surface water pools, this investigations objective is focused on understanding potential impacts that future dewatering activities at Mesa H may have on these areas.

2.1 Geology and Hydrogeology

Geological units and hydro-stratigraphic components in the Mesa H area are well understood. Areas where hydrogeological conceptual uncertainties were identified during the PFS were targeted in this investigation to clarify modelling scenarios based on the understating of geological units in the area.

2.1.1 Mesa H Conceptualisation

Key areas where conceptual uncertainties for the Mesa H FS included the Yeera Bluff location (MB17MEH0011 and MB17MEH0012) where limited drilling and hydrogeological investigations could clarify a groundwater throughflow boundary between CID aquifer and the Robe River Alluvial aquifer which supports what is considered a permanent surface water pool (KM-RR16) directly west of the Mesa H deposit. As such, drilling and bore development suggests the basement geology (unmineralised BIF) in this area causes a groundwater throughflow boundary. Further evidence of this groundwater boundary is suggested by very low airlift yields which shortly after commencing bore development became dry. Water samples were not collected as a result and a production bore to test hydrogeological parameters and hydraulic connectivity between CID and basement were deemed unnecessary.

The uncertainty of basement aquifer continuity in the north of the Mesa H was addressed by drilling at several locations including MB17MEH0007 - MB17MEH0010, MB17MEH0013, MB17MEH00014 in this program and an additional location MB17MEK0001 (RTIO-PDE-0156788) to determine the regional Wittenoom Aquifer throughflow direction north the Robe River. The results are reflected as water level contours shown in Figure 3. Additional information on geological units in the north area can be found in the borehole logs in Appendix A.

Geological and hydrostratigraphic unit uncertainties remain in areas where drilling requests could not be approved or where rig mobilisation was deemed unsafe. These areas are the Robe River alluvial and Jimmawurrada Creek locations.

2.1.2 Water supply

Areas drilled in for the purpose of water supply exploration and construction camp water supply had found varying results and success. In similar geological units, variations in hydrostratigraphic properties were found. As a result, drilling and test pumping was unable to clarify the suitability of the locations for water supply. For example exploration bores in the Southern Cutback (SCB) area of Mesa H (Otherwise known as Jimmawurrada deposit) encountered thick sequences of black, lignitic shale (McRae Shale) overlayed by a thick sequence of clay. While it was found to be largely impermeable, fractured and interbedded zones of chert layers had higher permeability allowing for yields during drilling. Where lost circulation occurred, the yields were at its highest however it is not known how extensive these fractures and cavities are in the area. A large fracture and lost circulation zone was intersected only at one drill pad location MB17MEH0004 and WB17MEH0005. Bore locations which did not encounter lost circulation in the SCB area were dry (MB17MEH0001 and MB17MEH0003) and or yielding very low or had issues developing due to the amount of fines in the sample (MB17MEH0002, MB17MEH0005 and MB17MEH0006). These bore locations were not recommended for production bore construction.

Bores in the north of the Mesa H close to the rail line (MB17MEH0013 & 14) had varying degrees of success for water supply potential for the Mesa H construction camp. The monitoring bores and production bores encountered similar geology with varying degrees of fracturing and weathering profiles within the alluvium and Wittenoom Formation. This suggests that continuous water supply may be at risk due to varying yield performance between the two production bores drilled here (WB17MEH0002 and WB17MEH0004).

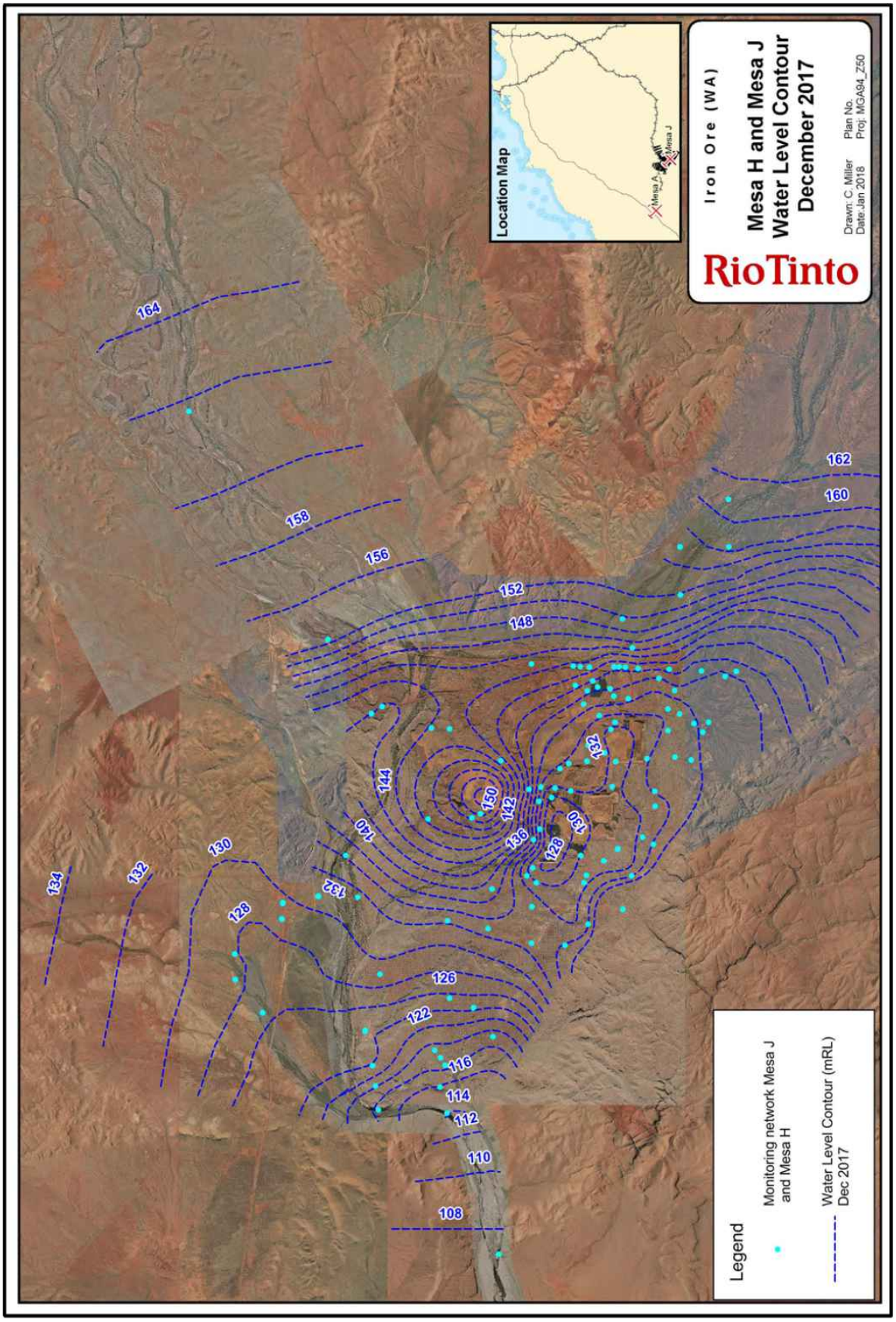

Figure 4 Groundwater level RL post drilling at Mesa C

Section 3 - Drilling Program

3.1 Drilling

Bunbury Drilling Pty Ltd (BDC), were commissioned to carry out the 2017 Mesa H Hydrogeological Drilling Program. A combination of Mud Rotary and Conventional Air Hammer drilling techniques were employed by BDC to ensure successful and timely completion of the project. Where it was deemed necessary, a combination of both techniques were used on the same hole, where mud rotary was used to seal the upper less stable sections, while the rest of the hole was completed using the quicker conventional air drilling technique. Post drilling and construction geophysical surveys were also completed on all production Bores between October 2017 and December 2017 by Kinetic. Installation of VWPs was carried out Foraco Fluid Potential

Drilling, Test Pumping and Geophysical surveys were managed by the Rio Tinto Water Resource Evaluation and Services group (WRE&S). During the field campaign, project logistics and safety oversight was provided by Project Field Coordinators, whilst Technical hydrogeological supervision was provided by Feld Hydrogeologists.

3.2 Mesa H Bore Construction

Bore construction was completed by BDC as per Scope of Works (SoW). Headworks for all bores were completed in accordance with the Rio Tinto Design Specification for Water and Monitoring Bore Headworks (RTIO-PDE-0089729). Complete details of all bore locations, drilling and construction and hydrogeological information collected during drilling and construction activities is provided in Tables 1, 2, 3, and 4 respectively. A summary of construction details for each bore type are below:

Production Bores:

- 12” threaded steel casing stick-up 150mm above the top of the plinth;
- Lockable steel lid with handle;
- Concrete plinth measuring 1 m^2 by 300 mm high (100 mm set below natural ground level).

Monitoring bores (includes dual nested monitoring bores)

- 50mm PVC Class 18 casing, fitted with a PVC cap
- Steel casing stick-up 500 mm above the top of the plinth;
- Lockable steel lid with handle;
- Concrete plinth measuring 1 m^2 by 300 mm high (100 mm set below natural ground level).
- Dual nested monitoring bores were constructed with bentonite seal to separate deep and shallow formations between slotted sections of PVC within the parent hole.
- All bores were gravel packed with graded gravel 3.2 - 6.4 mm in size, except the 3mm aperture monitoring bore which used 6.4-10mm graded gravel.

Vibrating Wire Piezometer (VWPs)

Grouting and instrumentation of VWPs was carried out by Foraco Fluid Potential in November 2017. Table 3 summarises the VWP installation details including depths and formations. All VWPs were sleeved using 50mm PVC by BDC. The multiple sensors were installed post drilling and sleeving activities and grouted up to the surface. A Quattro logger and tripod standard headworks were installed for downloading VWP data. Sensors recording frequency was set to record every 6 hours.

3.3 Geophysics

Gamma and Gyro geophysical surveys were conducted by BDC using the Driller Operated Gamma and Gyro Survey (DOGGS) tools provided by Reflex. Post drilling and construction, geophysical surveys were completed on all production bores in casing. Production bore geophysical surveys were carried out by Kinetic as outlined in the Scope of Works. The geophysics survey reports are presented in Appendix C.

3.4 Water quality

Water quality samples were collected after the end of airlifting activities for all monitoring and production bores. VWP locations were not developed and were not sampled. Any bores not sampled during the program were dry after a short period of airlifting. Sampled were tested for the hydro-geochemical parameters as per the Scope of Works. Hydro-geochemical analysis was completed by ALS environment Laboratory. Certificate of analysis are presented in Appendix D.

3.5 Summary of Field Program Learnings

While the field campaign was executed safely and successfully, a key number of learnings can be taken away from the program. Detailed below are some of the key learnings from Mesa H.

Mesa H Key Learnings

- MB17MEH0012 was planned as a nested piezo but was only constructed as a single piezo due to surfacing casing going to 40m and hence sealing off the CID unit Also, the CID is largely unsaturated. This was due to a large cavity encountered the adjacent monitoring bore.
- MB17MEH0011 was not drilled to planned depth of 110m due to a large cavity between 28 and 62 mbgl and 100% circulation loss. As this location is on the edge of the cliff, it can be assumed this cavity may have external lateral extents to the cliff face. Drilling further away from the cliff face showed there was no cavity there.
- MB17MEH0015 was installed as a 3mm 50mm PVC aperture and course gravel (6.4-10mm) to enable stygofauna surveys. Consequently, airlift had to be abandoned due to excessive silt and due to fear of clogging up the hole. Large aperture bores will allow elevated silt inflow during airlift, especially along the creek bed.
- WB17MEH0005 produced significantly more water than anticipated and was airlifted at 36 L/s. Despite the presence of black shale in the water, the bore was able so sufficiently clean up.

- HM17MEH0003 (17MEH_VW01) encountered significant fallback to37 mbgl from the drilled depth of 110m. It fell back to approximately the top of the clay sequence. The PVC casing was installed to depth using hollow rods. The PVC stayed open for the subsequent installation of the VWP and grouting.
- HM17MEH0001 (17MEH_VW01) and a number of other holes were drilled 16m shorter as basement which was fresh crystalline dolomite was encountered earlier than expected. Other basement contacts included Marra Mamba BIFs and shales.
- Significant clay bands of up to 12m thick were encountered at Mesa H. However these did not pose hole stability issues during mud drilling. Holes stayed open and there were no installation issues.
- Monitoring Bore MB17MEH0011 encountered significant circulation loss (29-62 mbgl), yet it took significantly less gravel than expected given the cavity. This indicates that most lost circulation at Warramboo is more likely a result of fractures and smaller voids, rather than “large cavities”.
- Drilling exploratory monitoring bores with mud limited ability to accurately measure yields and hence make it difficult to pick the best locations for production bores.
- A few locations where dual nested bores were planned have been changed to single installation due to lithology and lack of saturated aquifer thickness. This highlights geological uncertainties within Mesa H.
- Slow penetration rates in fresh basement rocks, especially dolomite. Penetration rates were as low as 2.5m/hr.
- Although the area was classified as fibrous likely, there were no fibrous materials intercepted.
- The use of threaded casing was successfully trailed at Mesa H.
- Deep water crossings and steep terrain posed significant hazards but were managed as per existing procedures and no safety incidents were reported.
- Exploratory monitoring holes/targets for production bores need to be drilled with CH or RC to accurately measure yields and select the best possible target for PBs
- PB bores installations, need to install slots well below water table to stop air getting into the hole and reduce turbulence during test pumping.
- Threaded casing was trialled successful
- Drilling in the pit posed challenges due to operational constraints. Time was lost due to waiting for escorts into and out of the pit.
- Incorporate terrain and discharge management plan into sump designs for potentially high yielding areas.

Section 4 - Test Pumping

4.1 Test Pumping Plan and Methods

Test pumping was conducted by McArthur Drilling and Test Pumping (MDP). The program consisted of a step rate test (SRT) and constant rate test (CRT) for 5 production bores within Mesa H in November 2017. All 5 production bores had 12" diameters. Figure 5 show the location of the production bores tested.

Test pumping objectives consisted of:

- Observe local drawdown in groundwater levels resulting from test pumping to further understand aquifer parameters to support Mesa J / H aquifer water supply capacity in the Southern Cutback borefield area; and
- Access aquifer parameters and bore hydraulics to support the Mesa H construction provisory camp water supply.

To measure water levels within the production bore, two dip tubes attached to the rising main in the pumping bore were utilised. Water levels in monitoring bores were measured with a combination of manual dipping and automated data loggers.

Test pumping involved the following:

- A calibration test to ensure all equipment was functional and to provide an indication of possible flow rates.
- Step drawdown rate test (SRT): Consisting of 5 x 60 or 100 minute tests with increasing yield rates to provide data for bore efficiency assessment and to determine an appropriate pumping rate for the constant rate test.
- Constant rate test (CRT): Consisting of a 24 hour test to provide data for estimation of aquifer properties. WB17MEH0001 had a 30 day test.
- Water sampling after one hour of pumping during the CRT for water quality analysis.
- At CRT cessation, water levels in the production bore were monitored until water level recovery reached 90% of the pre CRT water level.

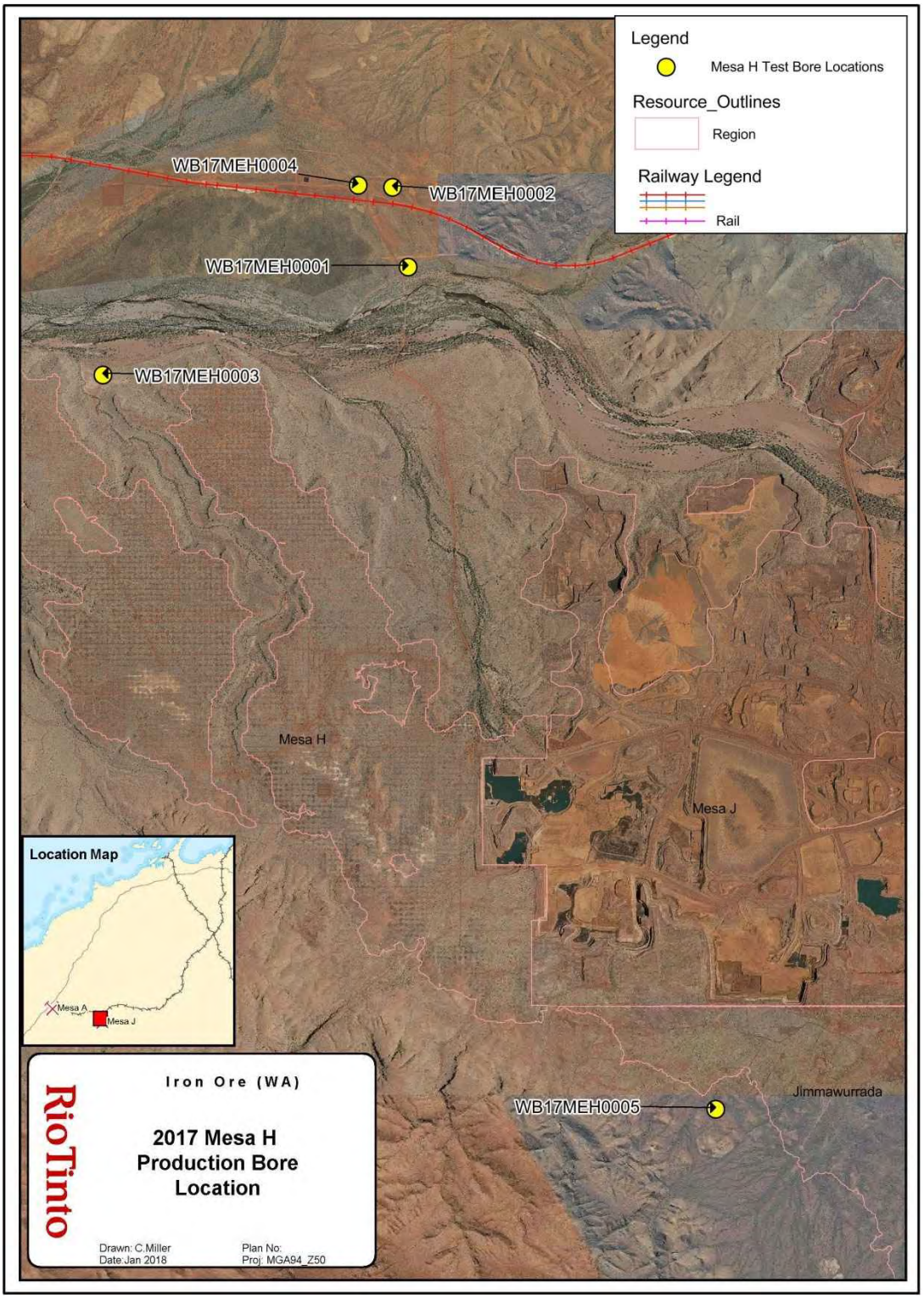

Figure 5: Mesa H production test bore locations

4.1 Aquifer Test Summary

The Hantush-Bierschenk analysis was used to analyse the step rate test data to determine the apparent well efficiency. The step test pumping rates were used to determine the pumping rate for the constant rate test.

The Constant Rate test drawdown results presented a combination of unconfined and semi-confined (leaky) aquifer response. In order to analyse the drawdown response and obtain aquifer paramentes the Moench (unconfined) and the Hantush-Jacob (leaky) solutions were chosen to match the curves.

A review of the test pumping results indicates the following:

- All bores presented a relatively low well loss ranging between $1x10^{-4}$ and $2x10^{-7}$.
- Hydraulic conductivity of the Alluvium ranges between 10.54 and 71.49 m/day.
- Hydraulic conductivity and storage coefficient of Dolomite was 44.9 m/day $6.39E^{-5}$.
- Hydraulic conductivity and storage coefficient of fractured BIF was 568 m/day $6.203E^{-5}$.
- No bores were screened exclusively within CID and therefore CID hydraulic conductivity and storage coefficient can't be estimated.
- WB15MEH0005 displayed accelerated drawdown towards the later portion of the test that indicates a boundary response most likely due to outcropping unmineralised Brockman Formation in the south.

A 30 days CRT test was carried out for WB17MEH0001 to access boundary conditions and for the purpose of a discharge trial to support drawdown mitigation strategies of the Robe River Pools. Although the bore was showing signs of development during the initial stages of the test (at 18 L/s and reduced later to 16 L/s); results indicates:

- hydraulic conductivity of ~70 m/day with a max drawdown lesser than 3m after 30 days, and an associated specific yield of 33%;
- A boundary response was displayed in MB17MEH0007 after 30000 minutes that resulted in an sharp drop in the water level as can be observed in Figure 6.

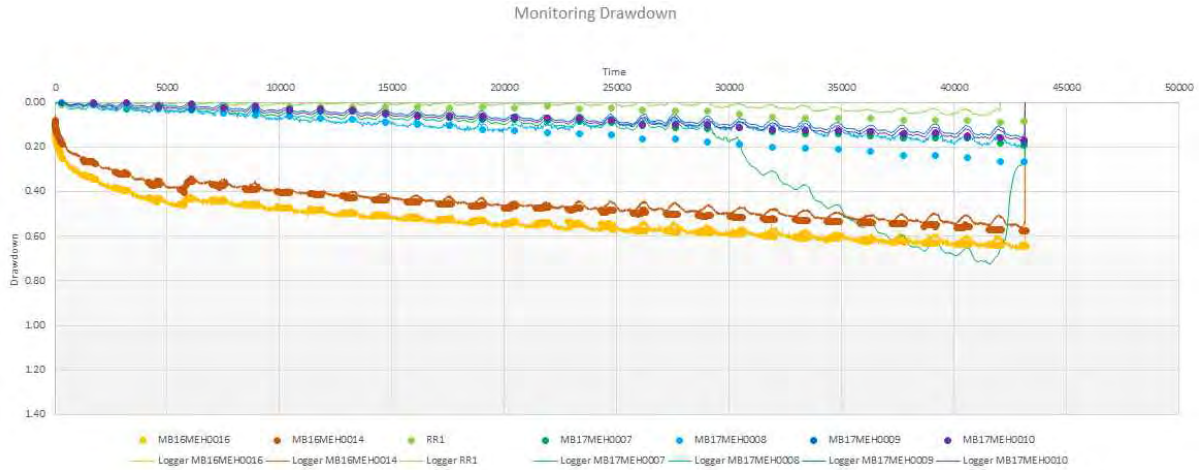

Figure 6: WB17MEH0001 CRT drawdown curves

Table 4 and Table 5 shows the summary of the step drawn-down test and constant rate test results. CRT drawdown curves and analysis using AQTSOLVE is presented in Appendix B.

Section 5 - Conclusions and Recommendations

The 2017 Mesa H hydrogeological program was executed within the approved budget and without incident. A combination of drilling techniques was successfully used to complete drilling activities including Air hammer and mud rotary methods. Through drilling and test pumping an increased understanding of the Mesa H Conceptualisation has been achieved. Conceptual gaps identified in the PFS in 2016 have been addressed with positive conceptualisation outcomes regarding areas of significant cultural and environmental value. Drilling and test pumping will be used to update and refine the Mesa H Conceptual and numerical model as part of the Mesa H FS requirements.

Water supply exploration had varying success for identifying potential future production supply locations. This is largely due to varying presence of fractured and weathered geology profiles which influenced yields in locations of similar geology. This variance and discontinuity in the geology will make it difficult to target future supply locations to meet water supply requirements.

The Robe River discharge trial confirmed an inferred aquifer boundary to the north of the Robe River, and will be valuable to assess hydraulic and engineering designs for the Robe River pools impact and associated mitigation strategy.

Table 1 Bore Locations Mesa H

Bore ID	Peg ID	Surveyed Easting (MGA)	Surveyed Northing (MGA)	Surveyed Ground Level mRL (m AHD)	Surveyed TOC mRL (m AHD)
Monitoring Bores					
MB17MEH0001	17MEH_MB06	420764.006	7591282.880	178.376	179.090
MB17MEH0004	17MEH_MB08	421705.351	7590918.035	174.947	175.681
MB17MEH0005	17MEH_MB09	421909.743	7590687.074	177.221	177.934
MB17MEH0006	17MEH_MB10	422272.376	7590689.111	178.401	179.201
MB17MEH0007	17MEH_MB04	417658.827	7600422.641	134.828	135.714
MB17MEH0008	17MEH_MB02	417119.022	7600417.544	134.784	135.477
MB17MEH0009	17MEH_MB01	416434.642	7599847.256	131.526	132.316
MB17MEH0010	17MEH_MB16	416447.194	7599849.354	131.704	132.466
MB17MEH0011	17MEH_MB05	414868.454	7596153.963	165.542	166.313
MB17MEH0012	17MEH_MB17	414881.979	7596152.854	165.589	166.430
MB17MEH0013	17MEH_MB12	418380.559	7599440.612	135.787	136.493
MB17MEH0014	17MEH_MB11	418723.950	7599428.420	136.890	137.609
MB17MEH0015	17MEH_MB015	416044.945	7597712.125	132.166	132.935
Nested Piezometres					
MB17MEH0002	17MEK_MB01	421409.959	7591295.997	173.672	174.158
MB17MEH0003	17MEK_MB01	421409.925	7591295.954	173.672	174.25
Vibrating Wire Piezometres (VWP)					
HM17MEH0001	17MEH_VW02	416034.012	7597714.217	TBC	132.378
HM17MEH0003	17MEH_VW01	414982.062	7596143.524	TBC	165.239
Production Bores					
WB17MEH0001	17MEH_PB02	418857.053	7598693.336	138.982	139.413
WB17MEH0002	17MEH_PB06	418711.747	7599423.723	136.836	137.194
WB17MEH0003	17MEH_PB03	416059.508	7597705.964	132.067	132.438
WB17MEH0004	17MEH_PB05	418388.056	7599451.981	135.829	136.356
WB17MEH0005	17MEH_PB04	421699.218	7590927.611	174.871	175.267

** Key: D = Deep Piezometre. S: Shallow Piezometre. NA: Not Applicable

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Table 2 Mesa H Water levels and Yields

Bore ID	Peg ID	Initial SWL (mBTOC)	Initial SWL (mAHD)	Peak Bore Development Airlift Yield (L/s)
Monitoring Bores				
MB17MEH0001	17MEH_MB06	44.510	134.580	TBC
MB17MEH0004	17MEH_MB08	41.080	134.601	1.000
MB17MEH0005	17MEH_MB09	40.800	137.134	1.500
MB17MEH0006	17MEH_MB10	41.540	137.661	0.500
MB17MEH0007	17MEH_MB04	7.620	128.094	TBC
MB17MEH0008	17MEH_MB02	7.150	128.327	0.500
MB17MEH0009	17MEH_MB01	5.910	126.406	1.200
MB17MEH0010	17MEH_MB16	6.000	126.466	1.100
MB17MEH0011	17MEH_MB05	49.850	116.463	TBC
MB17MEH0012	17MEH_MB17	49.950	116.480	TBC
MB17MEH0013	17MEH_MB12	7.030	129.463	TBC
MB17MEH0014	17MEH_MB11	8.090	129.519	2.000
MB17MEH0015	17MEH_MB015	8.830	124.105	TBC
Nested Piezometres				
MB17MEH0002	17MEH_MB07	38.180	135.978	0.25
MB17MEH0003	17MEH_MB07	39.840	134.410	0.1
Vibrating Wire Piezometres (VWP)				
HM17MEH0001	17MEH_VW02	NA	NA	NA
HM17MEH0003	17MEH_VW01	NA	NA	NA
Production Bores				
WB17MEH0001	17MEH_PB02	8.880	130.533	10
WB17MEH0002	17MEH_PB06	7.360	129.834	5
WB17MEH0003	17MEH_PB03	8.460	123.978	6
WB17MEH0004	17MEH_PB05	6.860	129.496	12
WB17MEH0005	17MEH_PB04	40.600	134.667	36
** Key: D = Deep Piezometre. S: Shallow Piezometre. NA: Not Applicable				

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Table 3 Construction Details Mesa H

Start Date	Completion Date	Drilled Depth	Cased Depth	Casing Details	Bore Type	Drilling Method	Collar Casing Diameter (mm)	Cased Collar Depth (m bgl)	Hole Diameter (mm)	Slotted Interval (m bgl)
20/08/2017	22/08/2017	104.000	95.000	PVC 50mm	MB: Single	MR	254.000	12.000	215.900	29-95
23/08/2017	26/08/2017	90.000	87.500	PVC 50mm	MB: Single	CH/MR	254.000	18.000	215.900	51.5-87.5
26/08/2017	27/08/2017	86.000	81.000	PVC 50mm	MB: Single	MR/CH	254.000	18.000	215.900	69-81
26/08/2017	28/08/2017	80.000	xx	PVC 50mm	MB: Single	MR/CH	254.000	18.000	215.900	xx
28/08/2017	29/08/2017	30.000	30.000	PVC 50mm	MB: Single	MR/CH	254.000	6.000	215.900	12-30.0
28/08/2017	29/08/2017	18.000	18.000	PVC 50mm	MB: Single	CH	254.000	6.000	215.900	12-18.0
29/08/2017	30/08/2017	43.000	41.000	PVC 50mm	MB: Single	CH	254.000	5.000	215.900	29-41
30/08/2017	31/08/2017	30.000	30.000	PVC 50mm	MB: Single	CH	254.000	xx	215.900	9-30.0
24/10/2017	29/10/2017	62.000	59.000	PVC 50mm	MB: Single	CH	254.000	4.000	215.900	47-59
25/10/2017	28/10/2017	116.000	80.000	PVC 50mm	MB: Single	CH	254.000	40.000	215.900	56-80
30/10/2017	1/11/2017	43.000	42.000	PVC 50mm	MB: Single	CH/MR	254.000	12.000	215.900	12-42.0
27/10/2017	29/10/2017	43.000	42.000	PVC 50mm	MB: Single	CH	254.000	18.000	215.900	18-42
2/11/2017	3/11/2017	37.000	30.000	PVC 50mm (3mm)	MB: Single	MR	254.000	3.000	215.900	12-30.0
20/08/2017	22/08/2017	80	79	PVC 50mm	MB: Nested	CH	203.2mm	18	215.9	61-79
20/08/2017	22/08/2017		48	PVC 50mm	MB: Nested					36-48
18/08/2017	19/08/2017	44.000	44.000	PVC 50mm	VWP: Multi Sensor	MR	254	xx	xx	39-44
28/08/2017	30/10/2017	110.000	110.000	PVC 50mm	VWP: Multi Sensor	CH	203.2	5	190.5	14-104
23/08/2017	26/08/2017	46.00	40.000	Threaded Steel 304.80mm	PB	CH	xx	xx	444.5	10-28.0
31/10/2017	3/11/2017	50.00	40.000	Threaded Steel 304.80mm	PB	MR	473.075	16	444.5	16-34
4/11/2017	11/11/2017	36.00	36.000	Threaded Steel 304.80mm	PB	MR	558.8	2	444.5	18-30
7/11/2017	10/11/2017	50.00	46.000	Threaded Steel 304.80mm	PB	MR	508	7	444.5	10-40.0
14/11/2017	19/11/2017	106.00	104.000	Threaded Steel 304.80mm	PB	MR	558.8	2	444.5	74-98

ore, VWP - Vibrating Wire Piezometer, MR - Mud Rotary, CH - Conventional Hammer Air

Table 4 Summary step rate testing at Mesa H

Bore ID	Number of steps	Step Duration (minutes)	Discharge Rates (L/s)	Bore Apparent Well Loss	Bore Equation
WB17MEH0001	5	100 each, 20 mins @ 20L/s	12, 14, 16, 18, 20		
WB17MEH0002	5	60 each, 20 mins @ 6.5L/s	4.5, 5, 5.5, 6, 6.5	1.304E-04	y = 1.304E-04x - 2.547E-02
WB17MEH0003	5	60	4, 6, 8, 10, 12	6.148E-06	y = 6.148E-06x + 4.626E-03
WB17MEH0004	5	60	10, 12, 14, 16, 18	8.651E-06	y = 8.651E-06x - 4.253E-03
WB17MEH0005	5	60	29, 34, 39, 44, 49	2.134E-07	y = 2.134E-07x + 3.475E-06

Table 5 Mesa H CRT summary

Test Bore	Diameter	Observation Bore	Distance from test bore	Discharge Rate (L/s)	CRT Duration (min)	Screened Unit	Aquifer Type	Max Drawdown (m)	Transmissivity (m^2/day)	Hydraulic Conductivity (m/day)	Storage Coefficient/ Specific Yield
WB17MEH0001	12″	WB17MEH0001	-	18L/s until 5760 mins, changed to 16L/s until 43200 mins	43200	Alluvium	Unconfined	4.1m @ 18L/s, 2.7m @ 16L/s	1013.2	52.77	3.843E-8
	50mm	MB16MEH0016	10.7m			Alluvium & CID		0.5m @ 18L/s, 0.7m @ 16L/s	1649.7	109.54	1.938E-5
	50mm	MB16MEH0014	14m			CID & Dolomite		0.4m @ 18L/s, 0.6m @ 16L/s	2027.6	36.79	3.011E-3
	50mm	MB17MEH0007	2105m			Dolomite		0.7m @18L/s by 1440mins	NA	NA	NA
	50mm	MB17MEH0008	2457m			Dolomite		0.2m @ 18L/s by 1440mins	NA	NA	NA
	50mm	MB17MEH0009	2682m			Dolomite		0.2m @ 18L/s by 1440mins	NA	NA	NA
	50mm	MB17MEH0010	2671m			CID & Clay		0.2m @ 18L/s by 1440mins	NA	NA	NA
WB17MEH0002	12″	WB17MEH0002	-	5.5	1440	Alluvium & Conglomerate	Leaky	16.8	9.418	0.523	6.448E-3
	50mm	MB17MEH0014	13m			Alluvium, CID & Dolomite		0.5	220.7	6.49	1.931E-3
	50mm	MB17MEH0013	333m			BIF		0	-	-	-
WB17MEH0003	12″	WB17MEH0003	-	10	1440	Alluvium	Unconfined	8.9	227.1	10.54	1.294E-6
	50mm	MB17MEH0015	15m			Alluvium		0.8	1513.4	71.49	1.012E-5
WB17MEH0004	12″	WB17MEH0004	-	15	1440	Dolomite	Unconfined	10.8	44.9	1.35	6.39E-5
WB17MEH0005	12″	WB17MEH0005	-	45	1440	BIF	Unconfined	4.2	568	17.14	6.203E-5

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Appendix A - Borehole Logs

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Bore Completion Details

HM17MEH0001

PROJECT: MESA H
LOCATION: Mesa H
DATE COMMENCED: 18/08/2017
DATE COMPLETED: 19/08/2017

DRILLING COMPANY: BDC
DRILLER: Luke Wallace
DRILLING METHOD: Mud Drilling
HYDROGEOLOGIST: Y. Alaak

GRID NAME: MGA94_50
EASTING: 416034.012
NORTHING: 7597714.217
ELEVATION: 132.378 mRL TOC

Well Notes: Collar Mud Rotary 0-1m using 12 1/4" drill bit, collar installed 8" steel casing 0-3m. Mud drilling 0-44m using 8 1/2" drill bit.

Depth mbgl	Geology	Lithology	Lithological Description	Gamma 0-100cps	Field Notes	Construction Details
0–15	Alluvium		ALLUVIUM: Alluvials composed of rounded to sun-rounded gravels with sand and clay infills. trace tragments of cherts, shales and pisolites present			50mm Blank PVC (0-3 mbgl)
15–35	CID		TPM: Moderately weathered red clayey and yellow orcherous goethite with.40% vitreous goethite, red brown sand and silts, angular to sub angular		SWL = 19 mbgl	VW17MEH0001 (15 mbgl)
15–35	CID		TPB: Weathered tertiary orcherous goethite and vitrous goethite, yellow, brown and white plastic clays with pislotic clasts of goethite. Increasing plasticity towards end of interval. clay content @ 20-30%			50mm Slotted PVC (3-39 mbgl)
35–40	Whitnoom Dolomite		DOLOMITE: Fresh chrystaline dolomite. light to dark blue, angular to sub-angular, hard to very hard hard. weathered zone at 40-42 mbgl			VW17MEH0002 (37 mbgl)
40						VW17MEJ0003 (40 mbgl)

Bore Completion Details HM17MEH0002

PROJECT: MESA H	**DRILLING COMPANY:** BDC	**GRID NAME:** MGA94_50
LOCATION: Mesa H	**DRILLER:** Joe Mason	**EASTING:** 421409.959
DATE COMMENCED: 20/08/2017	**DRILLING METHOD:** ROTARY HAMMER - AIR	**NORTHING:** 7591295.997
DATE COMPLETED: 22/08/2017	**HYDROGEOLOGIST:** YUOT ALAAK	**ELEVATION:** 174.158 mRL

Well Notes: Mud Rotary Collar 0-18m using 12 1/2" drill bit and installed 10" casing 0-17m. Mud drilled with 8 1/2" drill bit 18 - 80m (EOH). Deep piezometer MB17MEH0002, Shallow piezometer MB17MEH0003

Depth mbgl	Geology	Lithology	Lithological Description	Gamma 0-300cps	Field Notes	Construction Details
0	CID		CID: Weathered vitrous geothite and red clays. weathered pisloites. CID largely unsaturated			Bentonite (0 - 0.5 mbgl)
5						
10						8" Blank Steel (0-17 mbgl)
15						
20						
25						
30						50mm Blank PVC (0-36, 0-61 mbgl)
35	Clay		CLAY: Highly weathered white tertiary clays, resembling calcrete. Unsaturated and highly powdery. Highly plastic when saturated.		SWL Deep - (38.18 mbgl) SWL Shallow - (39.84 mbgl)	
40						50mm Slotted PVC (36 - 48 mbgl)
45					Deep Piezo Final Airlift - Yield - 0.25 L/s pH - 8.4 EC - 964 uS/cm Temp - 30.5 0C	End Cap (48 mbgl)
50						Bentonite Seal (48-52 mbgl)
55	Whitnoom Formation (Paraburdoo Dolomite)		WITTENOOM DOLOMITE: Fresh cyrstalline dolomite, sub-angular to angular, slightly fractured horizon from 60-65 but no significant increase in yields. evidence of contamination from overlaying CID in the chips. Very slow penetration through competent dolomite		FWS = 53 mbgl	
60					Field Chem (@60 mbgl EC=1021, pH=8.2, Temp = 32.8)	
65						
70					Field Chem (@66 mbgl EC=1118, pH=8.6, Temp = 32.8)	50mm Slotted PVC (61-79 mbgl)
75					Field Chem (@72 mbgl EC=1098, pH=8.2, Temp = 32.8)	End Cap (79 mbgl)
80						Fallback (79 - 80 mbgl))

Bore Completion Details

MB17MEH0001

PROJECT: MESA H	**DRILLING COMPANY:** BDC	**GRID NAME:** MGA94_50
LOCATION: Mesa H	**DRILLER:** Manu Rekena	**EASTING:** 420764.006
DATE COMMENCED: 20/08/2017	**DRILLING METHOD:** ROTARY HAMMER - AIR	**NORTHING:** 7591282.880
DATE COMPLETED: 22/08/2017	**HYDROGEOLOGIST:** Y. Alaak	**ELEVATION:** 179.090 mRL TOC

Mud drilled using 12 1/2" drill bit 0 - 16m and installed 8" surface casing 0-16 mbgl. Mud drilled 16-104 (EOH) using 8 1/2" bit

Depth mbgl	Geology	Lithology	Lithological Description	Gamma 0-210cps	Field Notes	Construction Details
0	CID		CID: Tertiary mixed pisolites, red to to reddish brown. 80% vitrous goethite with 10% sand and silts infill. trace orcherous goethite, angular to sub-angular and medium hard, slightly weathered			Bentonite (0 - 0.5 mbgl)
5						
10						8" Blank Steel (0-12 mbgl)
15						
20						50mm Blank PVC (0-29 mbgl)
25					SWL = 25 mbgl	
30					Final Airlift - Yield - 3 L/s pH - 8.6 EC - 1108 uS/cm Temp - 8.6 0C	
35			CID: TPB: Tertiary mixed piolites, red to reddish brown. Increased clay content.			Gravel (3.2-6.4mm) (0.5 - 95 mbgl)
40						
45	Wittenoom Formation (Bee Gorge)		SHALE/BIF: Weathered shales, dark to blue with 20-30% clay content. angular to sub-angular clay, medium hard. Fragments of BIF mostly composed of cherts and some quartz trace.			
50					Field Chem (@86 mbgl EC=1001, pH=7.8, Temp = 34)	50mm Slotted PVC (29-95 mbgl)
55						
60					Field Chem (@92 mbgl EC=1209, pH=8.2, Temp = 34)	
65						
70					Field Chem (@98 mbgl EC=1108, pH=8.6, Temp = 34)	
75						
80					FWS = 81 mbgl	
85	Wittenoom Formation (Paraburdoo Dolomite		WITTENOOM DOLOMITE: Fresh chrstalline dolomite, light to dark blue, angular to sub-angular, hard to medium hard. Slightly fractured towards end of hole			
90						
95						End Cap (95 mbgl)
100						Fallback (95 - 104 mbgl))

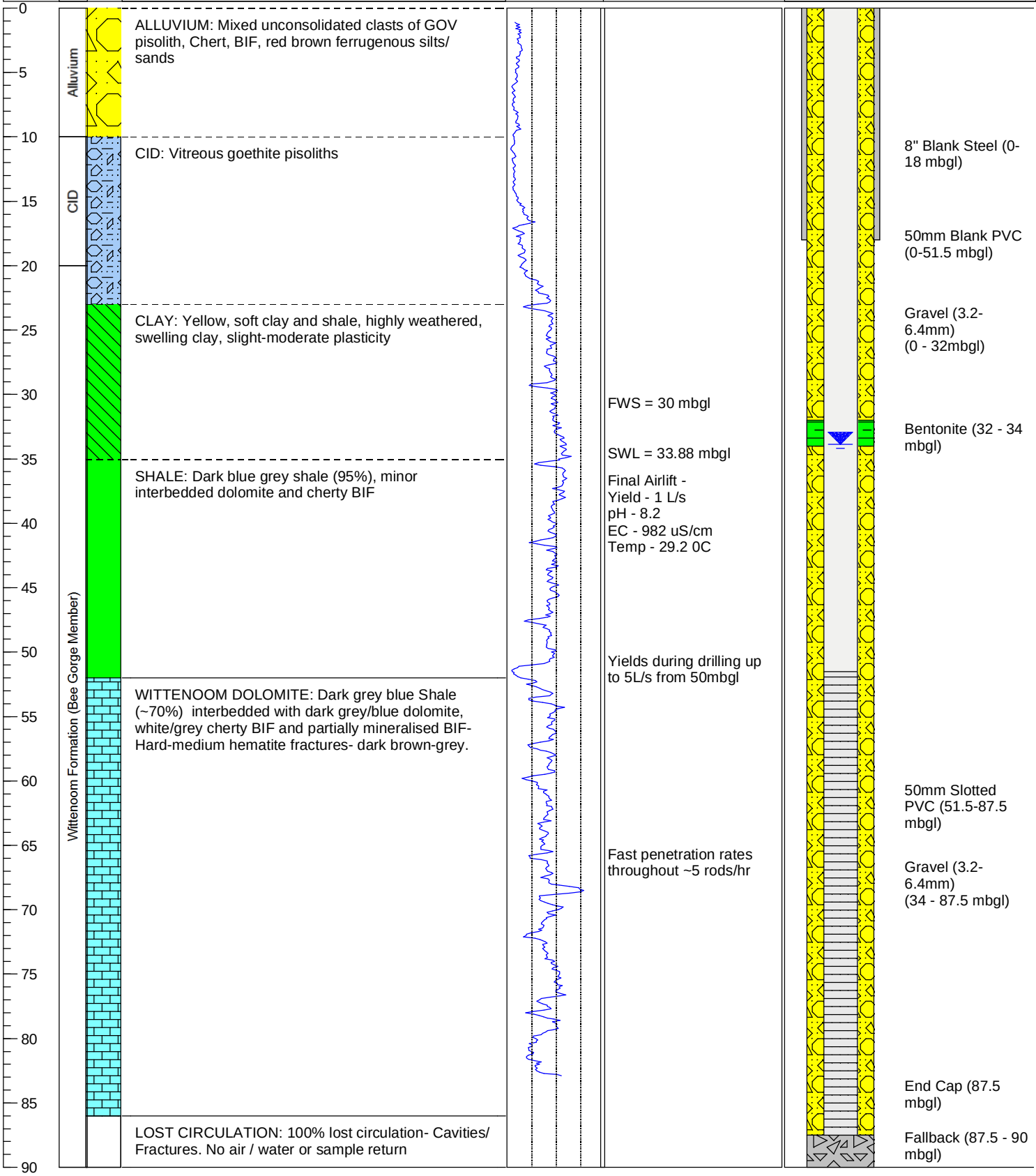
Bore Completion Details

MB17MEH0004

PROJECT: MESA H
LOCATION: Mesa H
DATE COMMENCED: 23/08/2017
DATE COMPLETED: 25/08/2017
DRILLING COMPANY: BDC
DRILLER: Luke Wallace
DRILLING METHOD: ROTARY HAMMER - AIR
HYDROGEOLOGIST: C. Miller
GRID NAME: MGA94_50
EASTING: 421705.351
NORTHING: 7590918.035
ELEVATION: 175.681

Mud rotary with 12 1/4" drill bit 0-18m for 8" Collar, Air hammer 6 1/2" drill bit from 18-90m (EOH)

Depth mbgl	Geology	Lithology	Lithological Description	Gamma 0-200cps	Field Notes	Construction Details
0	Alluvium		ALLUVIUM: Mixed unconsolidated clasts of GOV pisolith, Chert, BIF, red brown ferrugenous silts/ sands			
10	CID		CID: Vitreous goethite pisoliths			8" Blank Steel (0-18 mbgl)
20						50mm Blank PVC (0-51.5 mbgl)
25			CLAY: Yellow, soft clay and shale, highly weathered, swelling clay, slight-moderate plasticity			Gravel (3.2-6.4mm) (0 - 32mbgl)
30					FWS = 30 mbgl	
35			SHALE: Dark blue grey shale (95%), minor interbedded dolomite and cherty BIF		SWL = 33.88 mbgl Final Airlift - Yield - 1 L/s pH - 8.2 EC - 982 uS/cm Temp - 29.2 0C	Bentonite (32 - 34 mbgl)
40						
45	Wittenoom Formation (Bee Gorge Member)					
50					Yields during drilling up to 5L/s from 50mbgl	
55			WITTENOOM DOLOMITE: Dark grey blue Shale (~70%) interbedded with dark grey/blue dolomite, white/grey cherty BIF and partially mineralised BIF- Hard-medium hematite fractures- dark brown-grey.			
60						50mm Slotted PVC (51.5-87.5 mbgl)
65					Fast penetration rates throughout ~5 rods/hr	Gravel (3.2-6.4mm) (34 - 87.5 mbgl)
70						
75						
80						
85						End Cap (87.5 mbgl)
90			LOST CIRCULATION: 100% lost circulation- Cavities/ Fractures. No air / water or sample return			Fallback (87.5 - 90 mbgl)



Bore Completion Details

MB17MEH0005

PROJECT: Mesa H	**DRILLING COMPANY:** BDC	**GRID NAME:** MGA94_50
LOCATION: Mesa H	**DRILLER:** Luke Wallace	**EASTING:** 421909.743
DATE COMMENCED: 26/08/2017	**DRILLING METHOD:** ROTARY HAMMER - AIR	**NORTHING:** 7590687.074
DATE COMPLETED: 27/08/2017	**HYDROGEOLOGIST:** C. Miller	**ELEVATION:** 177.934 mRL TOC

Mud rotary with 12 1/4" drill bit 0-18m for 8" Collar, Air hammer 6 1/2" drill bit from 18-86m (EOH)

Depth mbgl	Geology	Lithology	Lithological Description	Gamma 0-250cps	Field Notes	Construction Details
0	Alluvium		ALLUVIUM: mixed pisolith, weathered detrital materials and ferrugenous sediments, limonite, GOV and silt and sileous material			Bentonite (0-2 mbgl)
5	CID		CID: weathered, limonitic goethite, fine limonite throughout, GOV clasts, weathered limonitic coatings			
10	Mt. McRae Shale		CLAY: Yellow/white clay, highly weathered Shale, competent soapy fragments throughout			
15						8" Blank Steel (0-18mbgl)
20					FWS = 20 mbgl	
25			BLACK SHALE: Fresh saturated black shale with some pyrite, minor chert bands interbedded			
30						Gravel (3.2-6.4mm) (2 - 86mbgl)
35						
40					SWL = 40.8 mbgl	
45						50mm Blank PVC (0-69 mbgl)
50					Final Airlift - Yield - 0.3 L/s pH - 8.1 EC - 839uS/cm Temp - 31.7 C	
55					Yields during drilling up to 3L/s from 62mbgl	
60						
65			CHERT: Chert Band- Black/grey hard			
70			BLACK SHALE: Fresh saturated black shale with some pyrite, minor chert bands interbedded, increased fracturing from 70mbgl, larger fragmentation and sample returns with white/ yellow weathered shale clasts		Fast penetration rates throughout ~5 rods/hr	50mm Slotted PVC (69-81 mbgl)
75						
80						PVC endcap (81 mbgl)
85					No reported drilling issues	Fallback (81-86 mbgl)

Bore Completion Details

MB17MEH0006

PROJECT: Mesa H	**DRILLING COMPANY:** BDC	**GRID NAME:**	MGA94_Z50
LOCATION: Mesa H	**DRILLER:** Luke Wallace	**EASTING:**	422272.376
DATE COMMENCED: 26/08/2017	**DRILLING METHOD:** Mud Rotary and Air Hammer	**NORTHING:**	7590689.111
DATE COMPLETED: 28/08/2017	**HYDROGEOLOGIST:** C. Miller	**ELEVATION:**	179.201

0-18m Mud Rotary for Collar installation, Air Hammer to EOH 80m

Depth mbgl	Geology	Lithology	Lithological Description	Gamma 0-250cps	Field Notes	Construction Details
0–80	Robe Pisolite		CID: Dark grey, medium hard vitreous goethite chip matrix with goethite pisolith and yellow brown limonite clay			Bentonite (0-2 mbgl)
						8" Blank Steel (0-18mbgl)
			TPB: Predominantly highly weathered ochreous and white clay matrix with vitreous goethite pisolith clasts mixed with angular- sub angular chert and dolomite fragments thoughout			50mm Blank PVC (0-41 mbgl)
						Gravel (3.2-6.4mm) (2 - 54mbgl)
					FWS = 38 mbgl	
					SWL= 41.574 mbgl	
					Final Airlift - Yield - 3 L/s pH - 8.4 EC - 935 uS/cm Temp - 30.3 0C	50mm Slotted PVC (41-53 mbgl)
	Mt Mc Rae Shale		BLACK SHALE: soft- competent saturated black shale, possibly pyritic with minor chert		Yields during drilling up to 2L/s	PVC endcap (53 mbgl)
						Bentonite (54-56 mbgl)
					Fast penetration rates throughout ~5 rods/hr	Gravel (3.2-6.4mm) (56-80 mbgl)
					No reported drilling issues	

Bore Completion Details

MB17MEH0007

PROJECT: Mesa H
LOCATION: Mesa H
DATE COMMENCED: 28/08/2017
DATE COMPLETED: 29/08/2017
DRILLING COMPANY: BDC
DRILLER: Luke Wallace
DRILLING METHOD: Air Hammer
HYDROGEOLOGIST: C. Miller
GRID NAME: MGA94_Z50
EASTING: 417658.827
NORTHING: 7600422.641
ELEVATION: 135.714 mRL TOC

Air Hammer 0-30m Drill bit 6 1/2" from 0-31m. Collar 12 1/4" drill bit from 0-6m.

Depth mbgl	Geology	Lithology	Lithological Description	Gamma 0-100cps	Field Notes	Construction Details
0			COLLUVIUM: red brown ferrugenous silt and sands, with minor clasts of chert, pisolith and dolomite			Bentonite (0-2 mbgl)
5			ALLUVIUM: increased GOV matrix clasts chips with sub rounded white and grey chert and dolomite		SWL = 7.62 mbgl	8" Blank Steel (0-6mbgl)
10			WITTENOOM DOLOMITE: Fractured, slightly weathered crystalline dolomite		FWS = 12 mbgl	50mm Blank PVC (0-12 mbgl)
15			WITTENOOM DOLOMITE: Hard fresh crystalline dolomite		Final Airlift - Yield - 1.2 L/s pH - 7.56 EC - 1288 uS/cm Temp - 25 0C	50mm Slotted PVC (12-30 mbgl)
20					Yields during drilling up to 10L/s	Gravel (3.2-6.4mm) (2 - 30mbgl)
25					Drilling difficult at fracture zone from 10-14mbgl	
30					Drilling in fresh Basement 12m/hr	PVC endcap (30 mbgl)

Bore Completion Details

MB17MEH0008

PROJECT: Mesa H
LOCATION: Mesa H
DATE COMMENCED: 28/08/2017
DATE COMPLETED: 29/08/2017
DRILLING COMPANY: BDC
DRILLER: Luke Wallace
DRILLING METHOD: Air Hammer
HYDROGEOLOGIST: C. Miller
GRID NAME: MGA94_Z50
EASTING: 417119.022
NORTHING: 7600417.544
ELEVATION: 135.477 mRL TOC

Air Hammer drilled 0-6m and installed 8" collar. Air Drilled 6-18 (EOH) using 8 1/2" drill bit

Depth mbgl	Geology	Lithology	Lithological Description	Gamma 0-100cps	Field Notes	Construction Details
0			COLLUVIUM: red brown ferrugenous silt and sands, with minor clasts of chert, pisolith and dolomite			Bentonite (0-2 mbgl)
			DOLOMITE: Hard fresh crystalline dolomite			8" Blank Steel (0-6mbgl)
5					SWL = 7.15 mbgl	
					Yields during drilling up to 0.5L/s	50mm Blank PVC (0-12 mbgl)
10					FWS = 11 mbgl	
					Final Airlift - Yield - 0.5 L/s pH - 7.41 EC - 1288 uS/cm Temp - 24.40C	50mm Slotted PVC (12-18 mbgl)
						Gravel (3.2-6.4mm) (2 - 18mbgl)
15						PVC endcap (18 mbgl)

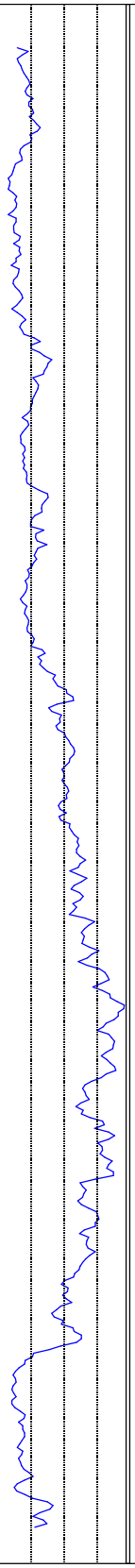
Bore Completion Details

MB17MEH0009

PROJECT: Mesa H
LOCATION: Mesa H
DATE COMMENCED: 29/08/2017
DATE COMPLETED: 30/08/2017
DRILLING COMPANY: BDC
DRILLER: Hayden Kent
DRILLING METHOD: Air Hammer
HYDROGEOLOGIST: C. Miller
GRID NAME: MGA94_Z50
EASTING: 416434.642
NORTHING: 7599847.256
ELEVATION: 132.316 mRL TOC

Air Hammer drilled 0-5m and installed 8" collar. Air Drilled 5-43 (EOH) using 8 1/2" drill bit

Depth mbgl	Geology	Lithology	Lithological Description	Gamma 0-100cps	Field Notes	Construction Details
0			COLLUVIUM: red brown ferrugenous silt and sands, with minor clasts of chert, pisolith and dolomite			Bentonite (0-2 mbgl)
5					Yields during drilling up to 1.2 L/s SWL = 5.92 mbgl	8" Blank Steel (0-6mbgl)
10					FWS = 11 mbgl	
15					Final Airlift - Yield - 1.2 L/s pH - 7.27 EC - 1266 uS/cm Temp - 25.80C	
20						
25						50mm Blank PVC (0-29 mbgl)
30			DOLOMITE: Hard fresh crystalline dolomite			Gravel (3.2-6.4mm) (2 - 41mbgl)
35						50mm Slotted PVC (29-41 mbgl)
40						PVC endcap (41mbgl) Fallback (41-43mbgl)



Bore Completion Details

MB17MEH0011

PROJECT: Mesa H
LOCATION: Mesa H
DATE COMMENCED: 24/10/2017
DATE COMPLETED: 29/10/2017
DRILLING COMPANY: BDC
DRILLER: Hayden Kent
DRILLING METHOD: Air Hammer
HYDROGEOLOGIST: Yuot Alaak
GRID NAME: MGA94_50
EASTING: 414868.454
NORTHING: 7596153.963
ELEVATION: 166.313 mRL

Air hammer drilled 0-4m with 12 1/4" drill bit, 8" steel collar installed 0-3m. Air hammer drilled 0-62m with 7 1/2" drill bit. Fallback 59-62m.

Depth mbgl	Geology	Lithology	Lithological Description	Gamma 0-100cps	Field Notes	Construction Details
0	CID		CID: TPH- Vitreous goethite with limonitic goethite, blue and brown, medium hardness, moderate weathering, angular to sub angular, fine gravel. Infilled with goethitic silt and sand.			Bentonite Seal (0-2 mbgl)
5						Blank Steel (0-4 mbgl)
10						
15						
20						Gravel (3.2-6.4mm)(2-59mbgl)
25			CID: Same as above with massive ocherous goethite 20-26m, less weathered 26-30 with large goethite pisolites in silt. 20-26m is predominantly silt and sand at 70%.			
30	Cavity		VOID: Cavity, no sample return from 30m.			50mm Blank PVC (0-47 mbgl)
35						
40						
45						50mm Slotted PVC (47-59 mbgl)
50					SWL = 49.85mbgl	SWL = 49.85mbgl
55						End Cap (59mbgl)
60						Fallback (59-62mbgl)

Bore Completion Details

MB17MEH0012

PROJECT: MESA H
LOCATION: Mesa H
DATE COMMENCED: 25/10/2017
DATE COMPLETED: 28/10/2017

DRILLING COMPANY: BDC
DRILLER: Hayden Kent
DRILLING METHOD: Rotary Hammer - Air
HYDROGEOLOGIST: Yuot Alaak

GRID NAME: MGA94_50
EASTING: 414881.979
NORTHING: 7596152.854
ELEVATION: 166.430 mRL TOC

Air drilled 0-40m using a 13 3/4" drill bit and 10" collar installed 0-40m. Air drilled 0-116m (EOH) using a 8 1/2" drill bit.

Depth mbgl	Geology	Lithology	Lithological Description	Gamma 0-50cps	Field Notes	Construction Details
0 - 30	CID		TPH: Bright to darkish yellow predominantly orcherous goethite, medium weathered and medium hardness, angular to sub-angular, 10-20% sand infills			Headworks; 10" Blank Steel (0-40mbgl)
30 - 45	CID		TPM: Moderately weathered yellow orcheous goethite at 70%, with trace limnonite towards end of interval, slighly less weathered than interval above. 5 %vitreous goethite fine gravel and silt towards end of hole			50mm Blank PVC (0-56 mbgl); Bentonite Seal (40-44mbgl)
45 - 70	BIF		MARRA MAMBA: Cherty marra mamba bifs with 20% silt infill, slightly weathered, angular to sub-angular, moderately fractured, hard to medium hard rock. 54-72 as above but more fractured and slightly less weathered, can be described as fresh marra mamba bif		SWL = 49.95 mbgl; FWS = 55 mbgl	Gravel (3.2-6.4mm) (0 - 40, 44 - 116 mbgl)
70 - 100	BIF		MARRA MAMBA: Shalley marra mamba bifs with chert bands and trace goethite with sand and silts infills		Airlift Yield - 2 L/s	50mm Slotted PVC (56-80 mbgl); PVC endcap (80 mbgl)
100 - 115	BIF		MARRA MAMBA: Fresh marra mamba bif composed mostly of cherts and shales, with predominantly high and silt content and trace quartz. highly fractured with angular to sub-angular ships upto 3.5cm			

Bore Completion Details

MB17MEH0013

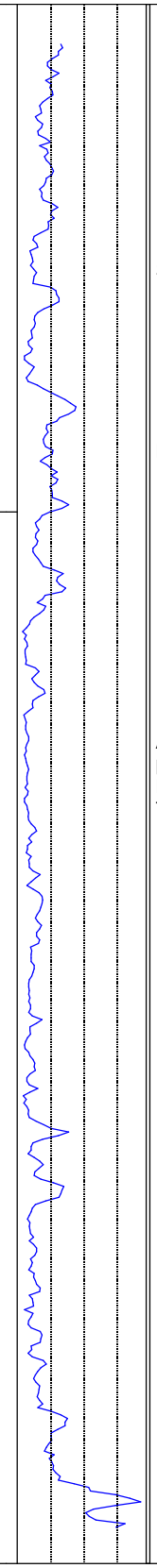
PROJECT: MESA H
LOCATION: Mesa H
DATE COMMENCED: 30/10/2017
DATE COMPLETED: 1/11/2017

DRILLING COMPANY: BDC
DRILLER: Hayden Kent
DRILLING METHOD: Rotary Hammer - Air
HYDROGEOLOGIST: Yuot Alaak

GRID NAME: MGA94_50
EASTING: 418380.559
NORTHING: 7599440.612
ELEVATION: 136.493 mRL

Air rotary drilled 0-12m using a 13 3/4" drill bit and 8" collar installed 0-12m. Air Rotary drilled 0-43m (EOH) using a 6 1/2" drill bit.

Depth mbgl	Geology	Lithology	Lithological Description	Gamma 0-100cps	Field Notes	Construction Details
0	ALLUVIALS		FILL: Tertiary alluvials composed of gravels@90 and silts and sands at 10%. Gravel size to 30 cm, moderately weathered.			Bentonite (0-2 mbgl)
5						8" Blank Steel (0-12mbgl)
					SWL = 7.03 mbgl	
10						50mm Blank PVC (0-12 mbgl)
					FWS = 12 mbgl	
15	DOLOMITE		DOLOMITE: Whitnoom dolomite, largely chrstalline with interbedded layers of moderately fractured zones. 18-22m moderately fractured zone with significant water strike @ 6-8 L/s, 32-36 moderately fractured but no visible increase in water flow			
20					Airlift Yield - 3.5 L/s pH - 7.59 EC - 1167 uS/cm Temp - 26.7 C	Gravel (3.2-6.4mm) (2 - 43mbgl)
25						
30						50mm Slotted PVC (12-42 mbgl)
35						
40						PVC endcap (42 mbgl) Fallback (42-43 mbgl)



Bore Completion Details

MB17MEH0014

PROJECT: MESA H
LOCATION: Mesa H
DATE COMMENCED: 27/10/2017
DATE COMPLETED: 29/10/2017
DRILLING COMPANY: BDC
DRILLER: Luke Wallace
DRILLING METHOD: Rotary Hammer - Air
HYDROGEOLOGIST: Yuot Alaak
GRID NAME: MGA94_50
EASTING: 418723.950
NORTHING: 7599428.420
ELEVATION: 137.609 mRL TOC

Mud drilled 0-18m using a 13 3/4" drill bit and 8" collar installed 0-18m. Air Rotary drilled 18-43m (EOH) using a 6 1/2" drill bit.

Depth mbgl	Geology	Lithology	Lithological Description	Gamma 0-100cps	Field Notes	Construction Details
0	ALLUVIALS		ALLUVIUM: Tertiary alluvials (gravels) upto 3cm. Medium weathered with silt and clay infills			Bentonite (0-2 mbgl)
5						8" Blank Steel (0-18mbgl)
10					SWL = 8.09 mbgl	50mm Blank PVC (0-18 mbgl)
15	ALLUVIALS		ALLUVIUM: Tertiary gravels in 50% clay matrix. medium plasticity with trace tertiary clays		FWS = 12 mbgl	
20	CID		CID: Vitrous goethite CID with silt infill upto 30%, blue to brown, with a medium weathered profile		Airlift Yield - 2 L/s pH - 8.75 EC - 1375 uS/cm Temp - 27 C	Gravel (3.2-6.4mm) (2 - 43mbgl)
25	DOLOMITE		DOLOMITE: Whitnoom dolomite 22-24 is fractured slightly. slightly weathered sequence to end od hole, tiny particle sizes, more competent during drilling from 39m but no evidence of freash chrstalline doomite in the chips samples. Angular to Sub-angular			
30						50mm Slotted PVC (18-42 mbgl)
35						
40						PVC endcap (42 mbgl) Fallback (42-43 mbgl)

Bore Completion Details

MB17MEH0015

PROJECT: Mesa H
LOCATION: Mesa H
DATE COMMENCED: 2/11/2017
DATE COMPLETED: 3/11/2017
DRILLING COMPANY: BDC
DRILLER: Manu Rekena
DRILLING METHOD: Mud
HYDROGEOLOGIST: Nik Adam
GRID NAME: MGA94_50
EASTING: 416044.945
NORTHING: 7597712.125
ELEVATION: 132.935

Mud Drilled 0-3m with 12 1/4" drill bit, collar installed 0-3m. Mud drilled 0-37m with 8 1/2" drill bit.

Depth mbgl	Geology	Lithology	Lithological Description	Gamma 0-100cps	Field Notes	Construction Details
0	Alluvium		ALLUVIUM: Dark red ferrugenous sand and clay with brown, sub rounded chert fine gravel. 40% Dark red ferrugenous fine to medium grain sand, completely weathered. 40% Brown and yellow chert, fine gravel, sub rounded and very hard. 20% red clay.		SWL = 8.7mbgl EC: 1130uS/cm pH: 7.92 Temperature: 34.2C	Bentonite Seal (0-2 mbgl) Blank Steel (0-3 mbgl) Blank PVC (0-12 mbgl)
15	Alluvium		ALLUVIUM: Dark red ferrugenous clay and sand with minor sub rounded chert. Clay content decreases with depth. 60% red ferrugenous clay, highly weathered and high plasticity. 20% red fine grain sand. 20% sub rounded brown chert, very hard, highly weathered.			Slotted PVC (12-30 mbgl)
25	Alluvium		ALLUVIUM: Dark red ferrugenous sand with a reduction in clay content.			Gravel (2-37 mbgl)
30	BIF		BIF: Slightly weathered bedrock cherty BIF, dark blue, magnetic, very hard.			No End Cap
35						

Bore Completion Details

WB17MEH0001

PROJECT: MESA H
LOCATION: Mesa H
DATE COMMENCED: 23/08/2017
DATE COMPLETED: 25/08/2017

DRILLING COMPANY: BDC
DRILLER: Hayden Kent
DRILLING METHOD: Mud Rotary
HYDROGEOLOGIST: C. Miller

GRID NAME: MGA94_50
EASTING: 418857.053
NORTHING: 7598693.336
ELEVATION: 139.413

Mud rotary with 17 1/2" Drill bit from 0-46m, No collar installed.

Depth mbgl	Geology	Lithology	Lithological Description	Gamma 0-25cps	Field Notes	Construction Details
0	Alluvium		ALLUVIUM: Mixture of Red brown ferrugenous silts and sands (0-4m) decreasing content with depth. Sub-rounded vitreous goethite and goethitic pisolith, increasing content with depth. Chert and white quartz up to 15mm, angular and sub-rounded jasperlite. BIF and dolomite moderately weathered, unconsolidated throughout.			No collar- too shallow
5						12" Blank Steel threaded casing (0-10 mbgl)
10					SWL = 8.8 mbgl	
15			DETRITALS: Detritals pisolith, predominantly vitreous goethite content as above with less Chert, BIF, Dolomite content with increased weathering.		Final Airlift - Yield - 10 L/s pH - 8.0 EC - 969 uS/cm Temp - 31.8 0C	12"Slotted Steel Threaded Casing (10-28 mbgl)
20						Gravel (3.2-6.4mm) (0 - 30mbgl) and (33-46 mbgl)
25			ALLUVIUM: As above, with increased white, yellow clay content 20-30% and less vitreous goethite, mixed with chips of moderately to highly weathered Dolomite, BIF and chert.			
30			CLAY: >80% white, yellow clay, highly plastic, with clasts of BIF, Dolomite, chert and goethite.			Bentonite (30 - 32 mbgl)
	Wittenoom Formation		WITTENOOM DOLOMITE: Grey mudstone, with white, yello clay pods, minor interbedded content of moderate to highly weathered, angular to sub-rounded dolomite.			
35			WITTENOOM DOLOMITE: As above, contaminated with Alluvials			12" Blank Steel threaded casing (28-40 mbgl)
40						End Cap (40 mbgl)
45			WITTENOOM DOLOMITE: hard - slightly weathered, sub-angular crystalline dolomite and chert. Contaminated with Alluvials. Slow drilling			No fallback

Bore Completion Details

WB17MEH0002

PROJECT: Mesa H
LOCATION: Mesa H
DATE COMMENCED: 31/10/2017
DATE COMPLETED: 3/11/2017
DRILLING COMPANY: BDC
DRILLER: Joe Mason
DRILLING METHOD: Mud 0-30m, Air 30-50m.
HYDROGEOLOGIST: Nik Adam/Casey Miller
GRID NAME: MGA94_50
EASTING: 418711.747
NORTHING: 7599423.723
ELEVATION: 139.413 mRL TOC

Mud drilled using 22" drill bit from 0-30m, collar installed 0-16m. Air Drilled from 30 -50m EOH.

Depth mbgl	Geology	Lithology	Lithological Description	Gamma 0-100cps	Field Notes	Construction Details
0	Alluvium		ALLUVIUM: 90% Chert and BIF, blue, red and brown, rounded, medium to coarse gravel grain size, very hard hardness, highly weathered. 10% Goethite, red, fine grain sand, completely weathered.			Bentonite (0 - 2 mbgl)
5			ALLUVIUM: 95% Chert and BIF with minor Goethite and Vitreous Goethite, blue, red and brown, angular to sub angular, fine to medium gravel, hard hardness, highly weathered. 5% Goethite, red brown, fine grain sand, completely weathered.		SWL = 7.36 mbgl	15 5/8" Blank Steel (0-16 mbgl)
10					Final Airlift - 2-5L/s, surging with 3 to 4 seconds break between surges. pH - 8.75 EC - 1350uS/cm Temp - 27C	Blank Steel (0-16 mbgl)
15						
20			ALLUVIUM: 70% Chert and BIF with minor Goethite and Vitreous Goethite, white, red brown, blue, angular to sub angular, fine to medium gravel, hard hardness, highly weathered. 10%Goethite, red brown, fine grain sand, completely weathered. 10% White clay and 10% Limonitic Goethite clay.			Slotted Steel (16-34 mbgl)
25			CONGLOMERATE: Chert and BIF, blue, red brown, medium to coarse gravel, well rounded, very hard, highly weathered.			
30	Conglomerate		CONGLOMERATE: Chert, Quartz and BIF, blue, red brown, sub angular to well rounded, fine to medium gravel, hard, highly weathered.			
35			DOLOMITE: 55% Cherty Dolomite, dark blue, fine grain gravel, angular to sub angular, very hard. 30% Chert and BIF, blue, red brown, sub angular to well rounded, fine to medium gravel. 15% Black shale, black coating over all the grains. Black water discharged from air drilling.			Bentonite Seal (34-36 mbgl)
40						Blank Steel (34-40mbgl)
45	Cherty Dolomite		DOLOMITE: 70% Cherty Dolomite, dark blue, angular, very hard, fine gravel. 20% Black shale that coats all of the grains.10% Quartz, blue and white, angular to sub angular, fine to medium gravel, hard (Probably contamination).			End Cap (40 mbgl)
50			DOLOMITE: Fresh Cherty Dolomite bedrock, dark blue, no shale present.			

Bore Completion Details

WB17MEH0003

PROJECT: Mesa H
LOCATION: Mesa H
DATE COMMENCED: 04/11/2017
DATE COMPLETED: 11/11/2017
DRILLING COMPANY: BDC
DRILLER: Manu Rekena
DRILLING METHOD: Mud Rotary 0-36m
HYDROGEOLOGIST: Nik Adam
GRID NAME: MGA94_50
EASTING: 416059.508
NORTHING: 7597705.964
ELEVATION: 132.438 mRL

Mud drilled using 22" drill bit from 0-2m, collar installed 0-2m. Mud Drilled using 17 1/2" drill bit from 0-36m EOH.

Depth mbgl	Geology	Lithology	Lithological Description	Gamma 0-100cps	Field Notes	Construction Details
0	Alluvium		ALLUVIUM: Predominantly highly weathered red brown chert with minor quartz and goethite. 75% chert, red brown, angular to sub rounded, fine to medium gravel, hard, highly weathered. 15% Goethite, yellow, angular to sub angular, fine to medium gravel, hard. 10% quartz, white, angular to sub angular, fine to medium gravel, hard.		SWL = 8.46 mbgl	Blank Steel (0-2 mbgl) Bentonite (0 - 2 mbgl)
10	Alluvium		ALLUVIUM: Highly weathered, dark red brown clay and sand with minor chert and goethite clasts. 40% Clay, red brown, high plasticity, soft. 40% red brown, fine grain sand. 10% chert, dark green and blue, angular to sub angular, fine gravel, hard. 10% vitreous goethite, dark blue and red, angular to sub angular, fine gravel, hard.		Final Airlift - 6L/s pH - 7.82 EC - 1108 mS/cm Temperature - 30.2C	Blank PVC (0-18 mbgl)
20	Alluvium		ALLUVIUM: Highly weathered red brown clay with a high proportion of chert, goethite and quartz clasts. 50% clay, red brown, medium plasticity. 50% alluvium consisting of quartz, chert and goethite, white, dark blue and red, angular to sub angular, fine gravel, hard.			Slotted PVC (18-30 mbgl)
25	Alluvium		ALLUVIUM: Moderately weathered chert, goethite and quartz, dark blue and white, angular to sub angular, fine to medium gravel, hard.			
30	Cherty BIF		BIF: Slightly weathered cherty BIF, magnetic, fractured, dark blue, platy, very hard. Problems drilling past 32m with the drill stopping on numerous occassions.			Blank PVC (30-36 mbgl)
35						End Cap (36 mbgl)

Bore Completion Details

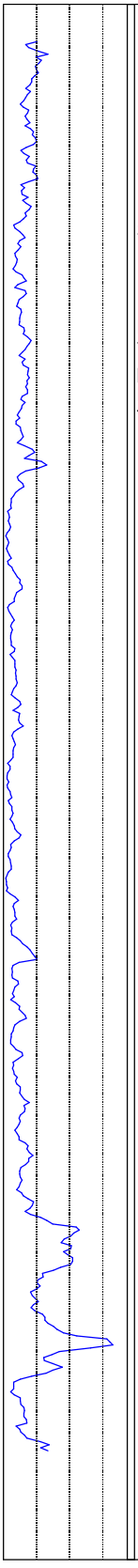
WB17MEH0004

PROJECT: MESA H
LOCATION: Mesa H
DATE COMMENCED: 7/11/2017
DATE COMPLETED: 10/11/2017
DRILLING COMPANY: BDC
DRILLER: Joe Mason
DRILLING METHOD: Mud Rotary
HYDROGEOLOGIST: Yuot Alaak
GRID NAME: MGA94_50
EASTING: 418388.056
NORTHING: 7599451.981
ELEVATION: 136.356 mRL BTOC

Mud rotary with 22" Drill bit from 0-7m, Installed 20" collar 0-7m. Mud drilled 7-50m using 17 1/2" drill bit. Threaded casing used by BDC.

Depth mbgl	Geology	Lithology	Lithological Description
0 - 7	CID		CID: channel iron deposits composed largely of geothite, moderartely weathered with 10% silt infills
7 - 20	Wittenoom Formation		DOLOMITE: blue to light blue whitnoom formation dolomite with chert interbeds, moderately weathered with visible clay in the chips, most probably from a thin clay band
20 - 50	Wittenoom Formation		DOLOMITE: moderately weathered whitnoom formation dolomite, light blue to dark blue with chrystalline interbeds, moderately fractured 20-24m

Gamma 0-100cps

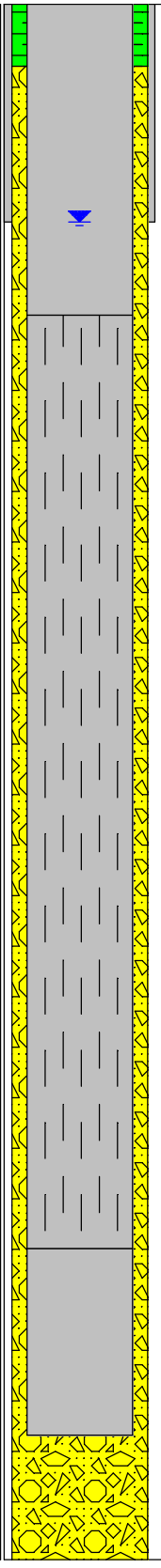


Field Notes

SWL = 6.86 mbgl

Final Airlift -
Yield - 12 L/s
pH - 7.92
EC - 1180 uS/cm
Temp - 24 0C

Construction Details



Bentonite Seal (0-2mbgl)

20" Collar (0-7m)

12" Blank Steel threaded casing (0-10mbgl)

12" Slotted Steel Threaded Casing (10-40 mbgl)

Gravel (3.2-6.4mm) (2 - 50mbgl)

12" Blank Steel threaded casing (40-46 mbgl)

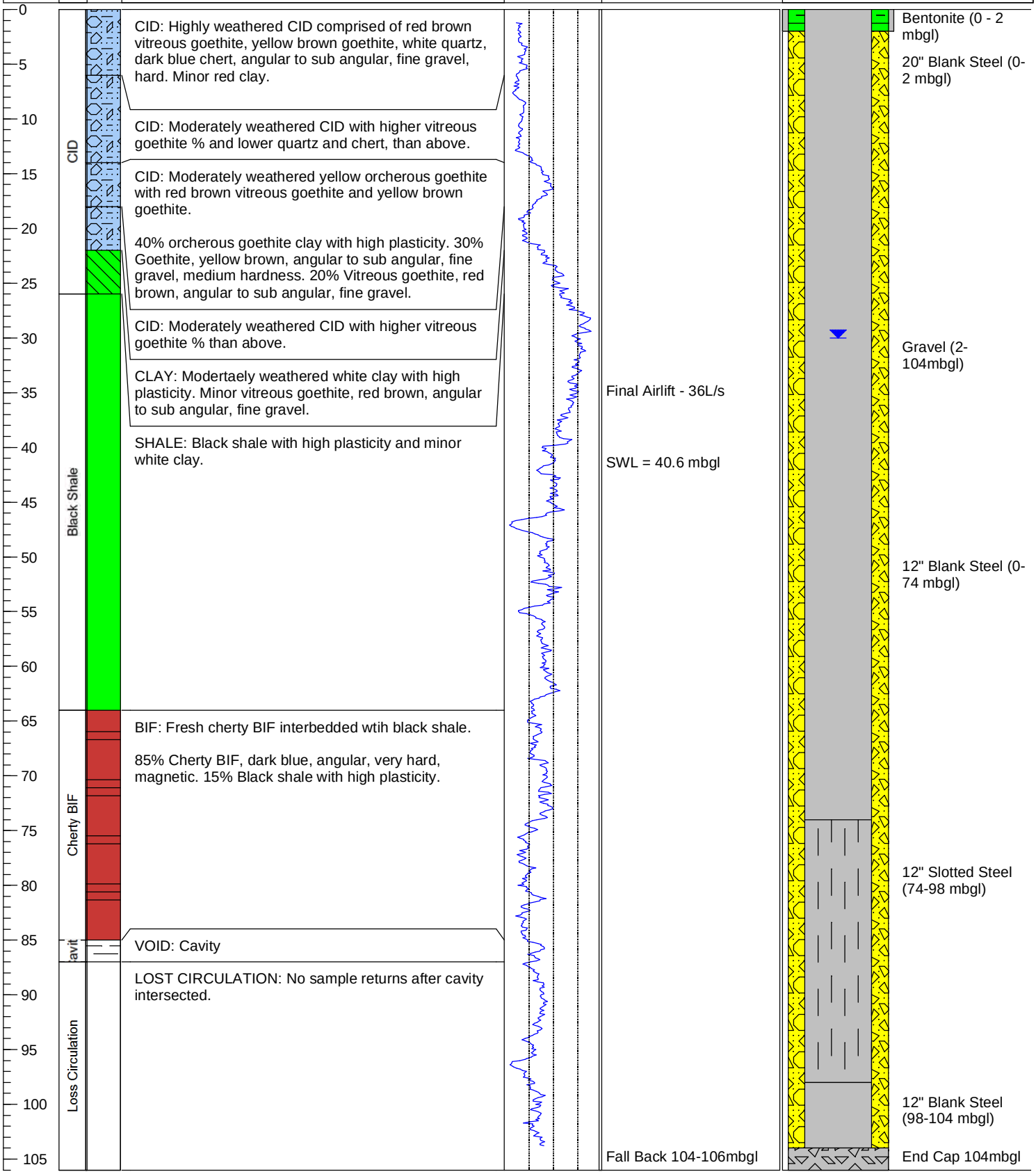
End Cap (46mbgl)

Bore Completion Details

WB17MEH0005

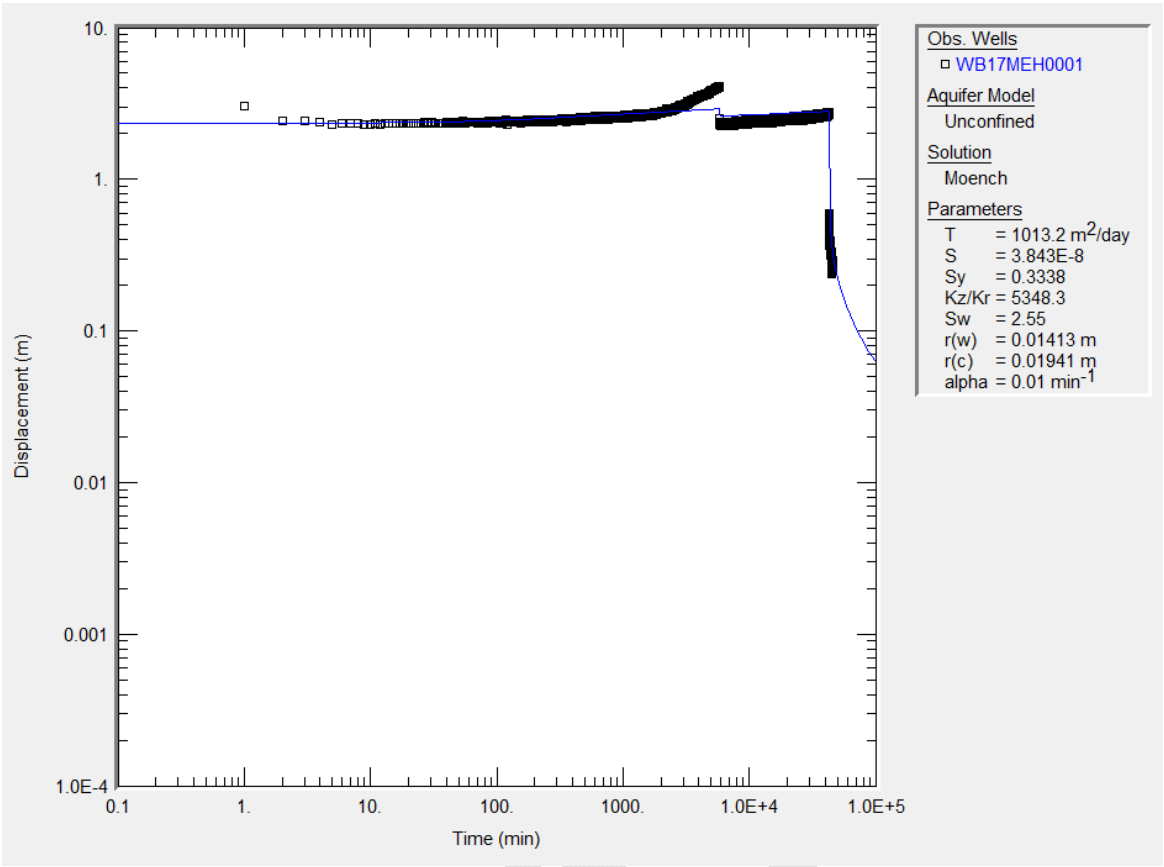
PROJECT: Mesa H
LOCATION: Mesa H
DATE COMMENCED: 14/11/2017
DATE COMPLETED: 19/11/2017
DRILLING COMPANY: BDC
DRILLER: Hayden Kent
DRILLING METHOD: Mud Rotary 0-106m
HYDROGEOLOGIST: Nik Adam
GRID NAME: MGA94_50
EASTING: 421699.218
NORTHING: 7590927.611
ELEVATION: 175.267 mRL TOC

Mud drilled using 22" drill bit from 0-2m, collar installed 0-2m. Mud Drilled using 17 1/2" drill bit from 0-106m EOH.



Appendix B - Constant Rate Test Analysis

DRAFT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0.01
0.001
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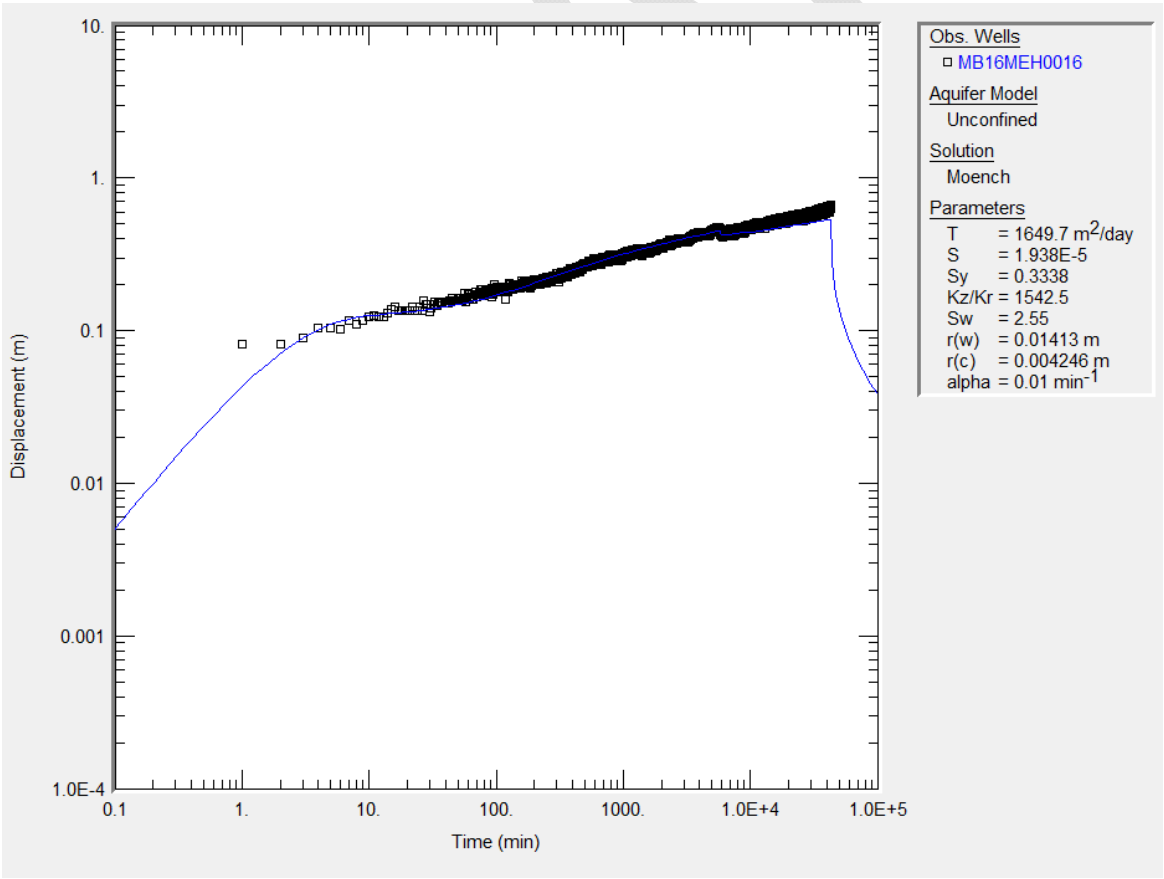
0.1
1.
10.
100.
1000.
1.0E+4
1.0E+5
Time (min)
Obs. Wells
WB17MEH0001
Aquifer Model
Unconfined
Solution
Moench
Parameters
T = 1013.2 m2/day
S = 3.843E-8
Sy = 0.3338
Kz/Kr = 5348.3
Sw = 2.55
r(w) = 0.01413 m
r(c) = 0.01941 m
alpha = 0.01 min-1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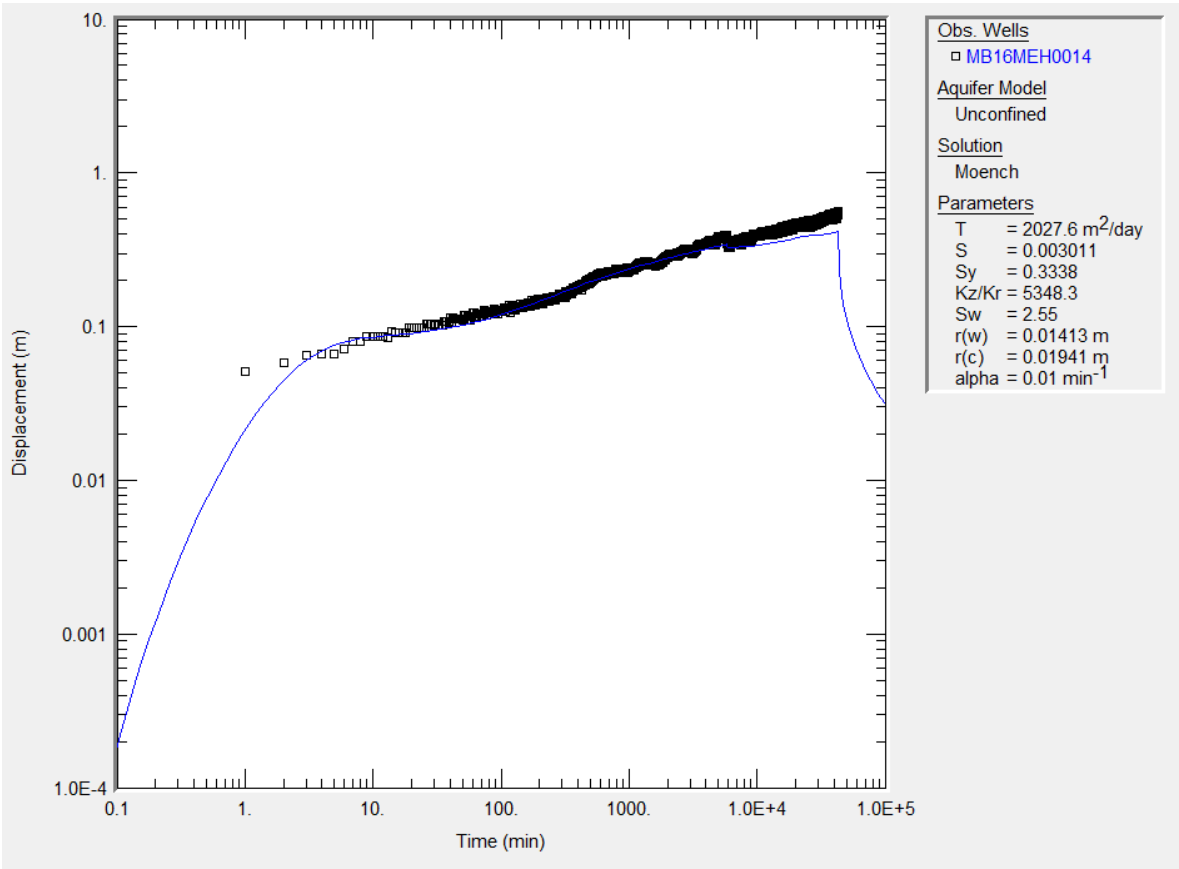
1.
10.
100.
1000.
1.0E+4
1.0E+5
Time (min)
Obs. Wells
MB16MEH0016
Aquifer Model
Unconfined
Solution
Moench
Parameters
T = 1649.7 m2/day
S = 1.938E-5
Sy = 0.3338
Kz/Kr = 1542.5
Sw = 2.55
r(w) = 0.01413 m
r(c) = 0.004246 m
alpha = 0.01 min-1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0.001
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1.
10.
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1000.
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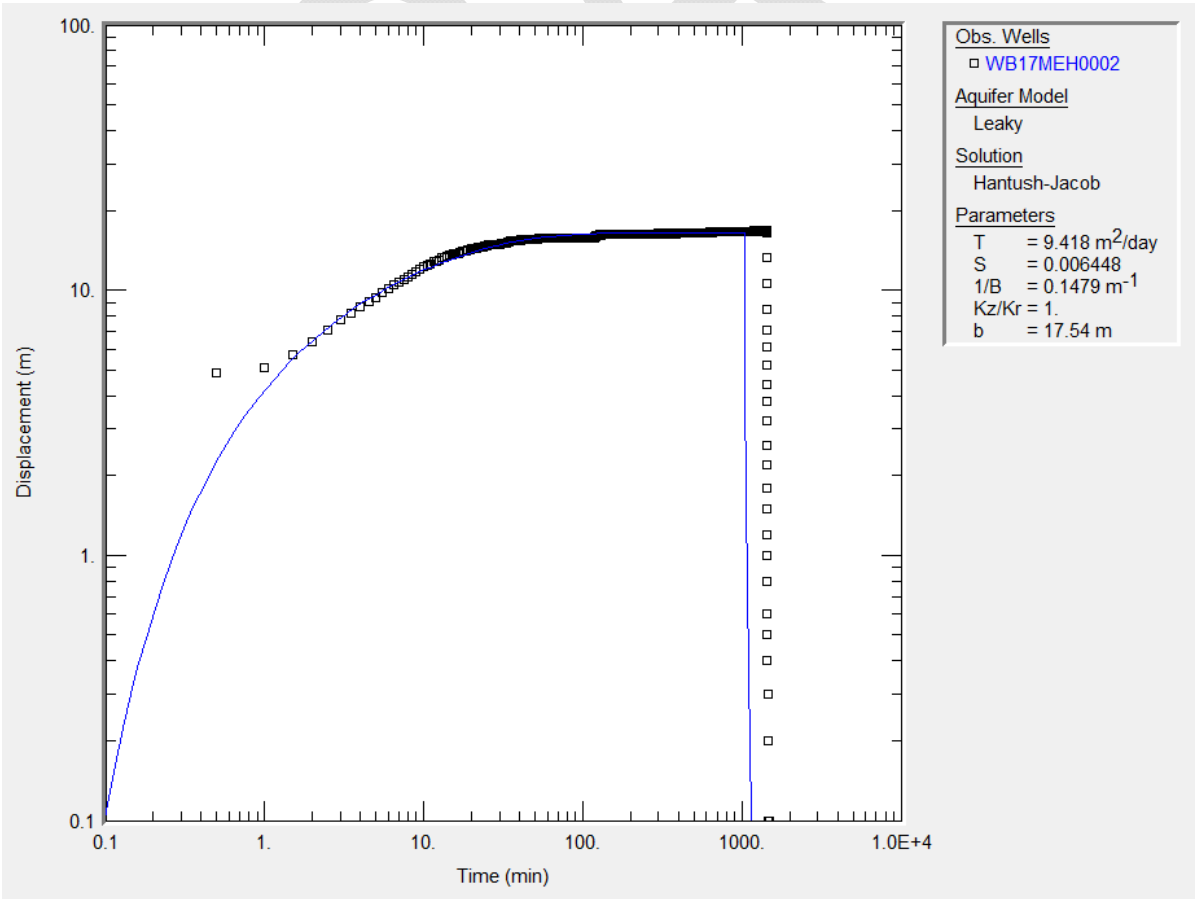
1.0E+5
Time (min)
Obs. Wells
MB16MEH0014
Aquifer Model
Unconfined
Solution
Moench
Parameters
T = 2027.6 m2/day
S = 0.003011
Sy = 0.3338
Kz/Kr = 5348.3
Sw = 2.55
r(w) = 0.01413 m
r(c) = 0.01941 m
alpha = 0.01 min-1


Displacement (m)
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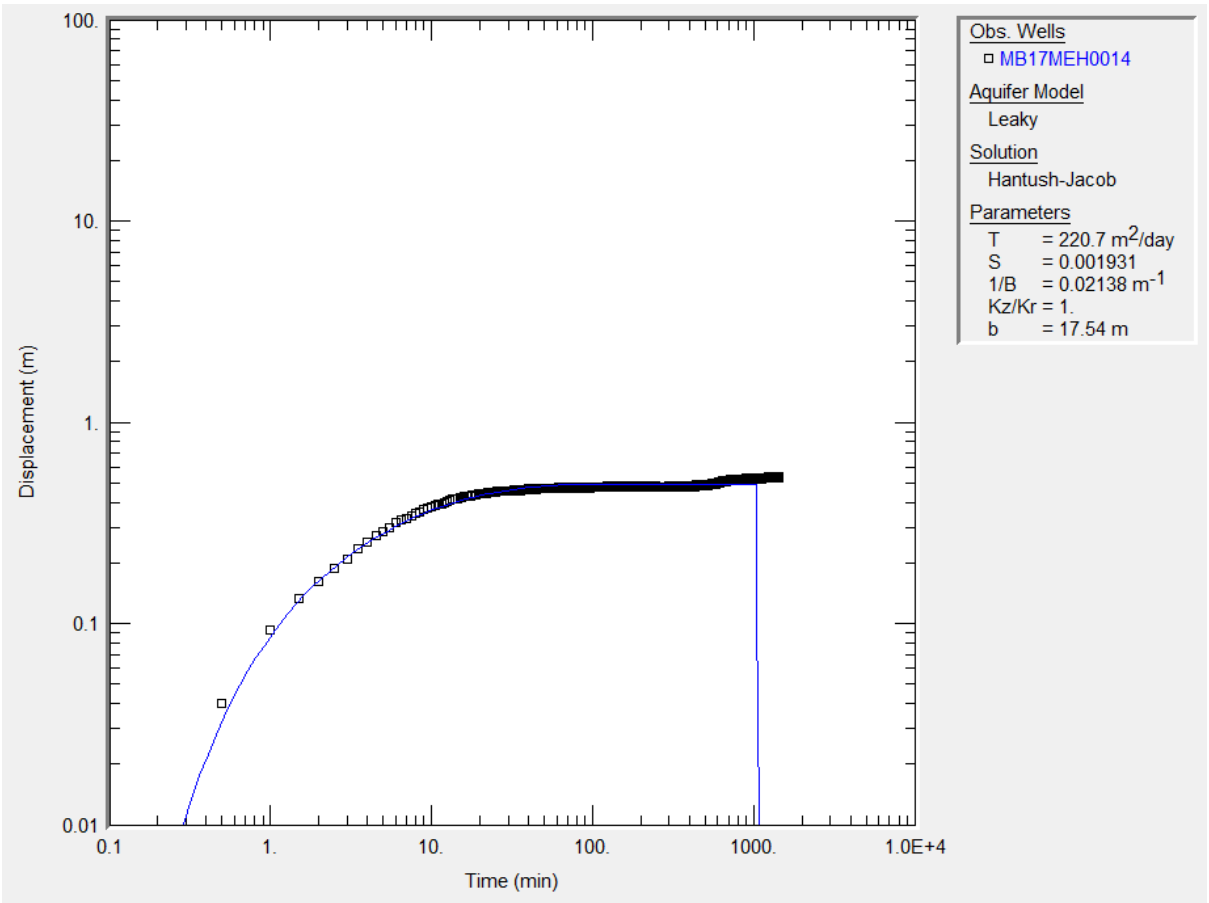
1.
0.1
0.1
1.
10.
100.
1000.
1.0E+4
Time (min)
Obs. Wells
WB17MEH0002
Aquifer Model
Leaky
Solution
Hantush-Jacob
Parameters
T = 9.418 m2/day
S = 0.006448
1/B = 0.1479 m-1
Kz/Kr = 1.
b = 17.54 m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Displacement (m)
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1.
10.
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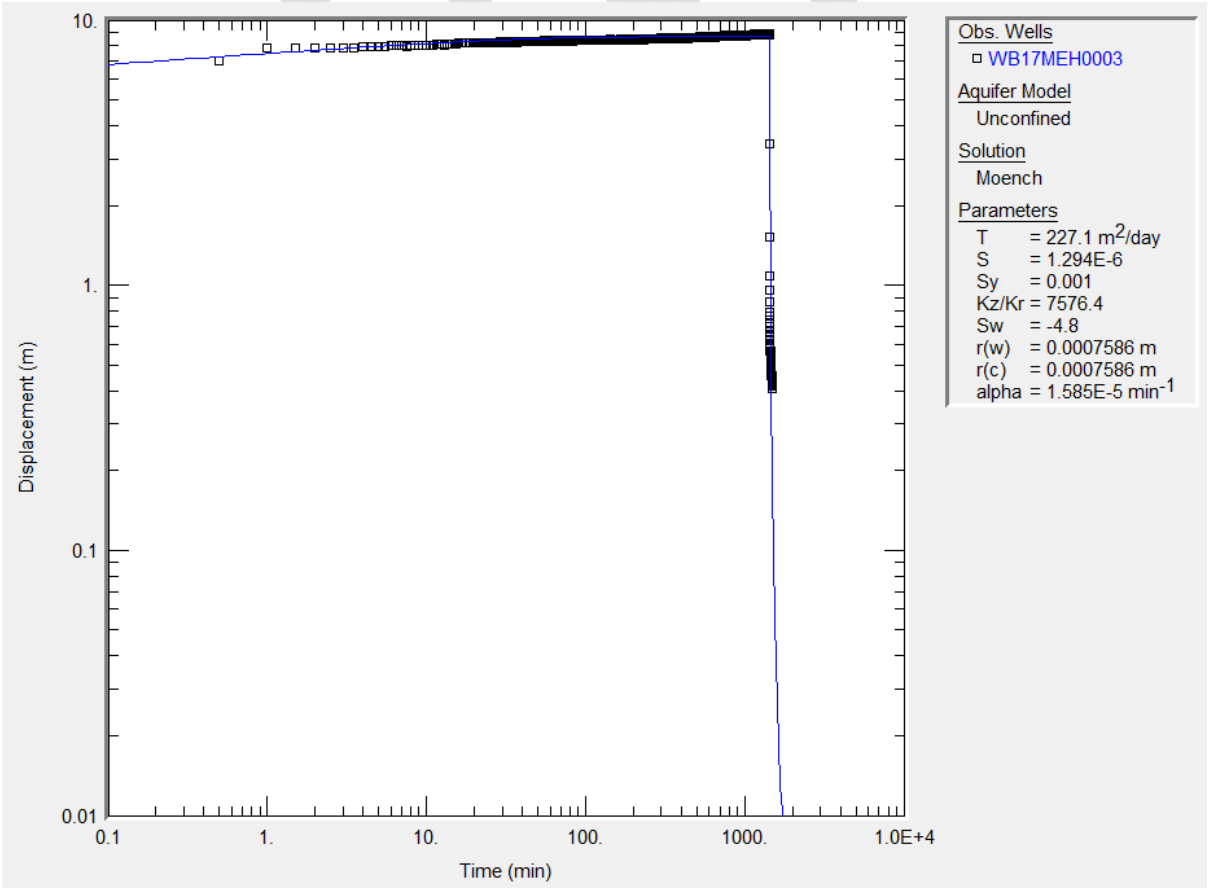
1000.
1.0E+4
Time (min)
Obs. Wells
MB17MEH0014
Aquifer Model
Leaky
Solution
Hantush-Jacob
Parameters
T = 220.7 m2/day
S = 0.001931
1/B = 0.02138 m-1
Kz/Kr = 1.
b = 17.54 m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0.01
Displacement (m)
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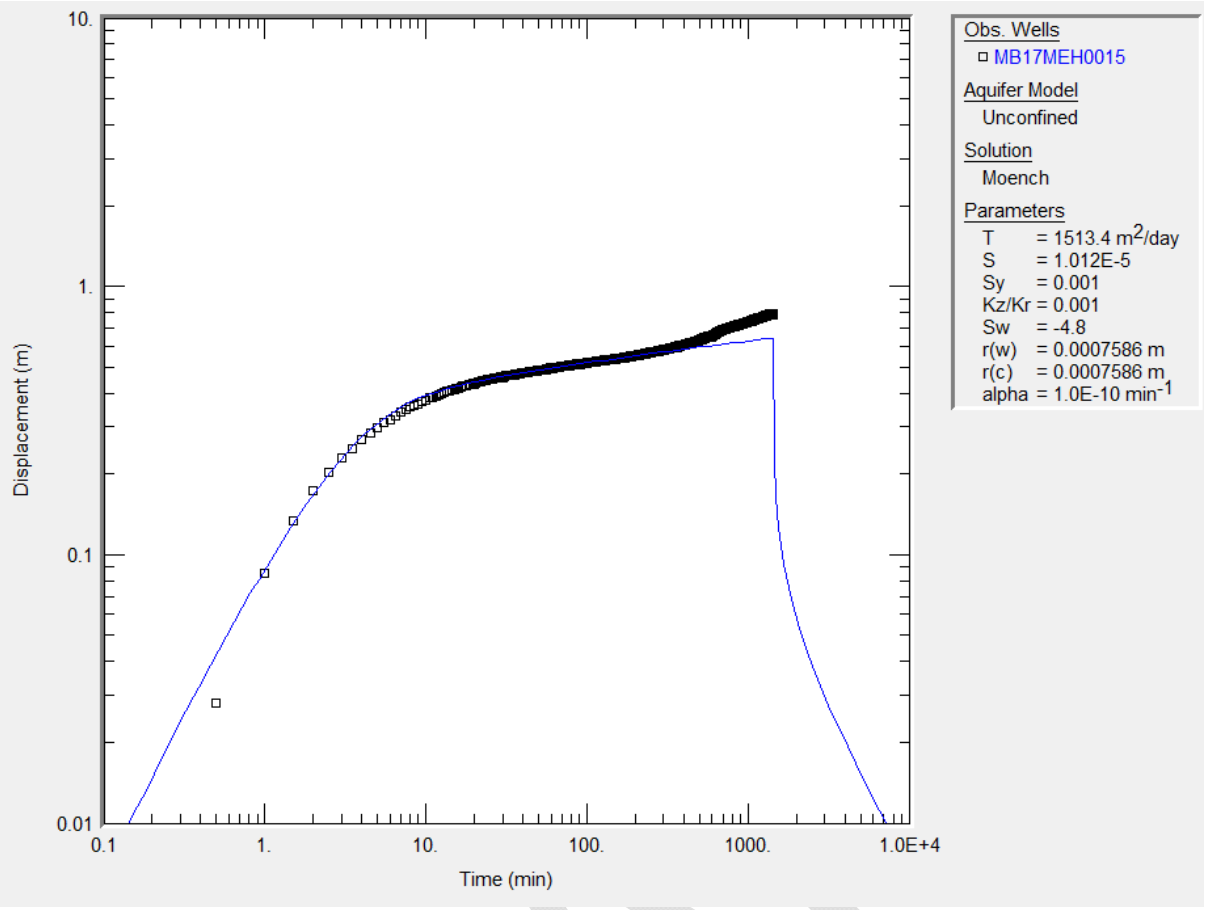
1.
10.
100.
1000.
1.0E+4
Time (min)
Obs. Wells
WB17MEH0003
Aquifer Model
Unconfined
Solution
Moench
Parameters
T = 227.1 m2/day
S = 1.294E-6
Sy = 0.001
Kz/Kr = 7576.4
Sw = -4.8
r(w) = 0.0007586 m
r(c) = 0.0007586 m
alpha = 1.585E-5 min-1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1.
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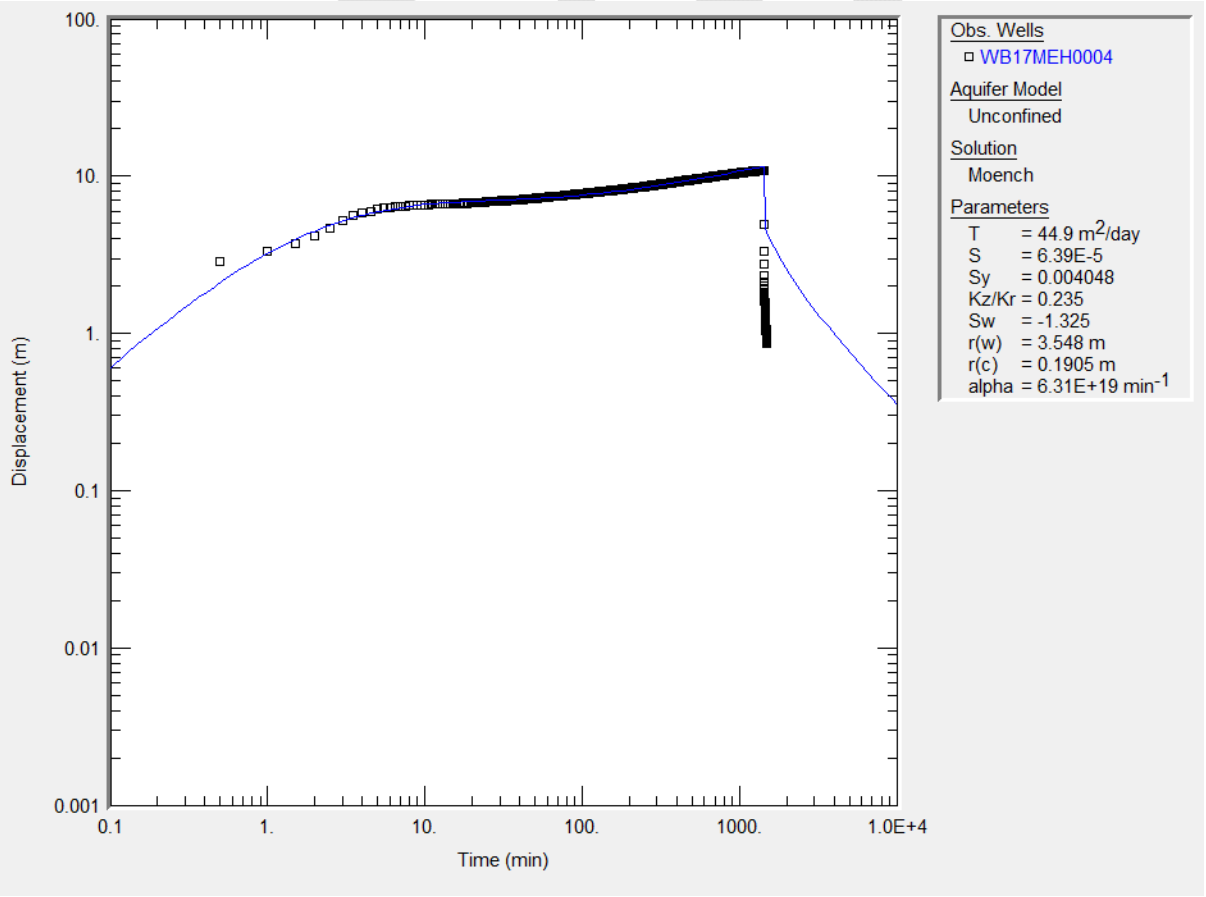
0.01
Displacement (m)
0.1
1.
10.
100.
1000.
1.0E+4
Time (min)
Obs. Wells
MB17MEH0015
Aquifer Model
Unconfined
Solution
Moench
Parameters
T = 1513.4 m2/day
S = 1.012E-5
Sy = 0.001
Kz/Kr = 0.001
Sw = -4.8
r(w) = 0.0007586 m
r(c) = 0.0007586 m
alpha = 1.0E-10 min-1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0.001
Displacement (m)
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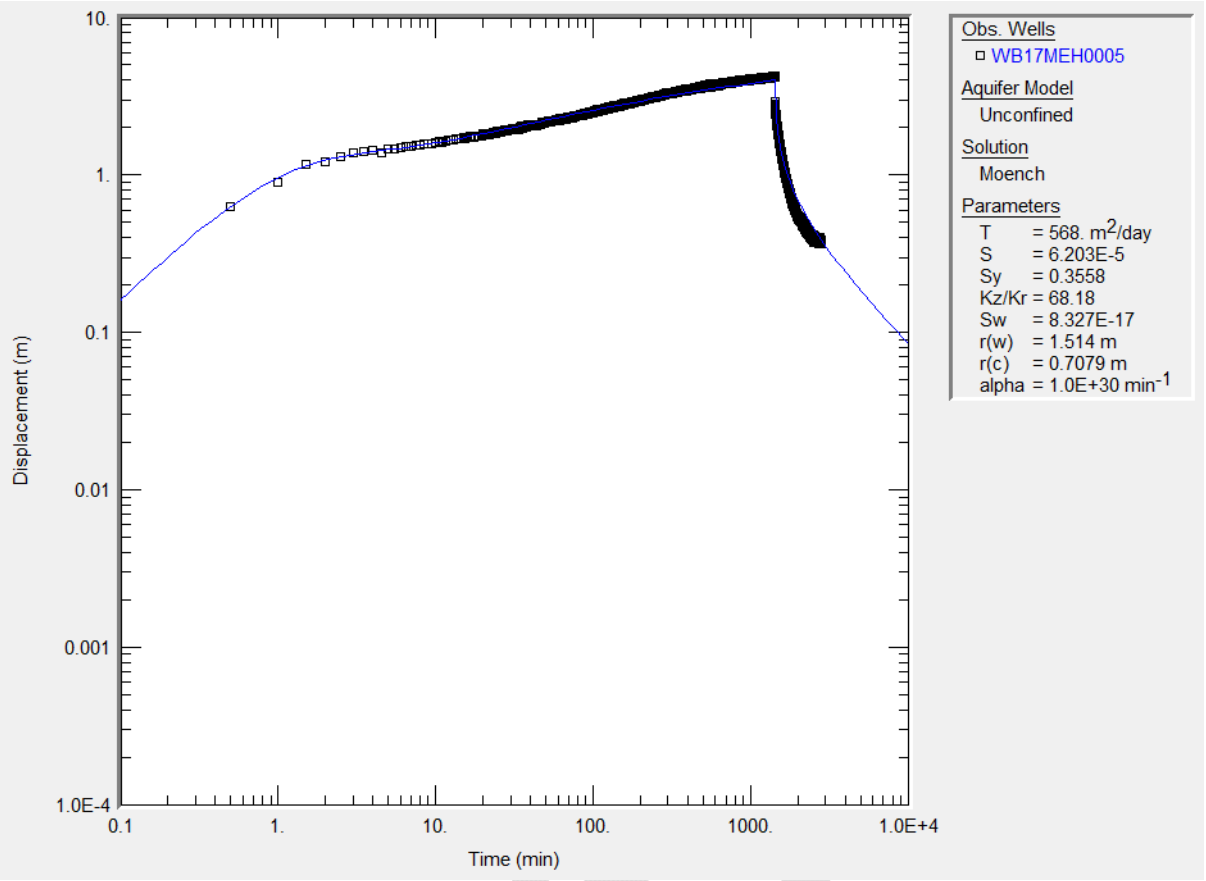
1.
10.
100.
1000.
1.0E+4
Time (min)
Obs. Wells
WB17MEH0004
Aquifer Model
Unconfined
Solution
Moench
Parameters
T = 44.9 m2/day
S = 6.39E-5
Sy = 0.004048
Kz/Kr = 0.235
Sw = -1.325
r(w) = 3.548 m
r(c) = 0.1905 m
alpha = 6.31E+19 min-1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0.1
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1.0E-4
Displacement (m)
0.1
1.
10.
100.
1000.
1.0E+4
Time (min)
Obs. Wells
WB17MEH0005
Aquifer Model
Unconfined
Solution
Moench
Parameters
T = 568. m2/day
S = 6.203E-5
Sy = 0.3558
Kz/Kr = 68.18
Sw = 8.327E-17
r(w) = 1.514 m
r(c) = 0.7079 m
alpha = 1.0E+30 min-1

DRAFT

Rio Tinto

Rio Tinto Iron Ore Hydrogeology – Mesa J Mine Site

Mesa H 2016 Pre-Feasibility Study Hydrogeological Drilling Program Completion Report

May 2016

EXECUTIVE SUMMARY

This report presents drilling and construction details for works completed as part of the Mesa H Pre-Feasibility Study (PFS).The works were carried out by Bunbury Drilling, Ranger Drilling and McArthur Drilling and Test Pumping between the 8th of February and the 25th of March 2016.

Four production bores were drilled using mud rotary drilling techniques and constructed with 12" blank and slotted steel casing. The production bores were subsequently test pumped including a step test, a constant rate test and a recovery test.

A total of three nested monitoring bores and twelve single monitoring bores were constructed. All monitoring bores were cased with 50 mm blank and slotted Class 18 PVC. The nested monitoring bores and one of the monitoring bores were drilled using the air-hammer method, with all remaining monitoring bores drilled using reverse circulation (RC). All holes were logged by a supervising Hydrogeologist and a downhole geophysical survey was conducted on each bore. Water samples were collected from each production bore at the completion of the test pumping and submitted for laboratory chemical analysis.

Drilling results helped define the extent of the Robe Pisolite (CID) underneath the Robe River alluvium, identify the Paraburdoo Member and the Bee Gorge Member of the Wittenoom Formation as local aquifers and at the same time classify the unmineralised BIF (whenever underlying the CID) as an aquitard.

The basal CID has horizontal continuity throughout the deposit, with an average thickness of 20 metres and continuing underneath the Robe River alluvium (Robe River Aquifer) to the north and potentially works as a partial boundary limiting the hydraulic connection between the CID and Wittenoom aquifer.

The Robe River aquifer has a saturated thickness of approximately 20 meters consisting of highly permeable and low storage quaternary sediments with a shallow water table. Drawdown response during the long term test pumping suggests potential hydraulic connection between this aquifer and the CID aquifer.

This work aimed to support the development of a conceptual model to predict the dewatering requirements and impacts of future dewatering activities, particularly in relation to the pools and riparian vegetation associated with the Robe River.

Project Details

Project Name:	Mesa H 2016 Pre-Feasibility Study Hydrogeological Drilling Program
Business Unit:	Orebody Knowledge and Planning
Project Sponsor:	Darren Sharp
Project Manager:	Alexandre Russo

Document Version Control

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Document Status:	Draft
Version No.:	Rev 3
File Name:	
Date:	April 2016

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0	20/03/16	Ashley Price	preliminary drilling report
1	15/04/16	Alexandre Russo	factual data and findings
2	25/04/16	Cally Sibley	added test pumping results
3	17/05/16	Shane Trott	1st revision
4	18/05/16	Wade Dodson	2nd revision

Document Acceptance

Name	Title	Date	Signature
Shane Trott	Superintendent Hydrogeology		
Wade Dodson	Principal Hydrogeology		
Darren Sharp	Manager WRE&S		

Document Distribution

Name	Title	Date
Jeremy English	Mesa H Study Manager	
Keith Brown	Superintendent Numerical Models	
Eddie Lee	Specialist Numerical Models	

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APPENDIX F WATER TABLE CONTOUR MAP

SECTION 1 - INTRODUCTION

1.1 PROGRAM DESCRIPTION

Hydrogeological drilling works were required at Mesa H in 2016 as part of the Pre-Feasibility Study (PFS) for the development of the proposed mine. Approximately 13% of the orebody occurs below the current water table (already depressed due to dewatering activities at the nearby Mesa J mine). As such, work is required to determine the likely dewatering requirements and impacts of future dewatering activities, particularly in relation to the pools and riparian vegetation associated with the Robe River.

The original program scope comprised:

- Drilling, installation and testing of four production bores to enable advancement of the conceptual hydrogeological model;
- Drilling and installation of ten single monitoring bores and six nested monitoring bores (comprising one shallow and one deep installation) across the site;
- Test pumping of all installed production bores including step drawdown test, constant rate test and recovery; and
- Groundwater sampling of all installed production bores.

Before earth works and drilling commenced Approvals Requests (AR-15-13678A and AR-15-13678B) were authorised to carry out the work, as part of this process a 26D license (CAW182227) was obtained to install four production bores during the drilling program.

3.1 DRILLING CONTRACTS

Bunbury Drilling Pty Ltd (BDC) and Ranger Drilling Pty Ltd (Ranger) were commissioned to carry out the 2016 Mesa H PFS Hydrogeological Drilling Program. Drilling was managed by the Rio Tinto Water Resource Evaluation and Services group (WRE&S). The program was undertaken between February and March 2016.

3.3 DRILLING AND CONSTRUCTION

Single well monitoring bores were drilled using reverse circulation (RC) drilling methods, nested monitoring bores were drilled using air-hammer and production bores were drilled using mud rotary techniques. Production bores were constructed with 12” blank steel and slotted steel casing.

Monitoring bores were constructed using blank and slotted 50mm Class 18 PVC casing with bentonite seals placed to isolate the deep and shallow installations. All bores were gravel packed using graded 3.2 - 6.4 mm gravel with headworks completed as per the Rio Tinto Design Specification for Water and Monitoring Bore Headworks (RTIO-PDE-0089729), as follows:

- Production bores:
    - 12” steel casing stick-up above the top of the plinth;
    - Lockable steel lid with handle;
    - Stick up and lid painted white;
    - Concrete plinth measuring 1 m^2 by 300 mm high (100 mm set below natural ground level).
- Monitoring bores:
    - Steel casing stick-up 500 mm above the top of the plinth;
    - PVC stick-up 350 mm above the top of the plinth and fitted with a PVC cap;
    - Lockable steel lid with handle;
    - Concrete plinth measuring 1 m^2 by 300 mm high (100 mm set below natural ground level).

Bore details are provided in Tables 1 (locations), 2 (construction details) and 3 (water levels/airlift yields), and Figure 1 shows the bore locations in relation to the Order of Magnitude (OoM) pit design (mesa_h_opt2_pit_rev4_mga). Bore logs and individual bore completion reports are presented in Appendices A and B respectively.

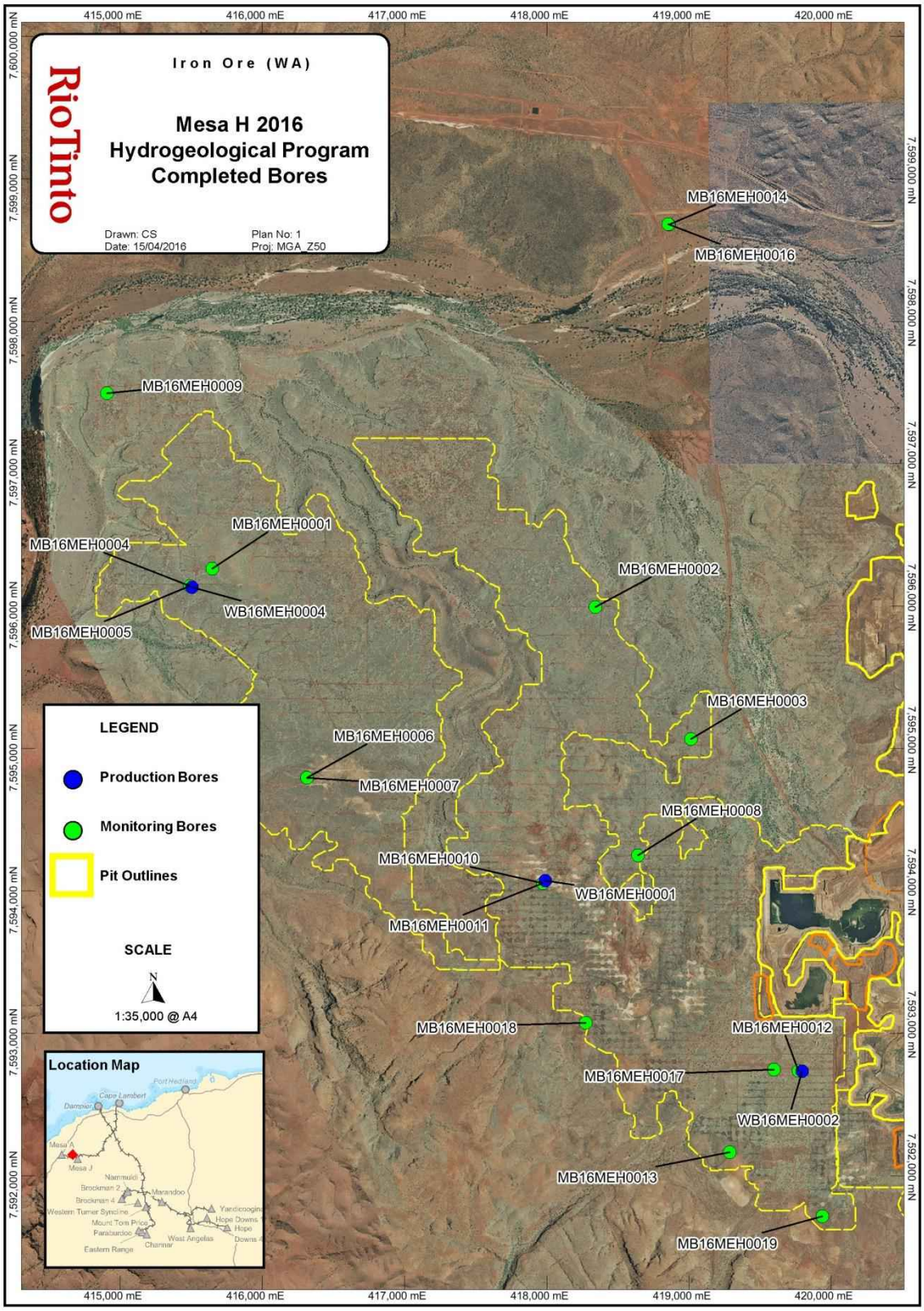


Figure 1 Completed Bore Locations (OoM pit design)

Table 1 Bore Locations

Bore ID	Peg ID	Surveyed Easting (MGA)	Surveyed Northing (MGA)	Surveyed TOC m RL (m AHD)	Surveyed GL m RL (m AHD)
Monitoring Bores					
MB16MEH0001	16MEH_M16	415648.30	7596263.24	166.52	166.06
MB16MEH0002	16MEH_M08	418342.63	7595994.38	167.57	167.11
MB16MEH0003	16MEH_M07	419013.90	7595067.08	175.67	175.09
MB16MEH0008	16MEH_M06	418640.88	7594248.67	160.24	159.49
MB16MEH0009	16MEH_M09	414906.39	7597496.70	161.91	161.12
MB16MEH0012	16MEH_M01	419768.32	7592737.21	165.22	164.50
MB16MEH0013	16MEH_M04	419286.91	7592165.60	183.13	182.45
MB16MEH0014	16MEH_M11	418861.54	7598680.02	139.33	138.77
MB16MEH0015	16MEH_M11	Hole abandoned and not constructed due to surface casing blowout and hole collapse			
MB16MEH0016	16MEH_M11	418854.63	7598682.99	139.435	138.88
MB16MEH0017	16MEH_M13	419597.88	7592744.90	165.684	165.03
MB16MEH0018	16MEH_M05	418273.51	7593072.81	168.337	167.55
MB16MEH0019	16MEH_M03	419938.38	7591715.26	178.53	177.85
Nested Monitoring Bores					
S: MB16MEH0004 D: MB16MEH0005	16MEH_M15	415490.51	7596140.85	S: 165.24 D: 165.31	164.50
S: MB16MEH0006 D: MB16MEH0007	16MEH_M02	416312.82	7594795.87	S: 170.5 D: 170.11	169.46
S: MB16MEH00010 D: MB16MEH00011	16MEH_M14	417971.10	7594055.67	S: 174.96 D: 175.08	174.40
Production Bores					
WB16MEH0001	16MEH_P02	417990.96	7594070.94	175.24	174.93
WB16MEH0002	16MEH_P01	419797.07	7592735.16	165.03	164.52
WB16MEH0003	16MEH_P03	416321.85	7594781.07	170.06	169.69
WB16MEH0004	16MEH_P04	415504.09	7596133.77	164.90	164.49

Key: S: shallow monitoring bores, D: deep monitoring bores

Table 2 Construction Details

Bore ID	Peg ID	Actual Start Date	Completion Date	Actual Drilled Depth	Cased Depth	Casing Details	Bore Type	Drilling Method	Collar Casing Diameter (mm)	Cased Collar Depth (m bgl)	Hole Diameter (mm)	Slotted Interval (m bgl)
Monitoring Bores												
MB16MEH0001	16MEH_M16	8/02/2016	10/02/2016	64	64	50mm PVC	MB: Single	RC	150	5	140	52 - 64
MB16MEH0002	16MEH_M08	10/02/2016	11/02/2016	80	74	50mm PVC	MB: Single	RC	150	5	140	56 - 74
MB16MEH0003	16MEH_M07	12/02/2016	14/02/2016	84	84	50mm PVC	MB: Single	RC	150	5	140	66 - 84
MB16MEH0008	16MEH_M06	15/02/2016	16/02/2016	58	58	50mm PVC	MB: Single	RC	150	5	140	40 - 58
MB16MEH0009	16MEH_M09	16/02/2016	17/02/2016	52	82	50mm PVC	MB: Single	RC	150	5	140	34 - 52
MB16MEH0012	16MEH_M01	18/02/2016	22/02/2016	49	47	50mm PVC	MB: Single	MR	250	8	216	35 - 47
MB16MEH0013	16MEH_M04	22/02/2016	23/02/2016	76	76	50mm PVC	MB: Single	RC	150	4	140	64 - 76
MB16MEH0014	16MEH_M11	18/02/2016	18/02/2016	64	64	50mm PVC	MB: Single	RC	150	5	140	40 - 64
MB16MEH0015	16MEH_M11	19/02/2016	19/02/2016	40	Hole abandoned and not constructed due to surface casing blowout and hole collapse							
MB16MEH0016	16MEH_M11	19/02/2016	20/02/2016	30	30	50mm PVC	MB: Single	RC	150	5	140	6 - 24
MB16MEH0017	16MEH_M13	20/02/2016	22/02/2016	76	50	50mm PVC	MB: Single	RC	150	8	140	32 - 50
MB16MEH0018	16MEH_M05	23/02/2016	23/02/2016	52	48	50mm PVC	MB: Single	RC	150	5	140	36 - 48
MB16MEH0019	16MEH_M03	23/02/2016	24/02/2016	70	64	50mm PVC	MB: Single	RC	150	5	140	40 - 64
Nested Monitoring Bores												
S: MB16MEH0004 D: MB16MEH0005	16MEH_M15	15/02/2016	16/02/2016	76	S: 60 D: 78	50mm PVC	MB: Nested	CH	250	6	216	S: 48 – 60 D: 66 – 78
S: MB16MEH0006 D: MB16MEH0007	16MEH_M02	14/02/2016	29/02/2016	74	S: 40 D: 76	50mm PVC	MB: Nested	CH	250	6	216	S: 28 - 40 D: 59 - 70
S: MB16MEH00010 D: MB16MEH00011	16MEH_M14	17/02/2016	18/02/2016	78	S: 58 D: 77	50mm PVC	MB: Nested	CH	250	6	216	S: 46 – 58 D: 65 - 77
Production Bores												

Bore ID	Peg ID	Actual Start Date	Completion Date	Actual Drilled Depth	Cased Depth	Casing Details	Bore Type	Drilling Method	Collar Casing Diameter (mm)	Cased Collar Depth (m bgl)	Hole Diameter (mm)	Slotted Interval (m bgl)
WB16MEH0001	16MEH_P02	20/02/2016	27/02/2016	84	84	Steel 305mm	PB	MR	473	2	432	45 - 81
WB16MEH0002	16MEH_P01	24/02/2016	02/03/2016	57	56	Steel 305mm	PB	MR	473	6	432	38 - 50
WB16MEH0003	16MEH_P03	01/03/2016	08/03/2016	70	70	Steel 305mm	PB	MR	473	2	432	46 - 70
WB16MEH0004	16MEH_P04	04/03/2016	13/03/2016	79	76	Steel 305mm	PB	MR	473	5	432	46 - 64

Key: MB - Monitoring Bore, PB – Production Bore, RC – Reverse Circulation, MR – Mud Rotary, CH – Conventional Hammer

Table 3 Water Levels and Airlift Yields

Bore ID	Peg ID	Initial SWL (m BTOC)	Initial SWL (m AHD)	Peak bore development airlift yield (L/s)
Monitoring Bores				
MB16MEH0001	16MEH_M16	46.94	132.93	0
MB16MEH0002	16MEH_M08	34.64	134.55	1
MB16MEH0003	16MEH_M07	41.12	132.22	0.1 - 0.2
MB16MEH0008	16MEH_M06	28.03	119.40	0.7
MB16MEH0009	16MEH_M09	42.52	131.28	0
MB16MEH0012	16MEH_M01	33.94	131.33	0.25
MB16MEH0013	16MEH_M04	51.80	129.89	<0.25
MB16MEH0014	16MEH_M11	9.44	132.93	2.5
MB16MEH0016	16MEH_M11	9.50	129.94	0.35
MB16MEH0017	16MEH_M13	34.10	131.58	0
MB16MEH0018	16MEH_M05	36.01	132.33	0
MB16MEH0019	16MEH_M03	43.50	135.03	0
Nested Monitoring Bores				
S: MB16MEH0004 D: MB16MEH0005	16MEH_M15	S: 45.89 D: 45.92	S: 119.35 D: 119.39	S: 0.2 D: 0.5
S: MB16MEH0006 D: MB16MEH0007	16MEH_M02	S: NA D: 44.62	S: NA D: 125.49	S: N/A D: 0.7 - 1
S: MB16MEH00010 D: MB16MEH00011	16MEH_M14	S: 42.12 D: 42.00	S: 132.96 D: 132.96	S: <0.25 D: 1.5
Production Bores				
WB16MEH0001	16MEH_P02	42.36	132.88	8 – 10
WB16MEH0002	16MEH_P01	33.86	131.17	1.25
WB16MEH0003	16MEH_P03	40.92	129.14	<0.1
WB16MEH0004	16MEH_P04	45.55	119.35	1.8

* No yield achieved

3.4 GEOPHYSICS

Surtron Technologies (Australia) PTY Ltd (Surtron) was commissioned to carry out the downhole geophysics, including: gamma, gyro and density.

Geophysical survey results are provided in Appendix C with gamma survey results also presented on the bore logs in appendix **A COMPOSITE BORE LOGS** A.

3.5 PROGRAM LEARNINGS

Overall, the program was completed successfully, on time, within the budget and with no injury, however there were some minor difficulties encountered which should be considered for future drilling, including:

- Varying degrees of lost circulation occurred in several drill holes within the CID, resulting in significant mud loss on occasion. In one instance, complete circulation loss was experienced in both the production bore (WB16MEH0002) and the adjacent monitoring bore (MB16MEH0012). Attempts were made to grout up the mud loss zone during drilling of WB16MEH0002 as it was above the water table, however, this was unsuccessful and the remainder of the hole was drilled blind;
- Several of the monitoring bores could not be developed due to inadequate yield and likely low submergence;
- Difficulties were encountered during construction of nested piezometer MB15MEH0005/006. The bore was initially drilled with air, however, a swelling clay zone restricted the installation of casing. As a result, the driller sourced some RC rods to enable casing to be run in-rod. The bore was successfully constructed;
- One production bore could not be properly developed due to inadequate yield and minimal submergence. Attempts were made to flush water down the annulus and inside the casing to break down the mud, however, the flow did not increase as the mud was cleared out.

SECTION 3 - TEST PUMPING

4.1 TEST PUMPING PLAN AND METHODS

Test pumping of the production bores was conducted in March 2016. The objective of the test pumping was to provide information on bore efficiency and yield, and to assess aquifer properties and test groundwater flow boundaries.

The test pumping was carried out by McArthur Drilling and Test Pumping (MDP). Two dip tubes attached to the rising main in the pumping bore was utilised to record water levels during the test. Water levels in monitoring bores were measured using a combination of manual dipping and automated level loggers (data loggers).

Test pumping comprised the following:

- A calibration test to ensure all equipment was functional and to provide an indication of possible flow rates;
- Step drawdown rate test (SRT): Five steps (60 minute duration) of increasing discharge rate to provide data for bore efficiency assessment and to determine an appropriate pumping rate for the constant rate test.
- Constant rate test (CRT): Pumping at a constant discharge rate for periods between 1 and 7 days to provide data for estimation of aquifer properties.
- Water sampling after one hour of pumping during the CRT for water quality analysis.
- Throughout the CRT, a logger with attached flow cell was used to record physiochemical parameters including; dissolved oxygen (DO), electrical conductivity (EC), oxygen reduction potential (ORP) and pH of the discharge water for WB16MEH002 and WB16MEH004.
- At the end of the CRT, recovering water levels in the production bore were monitored until recovery inside the bore reached at least 90% of the original water level.

4.3 STEP TEST ANALYSIS

The Hantush-Bierschenk analysis was used to analyse the step rate test data to determine the apparent well efficiency (see Appendix D). The data was also used to determine the pumping rates for the constant rate tests. A summary of the completed SRT is provided in **Table 4.**

Table 4: Summary of completed test pumps

Bore ID	Number of Steps	Step Duration (minutes)	Discharge Rates (L/s)	Bore Apparent Well Loss	Bore Equation
WB16MEH0001	5	60	5, 8, 11, 15, 18	$4.2E^{-06}$	Sw= 0.0056Q + 4e-6Q2
WB16MEH0002	4	60	1.5, 2, 2.5, 3	$1.66E^{-04}$	Sw= 0.0082Q + 1e-4Q2
WB16MEH0003	Bore could not be tested due to yield lower than 1.5 L/s				
WB16MEH0004	3	60	1.5, 2.5, 3.5	$3.4E^{-05}$	Sw= 0.015Q + 8e-5Q2

4.4 CONSTANT RATE AND RECOVERY TEST ANALYSIS

WB16MEH0001

WB16MEH0001 was constructed with slots over both the CID and Paraburdoo Member, and was pumped at 18 L/s, drawing the water level down a total of 20.67 m in 72 hours. WB16MEH0001 is located directly west of Mesa J Pit 11 Sump, a large source of water (Figure 2); in order to represent this water source in the pumping test analysis, a constant head boundary was entered.

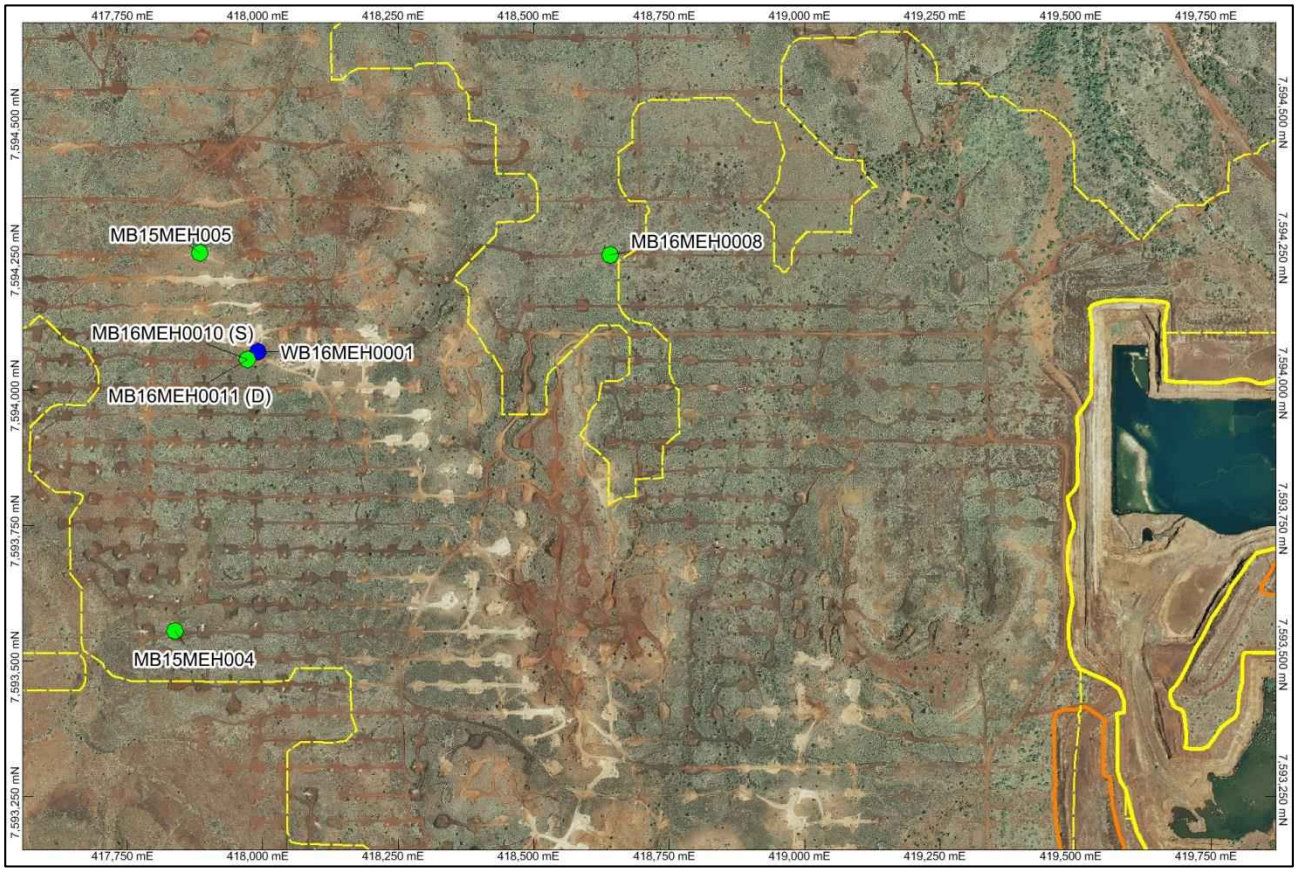


Figure 2: WB16MEH0001 CRT observation bores

The Newman-Witherspoon (1969) solution for a leaky, two aquifer system was fitted to the drawdown data for WB16MEH0001, producing a transmissivity (T) value of 61.8 m^2/day, a hydraulic conductivity (K) of 1.6 m/day and storage coefficient (S) of $8E^{-3}$ (Figure 3).

The closest adjacent bore was nested (HM16MEH0003), with a shallow piezometer (MB16MEH0010) slotted over the CID and a deep piezometer (MB16MEH0011) slotted over the Paraburdoo Member dolomite. The water level prior to pumping was similar in both the shallow (42.19 m) and deep (42.24 m) piezometers. However, MB16MEH0011 showed a much greater response to pumping, with 5.54 m of drawdown, compared to only 0.685 m of drawdown in the shallow bore MB16MEH0010.

The Cooley-Case (1973) solution for a leaky aquifer overlain by a water table aquitard was used to attempt to fit a curve to the drawdown data for MB16MEH0010 (Figure 4) producing a T of 323.30 m^2/day,

corresponding K of 20.21 m/day and S of 7.3E^{-4}. The Hantush-Jacob (1955) / Hantush (1964) solution for unsteady flow in a leaky aquifer was used to fit a curve to the drawdown data for MB16MEH0011, producing a T of 63.16 m^2/day, and corresponding K of 5.26 m/day and S of 3.3E^{-4} (Figure 5).

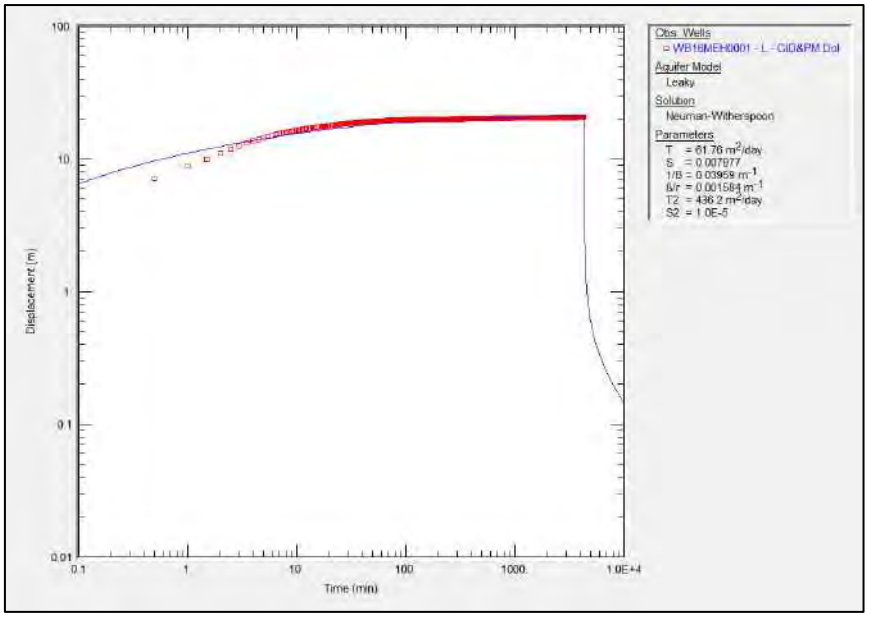


Figure 3: WB16MEH0001 CRT drawdown data with Neuman-Witherspoon solution

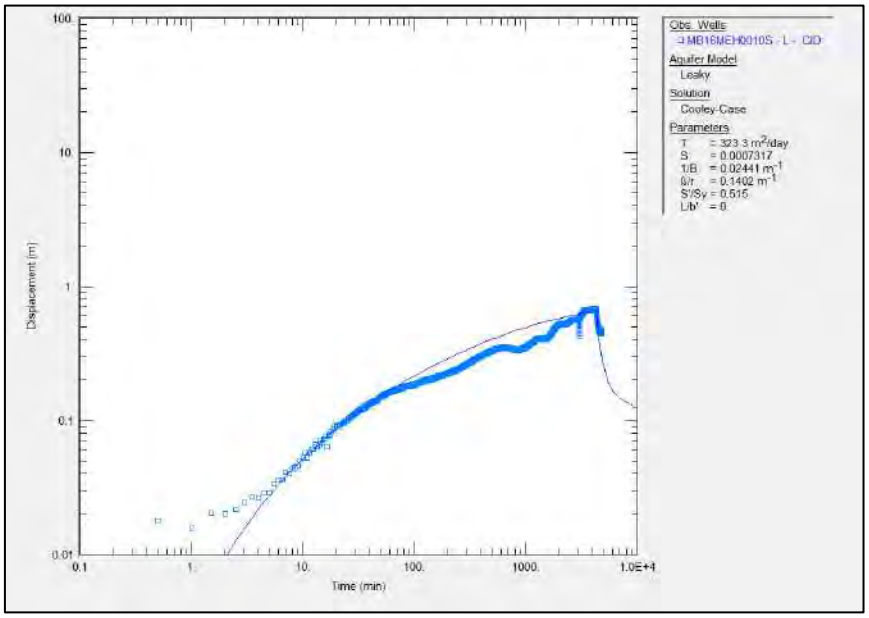


Figure 4: MB16MEH0010 CRT drawdown data with Cooley-Case solution

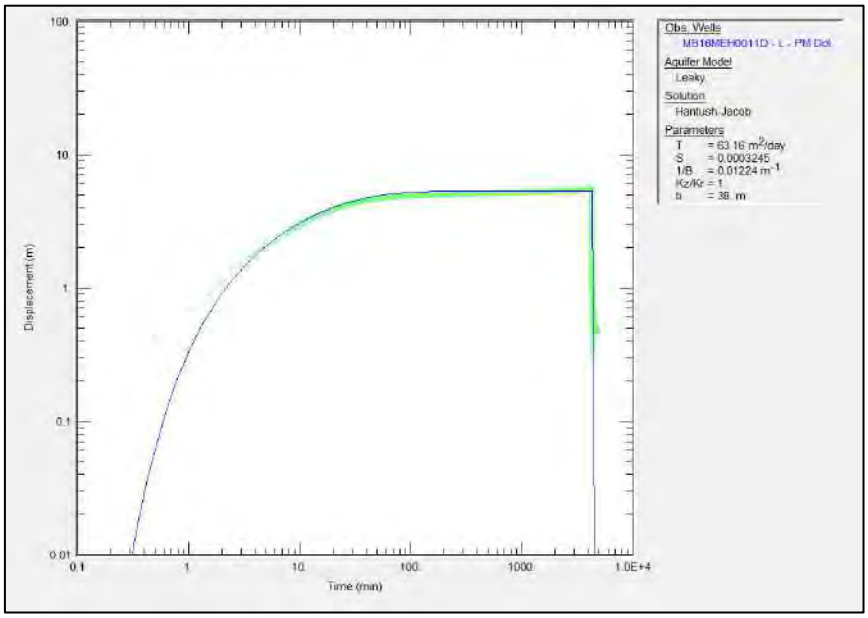


Figure 5: MB16MEH0011 CRT drawdown data with Hantush-Jacob solution

WB16MEH0002

WB16MEH0002 was slotted over the CID and pumped at a rate of 2.5 L/s, with a final drawdown of 11.05 m after 24 hours. WB16MEH0002 is located directly south of Mesa J Pit 11 Sump, a large source of water (Figure 6); in order to represent this water source in the pumping test analysis, a constant head boundary was entered. The drawdown data observed in WB16MEH0002 could not be analysed due to the lack of early data points with the steady state reached very early in the test (Figure 7).

The closest adjacent bore was MB16MEH0012, slotted over the CID and had a final drawdown of 1.41 m. The Hantush-Jacob (1955) / Hantush (1964) solution for unsteady flow in a leaky aquifer was used to fit the drawdown data for MB16MEH0012, producing a T of 19.5 m^2/day, and corresponding K of 1.5 m/day and S of $1.4E^{-4}$ (Figure 8).

Dissolved Oxygen (DO) and pH were stable during the CRT at respectively 1.6mg/L and 7.7. The electrical conductivity (EC) increased from 800 µS/cm to 860 µS/cm during the CRT , then declining to 780 µS/cm during the recovery test (Figure 9), this change in the EC is possibly associated with the increased contribution from a slightly more saline deeper aquifer as the test progresses.

Figure 6: WB16MEH0002 CRT observation bores

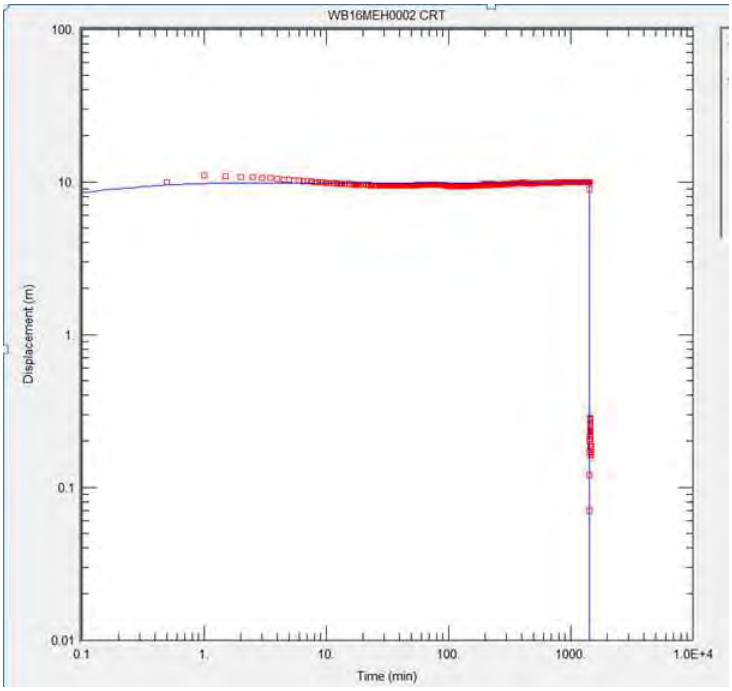


Figure 7: WB16MEH0002 CRT drawdown

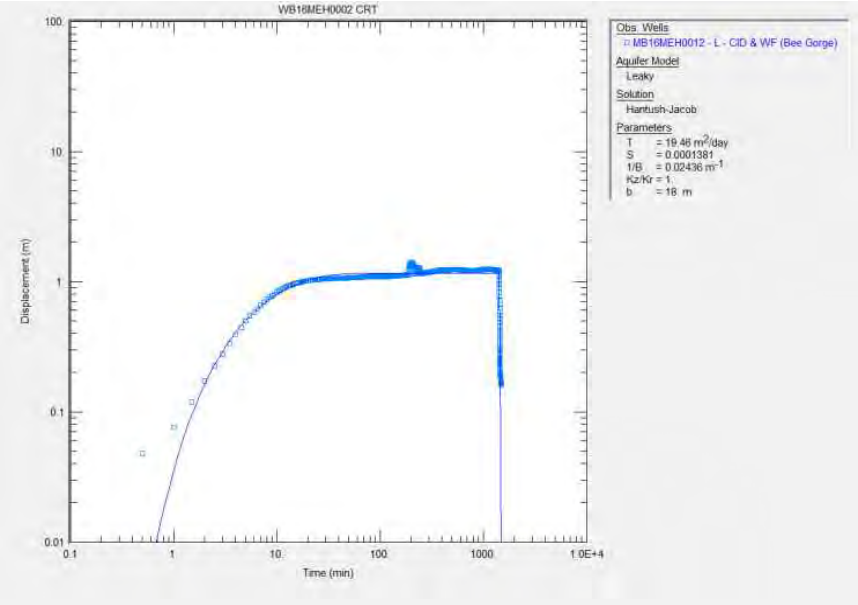


Figure 8: MB16MEH0012 CRT drawdown data with Hantush-Jacob solution

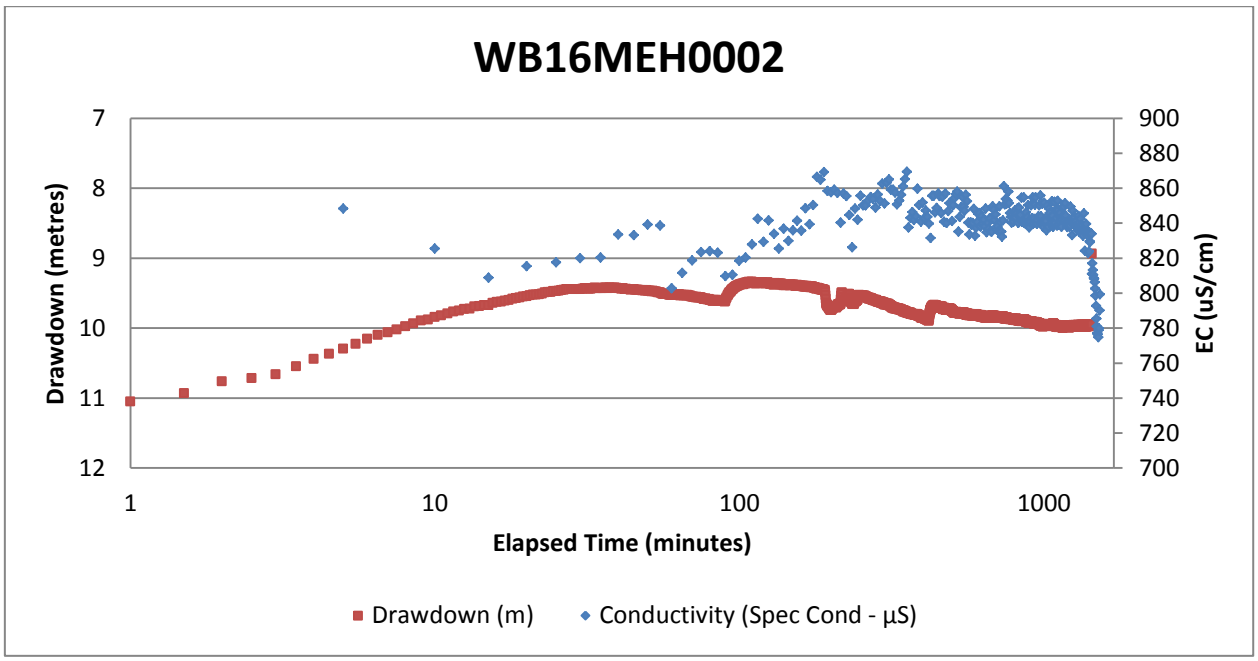


Figure 9: WB16MEH0002 drawdown and EC response during pumping test

WB16MEH0004

WB16MEH0004 was slotted over both the CID and Paraburdoo Member and pumped at 3.5 L/s for 2 days before the rate was lowered to 2.5 L/s for the remaining 8 days of the test. The water level was drawn down a total of 17.40 m over the 10 day period. WB16MEH0004 is in the northeast section of the proposed Mesa H mining area and approximately 1 km to the east of Yeera Bluff, one of the Robe River Pools (Figure 10); in order to represent this water source in the pumping test analysis, a constant head boundary was entered.

There is a dual nested monitoring bore close to the production bore, with the shallow piezometer MB16MEH0004 slotted over the CID and the deep piezometer, MB16MEH0005, slotted over the Paraburdoo Member. MB16MEH0005 showed a greater response to pumping, with 2.40 m of drawdown, compared to MB16MEH0004 with 1.20 m of drawdown.

The Newman-Witherspoon (1969) solution for a leaky, two aquifer system was fitted to the drawdown data for WB16MEH0004, producing a low T value of 10.23 m^2/day, a corresponding K of 0.43 m/day and S of $8.6E^{-6}$ (

Figure 11).

The Moench (Case 1) (1985) solution, for a leaky confined aquifer, was used fit a curve to the drawdown data for MB16MEH0004, calculating a T of 51.07 m^2/day, a corresponding K of 3.65 m/day and S of $2.7E^{-3}$ (Figure 12). The Neuman-Witherspoon (1969) solution was used to fit a curve to the drawdown data for MB16MEH0005, producing a T of 23.34 m^2/day, a corresponding K of 0.73 m/day and S of $1.8E^{-4}$ (Figure 13).

DO increased from 1 mg/L at 10 minutes, then to 2 mg/L at 650 minutes, and remained at this level until 2,880 minutes when the flow rate was decreased, and the DO declined to 1.75 mg/L until 6,000 minutes, where it levelled out for the duration of the test.

EC dropped from 940 µS/cm to 800 µS/cm at 720 minutes where it stabilised until the rate was changed, then rose to 860 µS/cm with the drawdown recovery of 7 metres in the bore until 4,000 minutes, where it started decreasing again to 800 µS/cm, and stabilising at this reading until 7,000 minutes, where the EC began to slowly increase to 850 µS/cm at the end of the test (Figure 14). ORP increased to 50 mV over the first 1,500 minutes, and then plateaued until dropping to 0 mV at 2,890 minutes, when the flow rate was dropped, with ORP increasing exponentially to 184 mV at 4,200 minutes, then at a slower rate to 231 mV until 5,700 minutes, where there was a slight decrease to 229 mV. For the rest of the test, the ORP continued to increase slowly, reaching a maximum of 248 mV by 11,410 minutes (Figure 15). Further analysis of ORP and EC change over time during the CRT test are not conclusive.

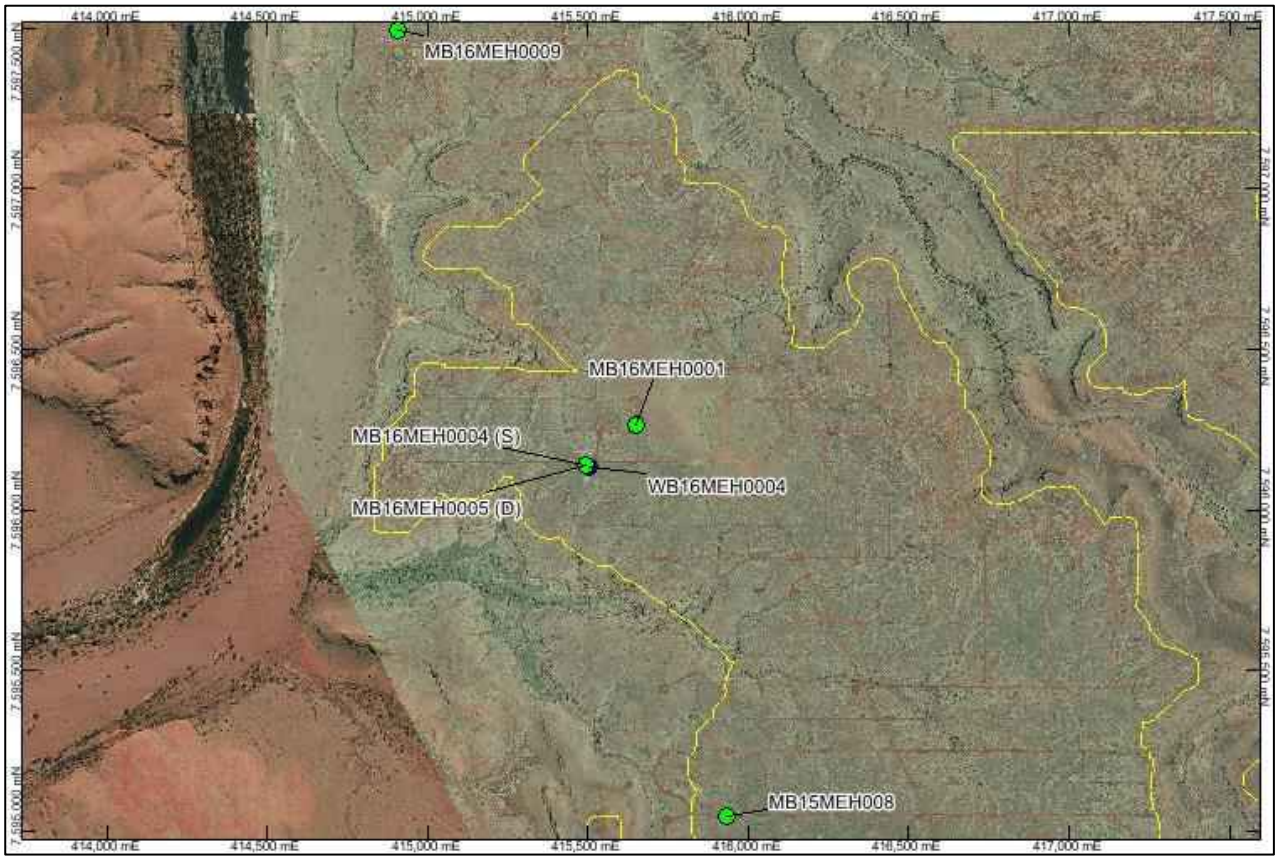


Figure 10: WB16MEH0004 CRT observation bores (Scale 1:15,000)

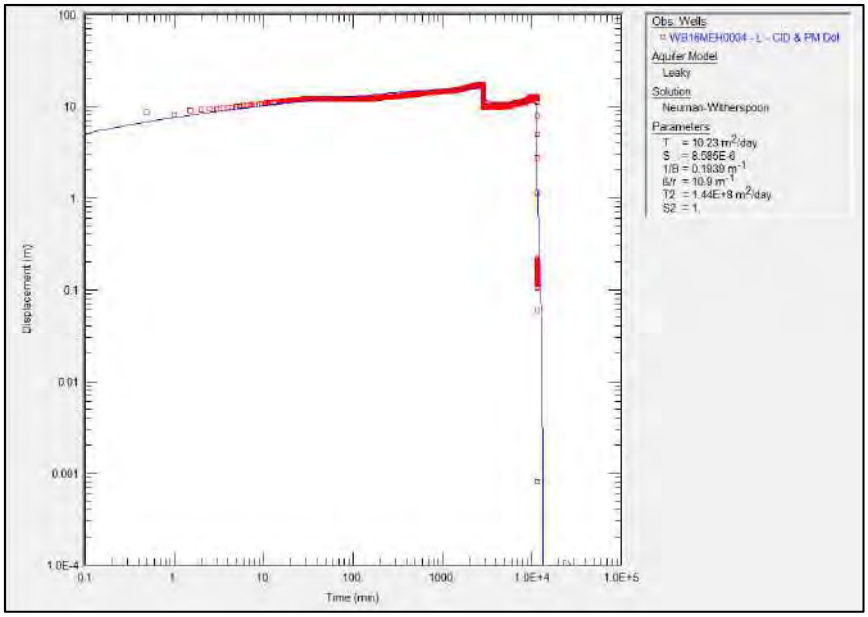


Figure 11: WB16MEH0004 CRT drawdown data with Neuman-Witherspoon solution

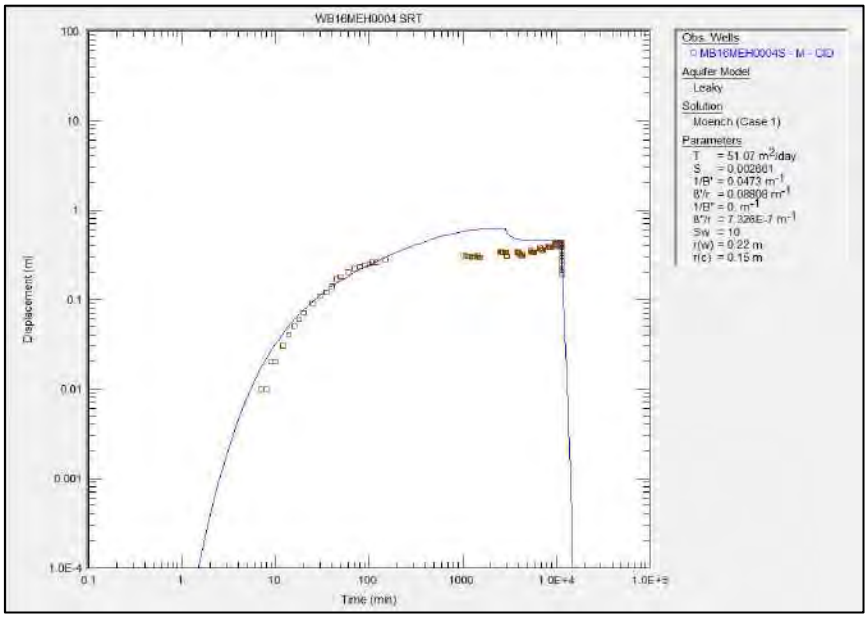


Figure 12: MB16MEH0004 CRT drawdown data with Moench solution

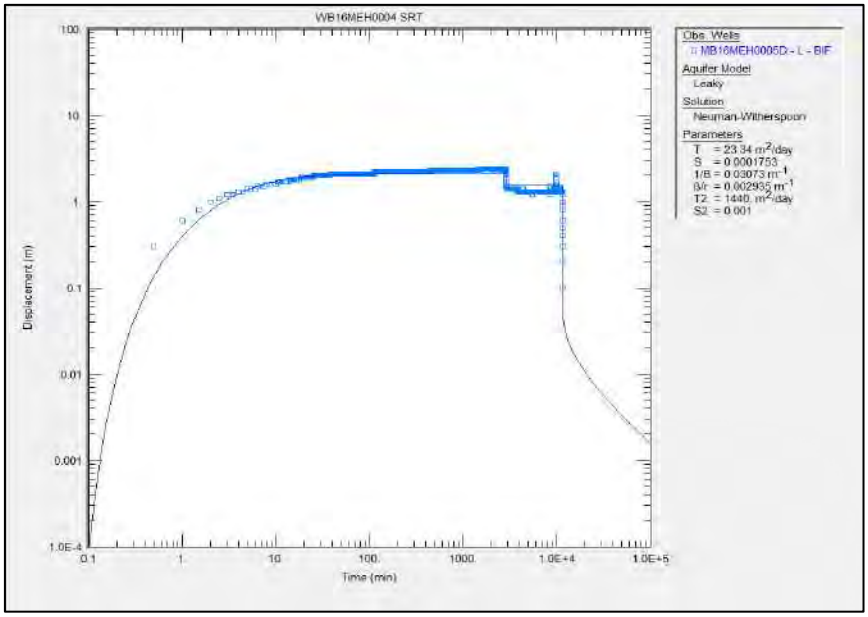


Figure 13: MB16MEH0005 CRT drawdown data with Neuman-Witherspoon solution

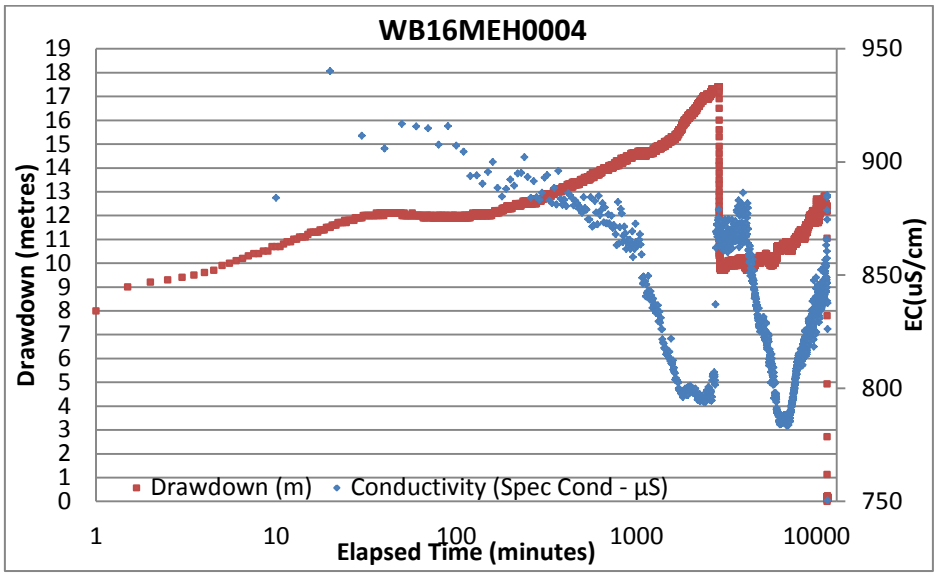


Figure 14: WB16MEH0004 CRT drawdown and EC response during pumping test

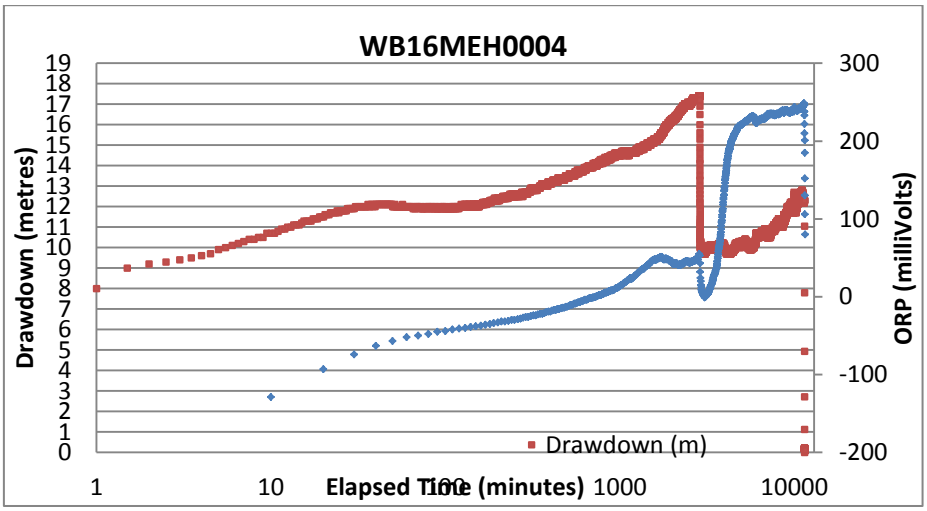


Figure 15: WB16MEH0004 CRT drawdown and ORP response during pumping test

A summary of the constant rate test analyses is presented in Table 5.

Table 5: Summary of CRT results and analysis

Test Site	Bore ID	Distance From Water Bore (m)	Discharge Rate (L/s)	CRT Duration (min)	Screened Unit	Aquifer Type	Max Drawdown (m)	Transmissivity (m2/day)	Hydraulic Conductivity (m/day)	Storage Coefficient / Specific Yield
WB16MEH0001	WB16MEH0001 RECOVERY	0	18	4,320	CID & Paraburdoo Member	Leaky	20.7	61.8	1.6	7.98 x 10-3
	MB16MEH0010	23			CID		0.7	323.3	20.2	7.32 x 10-4
	MB16MEH0011	23			Paraburdoo Member		5.5	63.2	5.3	3.25 x 10-4
	MB15MEH005	202			CID & Paraburdoo Member		Could not be analysed due to negligible drawdown			
	MB15MEH004	537			CID		Could not be analysed due to negligible drawdown			
	MB16MEH0008	620			Paraburdoo Member		Could not be analysed due to negligible drawdown			
WB16MEH0002	WB16MEH0001 RECOVERY	0	2.5	1,440	CID	Leaky	11.1	19.2	1.2	4.21 x 10-6
	MB16MEH0012	36			Paraburdoo Member		1.4	19.5	1.5	1.38 x 10-4
	MB16MEH007	275			CID		Could not be analysed due to negligible drawdown			
	MB16MEH0017	195			CID		Could not be analysed due to negligible drawdown			
	MB15MEH003	630			CID		Could not be analysed due to negligible drawdown			
WB16MEH0004	WB16MEH0004 RECOVERY	0	3.5, 2.5	11,460	CID & Paraburdoo Member	Leaky	17.4	10.2	0.4	8.59 x 10-6
	MB16MEH0004	17			CID		1.2	51.1	3.7	2.66 x 10-3
	MB16MEH0005	17			Paraburdoo Member		2.4	23.3	0.7	1.75 x 10-4
	MB16MEH0001	190			Marra Mamba Iron Formation		Could not be analysed due to negligible drawdown			
	MB15MEH008	1,170			CID & Paraburdoo Member		Could not be analysed due to negligible drawdown			
	MB16MEH0009	1,490			Wittenoom Formation		Could not be analysed due to negligible drawdown			

4.5 AQUIFER TESTING SUMMARY

A review of the pumping test results suggests the following:

- Hydraulic conductivity and storage coefficient of the CID ranges between 1.2 and 20.2 m/day and $2.6E^{-3}$ and $4.2E^{-6}$ respectively.
- Hydraulic conductivity of the Paraburdoo Member dolomite ranges between 0.7 and 5.3 m/day with a storage coefficient of approximately $2E^{-4}$.
- The bulk average hydraulic conductivity of the CID and Wittenoom aquifer has been calculated as 2.5 m/day with a storage coefficient of 5.5 E^{-3}.
- Basal CID works as a partial boundary to the vertical flow between the CID and the Wittenoom Formation aquifers observed by the difference in drawdown between the shallow and deep monitoring bores associated with the WB16MEH001 and WB16MEH004 test;
- The Robe Alluvium aquifer seems to be in hydraulic connection with the CID aquifer as suggested by the WB16MEH0004 drawdown, EC and ORP analysis.

SECTION 4 - WATER QUALITY ANALYSIS

Water quality parameters (pH, electrical conductivity (EC) and temperature) were measured on site at the end of air development with a TSP WP-81 water quality meter. Field water quality results are presented in Table 6.

Table 6 Field Water Quality

Bore ID	Peg ID	pH	EC (µS/cm)	Temp (°C)
Monitoring Bores				
MB16MEH0001	16MEH_M16	No yield achieved		
MB16MEH0002	16MEH_M08	8.04	683	32.7
MB16MEH0003	16MEH_M07	8.36	606	32.8
MB16MEH0008	16MEH_M06	8.38	606	31.8
MB16MEH0009	16MEH_M09	No yield achieved		
MB16MEH0012	16MEH_M01	8.65	583	32.3
MB16MEH0013	16MEH_M04	8.77	725	29.0
MB16MEH0014	16MEH_M11	8.08	1096	31.6
MB16MEH0016	16MEH_M11	8.33	957	30.4
MB16MEH0017	16MEH_M13	No yield achieved		
MB16MEH0018	16MEH_M05	No yield achieved		
MB16MEH0019	16MEH_M03	No yield achieved		
Nested Monitoring Bores				
S: MB16MEH0004 D: MB16MEH0005	16MEH_M15	S: 8.47 D: 5.31	S: 675 D: 609	S: 32.4 D: 31.9
S: MB16MEH0006 D: MB16MEH0007	16MEH_M02	S: No yield D: 8.60	S: No yield D: 1009	S: No yield D: 32.6
S: MB16MEH00010 D: MB16MEH00011	16MEH_M14	S: No yield D: 8.16	S: No yield D: 630	S: No yield D: 31.9
Production Bores				
WB16MEH0001	16MEH_P02	8.42	642	33.0
WB16MEH0002	16MEH_P01	8.76	550	32.5
WB16MEH0003	16MEH_P03	8.55	774	32.4
WB16MEH0004	16MEH_P04	8.66	677	31.7
Pools				
Yeera Bluff	Yeera Bluff	7.12	1350	28.5

Five samples were collected from the production bores at the beginning of each test (WB16MEH0004 also had a sample collected at the end of the test) and sent to the laboratory for analysis. The full hydrochemical

analysis results are provided in Appendix E.appendix **C SURTRON GEOPHYSICS RESULTS**

Sample WB16MEH0003 returned a significant number of anomalous and conflicting results which suggests that due to very low yield (lesser then 1L/s) the bore could not be properly developed after construction.

The results of the remaining four samples reflect the hydraulic interconnection between the CID and the Wittenoom aquifers. All the analysed parameters returned with values within the Australian Drinking Water Guidelines (2011), including:

- pH between 7.1 – 7.75
- Total Dissolved Solids between 497 – 663 mg/L
- Total Alkalinity as CaCO3 between 160 – 194 mg/L
- Sulphate as SO_4 between 24 – 38 mg/L
- Chloride between 60 – 76 mg/L
- Total Nitrate between 0.54 – 0.86 mg/L

SECTION 5 - PROGRAM FINDINGS

The PFS Hydrogeological Drilling Program at Mesa H enabled the improvement of several conceptual aspects of the hydrogeological system of the deposit. Below is a list of key findings:

- The Paraburdoo Member and the Bee Gorge Member of the Wittenoom Formation are a local aquifer with an approximate thickness of 25 metres associated with the weathered zone;
- The production bore installed outside the OoM pit shell (WB16MEH0003) and slotted across the CID and the Wittenoom Formation could not be tested or developed properly due to very low yield (<1L/s), suggesting the weathering zone of the Wittenoom Fm. is potentially associated with the mineralisation of the CID, and where the mineralisation is absent, the weathering of this stratigraphic unit is less pronounced.
- The unmineralised BIF when underlying the CID is an aquiclude, hence presenting no permeability;
- The groundwater table sits at the CID and flows from southeast to northwest ranging between 132 and 118 mRL, with a hydraulic gradient of 0.002 along the deposit area. The interpreted water table contour map is presented on Appendix F.
- The basal CID, consisting mostly of a clayish pisolite (waste) has horizontal continuity throughout the deposit, with an average thickness of 20 metres and continues underneath the Robe River alluvium towards Mesa I to the north; its hydraulic properties could not be tested but test pumping analysis suggests it works as a partial boundary reducing, but not removing, the hydraulic connection between aquifers;
- The Robe River alluvium has a thickness of approximately 20-25 meters consisting of highly permeable and low storage quaternary sediments with a shallow water table (2-10 mbgl). The long term test pumping carried out on WB16MEH0004 suggests the hydraulic connection between this aquifer and the CID aquifer;
- Test pumping results indicate an average transmissivity of 160 m^2/day, with an associated K of 2.5 m/day and storage coefficient of $5.5E^{-3}$;
- Water samples collected from the production bores suggest the hydraulic interconnection between the CID and the Wittenoom aquifers.

SECTION 6 - MEASURE OF SUCCESS

As described in the original scope, the success of the project was measured against the following drivers:

HSE:

- All drilling and clearances were contained within approved AR;

- Program was completed with one single incident: heat stress; the patient notified his supervisor immediately upon feeling unwell and was transported to the medic who advised some rest in a cool place;
- The single incident was reported and acted upon within minimal time.

Technical drivers:

- Installation and testing of 4 production bores;
- Installation of 18 monitoring bores;
- Water sampling of selected bores;

Project management drivers:

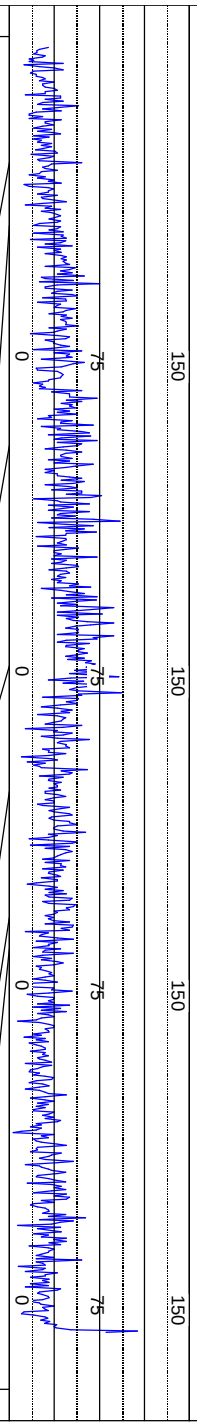
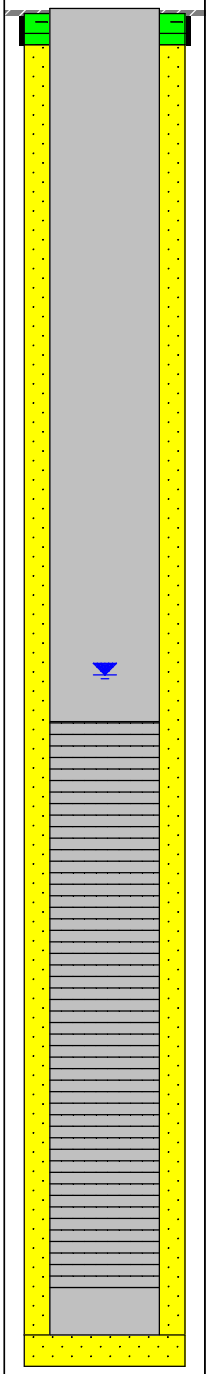
- Completion of the program free of incidents;
- Completion of the program within the schedule duration;
- Completion of the program within budget;
- Provision of accurate drilling and test pumping data;
- Maintained / enhanced relationship with site Study Manager;
- Enhanced conceptual model for dewatering planning and understanding risks of mining related impacts to groundwater levels in the Rights Reserve in support of Mesa H PFS.

APPENDIX A COMPOSITE BORE LOGS

WB16MEH0001

HOLE DETAILS	DRILLING DETAILS	LOCATION
PROJECT: Mesa H PFS 2016	**DRILLING COMPANY:** Bunbury Drilling Company	**GRID NAME:** MGA94 Zone 50
LOCATION: Mesa H	**DRILLER:** John Nesbitt	**EASTING:** 417990.96
DATE COMMENCED: 20/02/2016	**DRILLING METHOD:** Mud Rotary	**NORTHING:** 7594070.94
DATE COMPLETED: 27/02/2016	**HYDROGEOLOGIST:** Marisa Mochizuki	**ELEVATION:** 175.24 mRL (TOC)

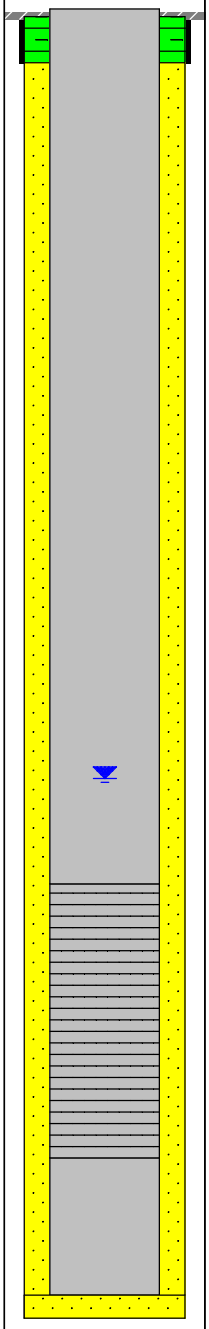
Peg ID: 16MEH_P02
Mud Rotary Tricone Bit: 17½" diameter 0 - 86 mbgl. 0 - 2 mbgl reamed to 22" diameter.

Depth (mbgl)	Geology	Lithology	Lithological Description	Gamma (0-150cps)	Field Notes	Well Design	Well Construction
0 - 85	Robe Pisolite; Wittenoom Formation (Bee Gorge)		CID: (0 - 8 mbgl): Well weathered grey, brown and red goethite, hematite and vitreous goethite, fragments of cemented pisolites and minor individual pisolites, minor off-white calcrete and yellow limonitic clay, clay increases with depth to 6 m, ony trace calcrete by 8m. CID: (8 - 12 mbgl): Well weathered mostly grey vitreous and vuggy goethite, brown and red goethite and hematite and fragments of cemented pisolites, trace individual pisolites, minor off-white calcrete and increased yellow limonitic clay. CID: (12 - 26 mbgl): Weathered grey and brown vitreous goethite with minor vughs. Moderate limonite and limonitic clay reducing from 18-26m, minor hematite and red staining. CID: (26 - 40 mbgl): Weathered grey, brown and red goethite and hematite,, fragments of cemented pisolites (to 1 mm) and minor individual pisolites, moderate yellow limonitic and grey clay reducing to minor with trace multi-coloured fine to coarse quartz sands from 36-40m CID: (40 - 48 mbgl): Well weathered grey, brown and red 1 mm goethite and hematite pisolites in a vitreous goethite matrix, minor to moderate yellow limonitic clay, increasing amounts of massive vitreous goethite from 44 - 46 mbgl. CID: (48 - 56 mbgl): Weathered grey, vitreous goethite with minor pisolite chips as described above, moderate yellow and grey clay with increased amounts from 48 - 50 mbgl. CID: (56 - 58 mbgl): Weathered grey, vitreous goethite with minor chert, shale and quartz. SHALE: (58 - 86 mbgl): Moderately weathered and fractured grey and black shale, chert and clay, minor brown shale increasing with depth, minor green chert, minor BIF and white quartz after 60m, chips up to 5 mm, becoming fresher after 78m.		Final airlift WQ: pH = 8.42 EC = 642 µS/cm Temp = 33.0°C Final airlift yield: 8-10 L/s 30-40% lost circulation at 34 mbgl. SWL: 42.04 mbgl (42.36 mbtoc)		12" steel stick up 0.35 magl, fitted with cap. Concrete plinth 1m x 1m x 300 mm (200 mm above ground level). 0 - 2 mbgl, 18 5/8" steel collar cemented in place. 2 - 84 mbgl, 3.2 - 6.4 mm graded gravel pack. 0 - 45 mbgl, 12" blank steel casing. 45 - 81 mbgl, 12" slotted steel (1mm aperture). 81 - 84 mbgl, blank steel casing with steel end cap.

WB16MEH0002

HOLE DETAILS	DRILLING DETAILS	LOCATION
PROJECT: Mesa H PFS 2016	**DRILLING COMPANY:** Bunbury Drilling Company	**GRID NAME:** MGA94 Zone 50
LOCATION: Mesa H	**DRILLER:** Dave Usher	**EASTING:** 419797.07
DATE COMMENCED: 24/02/2016	**DRILLING METHOD:** Mud Rotary	**NORTHING:** 7592735.16
DATE COMPLETED: 02/03/2016	**HYDROGEOLOGIST:** A. Price/ M. Mochizuki	**ELEVATION:** 165.03 mRL (TOC)

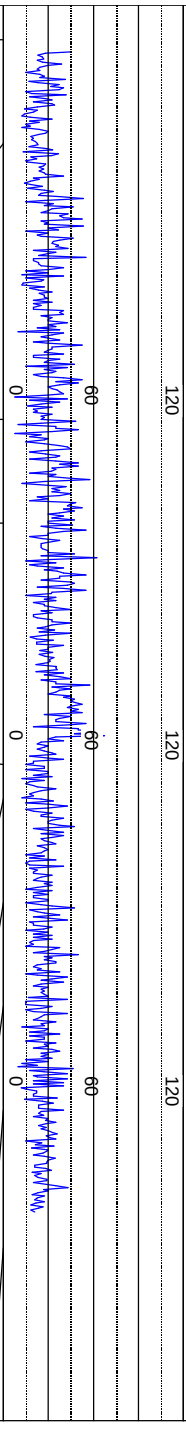
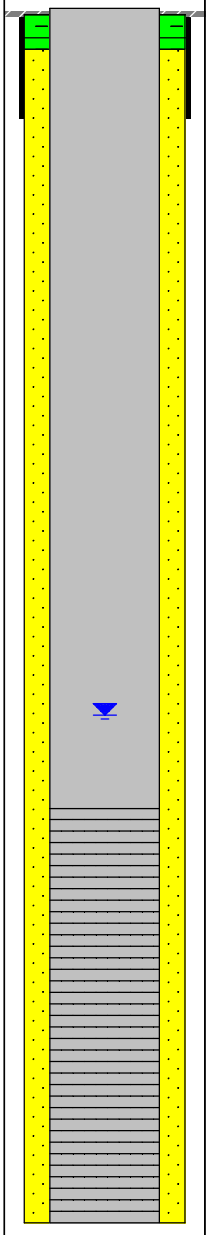
Peg ID: 16MEH_P01
Mud Rotary Tricone Bit: 17½" diameter 0 - 57 mbgl. 0 - 6 mbgl reamed to 22" diameter.

Depth (mbgl)	Geology	Lithology	Lithological Description	Gamma (0-120cps)	Field Notes	Well Design	Well Construction
0 – 60	Robe Pisolite / Wittenoom Fm		ALLUVIUM: (0 - 6 mbgl): Reddish-brown, sand and silt, sub-rounded to sub-angular gravel to 3 cm of chert, shale and BIF, vuggy goethite, minor round to sub-round goethite and hematite pisolites. CID: (6 - 8 mbgl): Weathered grey, red and brown goethite and hematite pisolites and chips of vitreous goethite minor yellow limonitic clay/mudstone, moderate fall-back/contamination. CLAY: (8 - 10 mbgl): Grey, silty clay with gravel (to 3 cm) of chert, shale, BIF, goethite and hematite. CID: (10 - 12 mbgl): Weathered grey vitreous and yellow ochreous goethite, minor pisolites, hematite and grey and yellow limonitic clay. CLAY: (12 - 14 mbgl): Grey and yellow clay with weathered vitreous to earthy goethite and minor hematite. CID: (14 - 18 mbgl): Moderately weathered vitreous and mildly vuggy hematite and goethite, minor yellow ochreous goethite, grey and yellow clay, trace hematite pisolites. CID: (16 - 20 mbgl): Weathered yellow ochreous goethite and grey vitreous to siliceous goethite, minor hematite and cemented fine (to 1mm) yellow and brown individual pisolites and pisolite clasts. CID: (20 - 32 mbgl): Red hematite and yellow ochreous to grey goethite, clasts of fine (to 1mm) cemented pisolites, minor vitreous to highly vitreous goethite. Driller notes slightly harder ground. NO SAMPLE: (32 - 62 mbgl): No sample, lost circ.	0 60 120 0 60 120	Final airlift WQ: pH = 8.76 EC = 550 µS/cm Temp = 32.5℃ Final airlift yield: 1.25 L/s SWL: 33.36 mbgl (33.86 mbtoc) Complete lost circulation at 32 mbgl. Completed two cement jobs to seal up. Continued to drill then lost full circulation at 34 mbgl. Drilled blind for remainder of hole. Hard ground from ~48 mbgl.		12" steel stick up 0.35 magl, fitted with cap. Concrete plinth 1m x 1m x 300 mm (200 mm above ground level). 0 - 6 mbgl, 18 5/8" steel collar cemented in place. 2 - 57 mbgl, 3.2 - 6.4 mm graded gravel pack. 0 - 38 mbgl, 12" blank steel casing. 38 - 50 mbgl, 12" slotted steel (1mm aperture). 50 - 56 mbgl, blank steel casing with steel end cap.

WB16MEH0003

HOLE DETAILS	DRILLING DETAILS	LOCATION
PROJECT: Mesa H PFS 2016	**DRILLING COMPANY:** Bunbury Drilling Company	**GRID NAME:** MGA94 Zone 50
LOCATION: Mesa H	**DRILLER:** John Nesbitt	**EASTING:** 416321.85
DATE COMMENCED: 01/03/2016	**DRILLING METHOD:** Mud Rotary	**NORTHING:** 7594781.07
DATE COMPLETED: 08/03/2016	**HYDROGEOLOGIST:** Marisa Mochizuki	**ELEVATION:** 170.06 mRL (TOC)

Peg ID: 16MEH_P03
Mud Rotary Tricone Bit: 17½" diameter 0 - 70 mbgl. 0 - 2 mbgl reamed to 22" diameter.

Depth (mbgl)	Geology	Lithology	Lithological Description	Gamma (0-120cps)	Field Notes	Well Design	Well Construction
0 - 70	Robe Pisolite; Wittenoom Formation (Bee Gorge)		CID: (0 - 6 mbgl): Moderately weathered grey and brown vitreous goethite, minor calcrete, and yellow ochreous goethite. Most chips are 3mm with some rare 5mm chips. CID: (6 - 22 mbgl): Moderately weathered grey and brown vitreous goethite, minor yellow ochreous goethite, calcrete, hematite, trace yellow and grey clay, increase in ochreous goethite from 16m, trace individual (to 1mm) pisolites and pisolites in a vitreous goethite matrix from 18-22m. CID: (22 - 28 mbgl): Pisolite as above with significant yellow and grey clay and hematite, trace red clay from 26-28 mbgl. CID: (28 - 42 mbgl): Mix of hematite, yellow ochreous and grey vitreous goethite, minor pisolites in a vitreous goethite matrix, minor grey, yellow and red clay, significant grey and yellow clay at 40-42m and chips of highly weathered/decomposed pisolite (pisolites and brecciated clasts of goethite (to 1mm) in a yellow orange and grey clay matrix, soft and friable). CLAY: (42 - 44 mbgl): Grey and yellow clay with minor hematite, ochreous and vitreous goethite, and highly weathered pisolite. CID: (44 - 50 mbgl): Mix of hematite, ochreous and vitreous goethite, significant grey and yellow clay and chips of highly weathered pisolite. CLAY: (50 - 56 mbgl): Sandy olive grey dolomitic clay from highly weathered dolomite and minor hematite, ochreous goethite and highly weathered pisolite. DOLOMITE: (56 - 62 mbgl): Olive grey chips (to 10mm) of soft and friable, highly weathered dolomite, minor sub rounded chips (to 5mm) of hematite, ochreous and vitreous goethite and dolomitic clay. Driller notes ground becoming harder. DOLOMITE: (62 - 70): Olive grey angular chips (to 3mm) of fresh microcrystalline dolomite and dark grey chert. becoming darker and harder from 66m. Driller notes very hard ground and slow penetration rates.		Final airlift WQ: pH = 8.55 EC = 774 µS/cm Temp = 32.4 ℃ Final airlift yield: <0.1 L/s Hard ground, slow penetration rates (1 m/hr) from 0 - 14 mbgl. SWL: 40.56 mbgl (40.92 mbtoc) Very low developing yield, well clean was used, the well was surged with water and water was injected into the annulus to help breakup and remove the mud and fines. Very hard ground, slow penetration rates (1-3 m/hr) from 62.5 - 70 mbgl.		12" steel stick up 0.35 magl, fitted with cap. Concrete plinth 1m x 1m x 300 mm (200 mm above ground level). 0 - 6 mbgl, 18 5/8" steel collar cemented in place. 2 - 70 mbgl, 3.2 - 6.4 mm graded gravel pack. 0 - 46 mbgl, 12" blank steel casing. 46 - 70 mbgl, 12" slotted steel (1mm aperture), with steel end cap.

WB16MEH0004

HOLE DETAILS

PROJECT: Mesa H PFS 2016
LOCATION: Mesa H
DATE COMMENCED: 04/03/2016
DATE COMPLETED: 13/03/2016

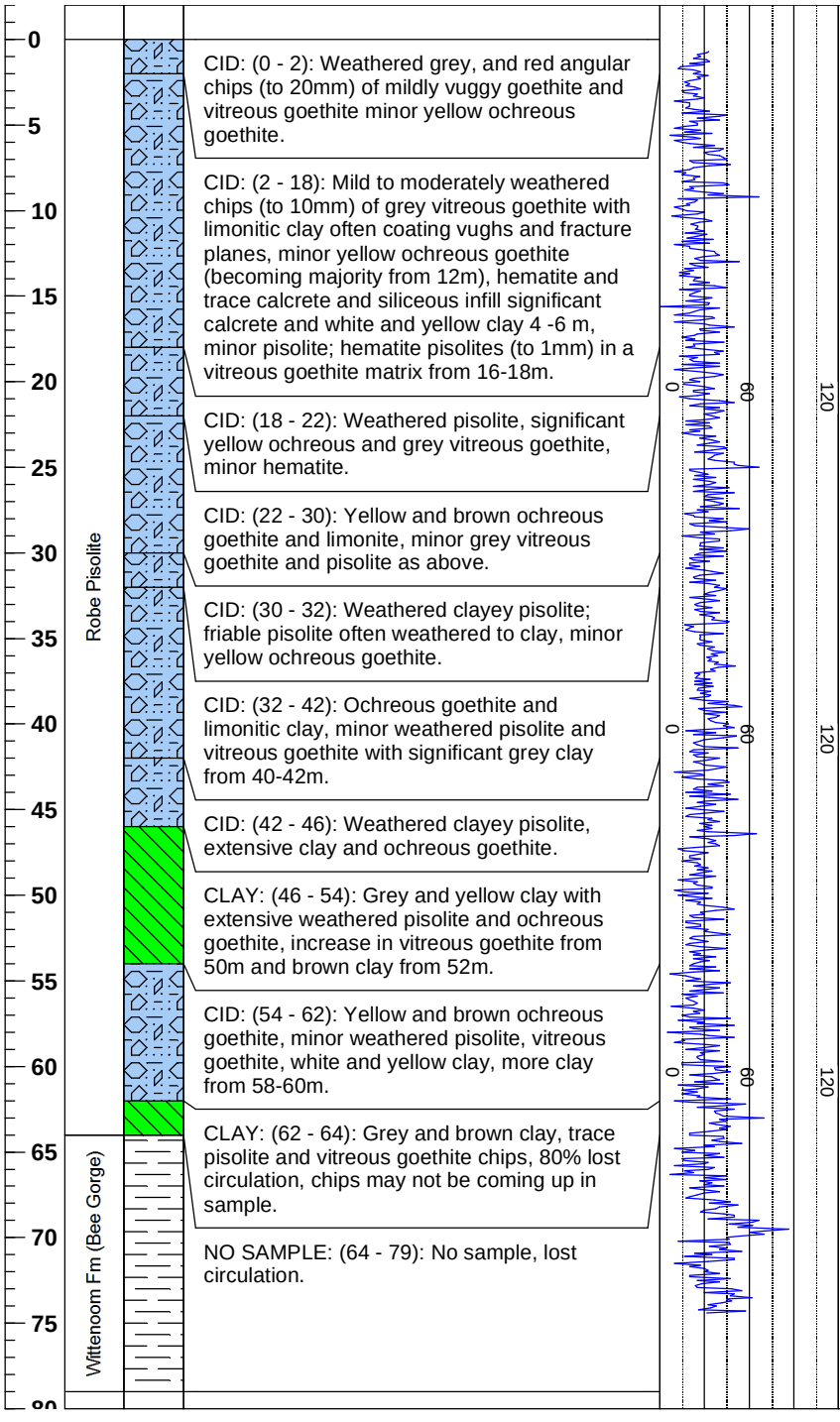
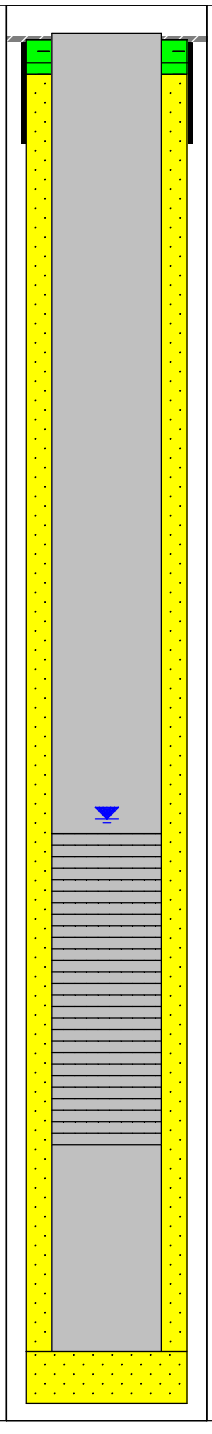
DRILLING DETAILS

DRILLING COMPANY: Bunbury Drilling Company
DRILLER: Tom Massey
DRILLING METHOD: Mud Rotary
HYDROGEOLOGIST: Marisa Mochizuki

LOCATION

GRID NAME: MGA94 Zone 50
EASTING: 415504.09
NORTHING: 7596133.77
ELEVATION: 164.90 mRL (TOC)

Peg ID: 16MEH_P04
Mud Rotary Tricone Bit: 17½" diameter 0 - 79 mbgl. 0 - 6 mbgl reamed to 22" diameter.

Depth (mbgl)	Geology	Lithology	Lithological Description	Gamma (0-120cps)	Field Notes	Well Design	Well Construction
0 - 80	Robe Pisolite / Wittenoom Fm (Bee Gorge)		CID: (0 - 2): Weathered grey, and red angular chips (to 20mm) of mildly vuggy goethite and vitreous goethite minor yellow ochreous goethite. CID: (2 - 18): Mild to moderately weathered chips (to 10mm) of grey vitreous goethite with limonitic clay often coating vughs and fracture planes, minor yellow ochreous goethite (becoming majority from 12m), hematite and trace calcrete and siliceous infill significant calcrete and white and yellow clay 4 -6 m, minor pisolite; hematite pisolites (to 1mm) in a vitreous goethite matrix from 16-18m. CID: (18 - 22): Weathered pisolite, significant yellow ochreous and grey vitreous goethite, minor hematite. CID: (22 - 30): Yellow and brown ochreous goethite and limonite, minor grey vitreous goethite and pisolite as above. CID: (30 - 32): Weathered clayey pisolite; friable pisolite often weathered to clay, minor yellow ochreous goethite. CID: (32 - 42): Ochreous goethite and limonitic clay, minor weathered pisolite and vitreous goethite with significant grey clay from 40-42m. CID: (42 - 46): Weathered clayey pisolite, extensive clay and ochreous goethite. CLAY: (46 - 54): Grey and yellow clay with extensive weathered pisolite and ochreous goethite, increase in vitreous goethite from 50m and brown clay from 52m. CID: (54 - 62): Yellow and brown ochreous goethite, minor weathered pisolite, vitreous goethite, white and yellow clay, more clay from 58-60m. CLAY: (62 - 64): Grey and brown clay, trace pisolite and vitreous goethite chips, 80% lost circulation, chips may not be coming up in sample. NO SAMPLE: (64 - 79): No sample, lost circulation.		Final airlift WQ: pH = 8.66 EC = 677 µS/cm Temp = 31.7℃ Final airlift yield: 1.8 L/s SWL: 45.15 mbgl (45.55 mbtoc) Water loss (to 70-80%) was experienced between 54-62 mbgl. Complete lost circulation from 62 mbgl.		12" steel stick up 0.35 magl, fitted with cap. Concrete plinth 1m x 1m x 300 mm (200 mm above ground level). 0 - 6 mbgl, 18 5/8" steel collar cemented in place. 2 - 79 mbgl, 3.2 - 6.4 mm graded gravel pack. 0 - 46 mbgl, 12" blank steel casing. 46 - 64 mbgl, 12" slotted steel (1mm aperture).

MB16MEH0001

HOLE DETAILS	DRILLING DETAILS	LOCATION
PROJECT: Mesa H PFS 2016	**DRILLING COMPANY:** Ranger Drilling	**GRID NAME:** MGA 94, Zone 50
LOCATION: Mesa H	**DRILLER:** Adam Mennell	**EASTING:** 415648.30
DATE COMMENCED: 22/02/16	**DRILLING METHOD:** RC	**NORTHING:** 7596263.24
DATE COMPLETED: 23/02/16	**HYDROGEOLOGIST:** Marisa Mochizuki	**ELEVATION:** 166.52 mRL (TOC)

Peg ID: 16MEH_M16
RC: 7½" diameter 0 - 5 mbgl. 5 - 76 mbgl 5½" diameter.

Depth (mbgl)	Geology	Lithology	Lithological Description	Gamma (0-80cps)	Field Notes	Well Design	Well Construction
0	Alluvium		ALLUVIUM: (0 - 4 mbgl): Reddish-brown, angular to sub-round gravel (to 3cm), brown sand and silt.	0 40 80	No airlift yield.		6" PVC collar grouted, 0 - 6 mbgl. Steel stick up 700 mm above natural surface. 1 m x 1 m x 300 mm concrete plinth (200 mm above ground level).
5	Robe Pisolite		CID: (4 - 24 mbgl): Brown and grey with yellow ocherous goethite, moderately weathered in places (particularly btwn 4 and 8 mbgl). Minor limonitic clay, rare calcrete and hematite.				0 - 2 mbgl, bentonite seal.
10							50mm blank PVC casing, -0.50 - 52 mbgl.
15							
20							
25	Marra Mamba		BIF: (24 - 28 mbgl): Weathered BIF. Yellow, red and grey chert. Minor grey shale, rare quartz. Strongly weathered and fractured.				2 - 64 mbgl, 3.2 - 6.4 mm graded gravel pack.
30			BIF: (28 - 40 mbgl): Brownish-red and yellow chert, yellow ocherous goethite. Metallic grey BIF. Rare quartz. Some fracturing and minor weathering.				
35							
40			BIF/CLAY: (40 - 42 mbgl): Stiff green, grey and red clay (banded). Softer yellow clay, minor dark grey and yellow chert and quartz.				
45			BIF: (42 - 44 mbgl): Black, grey and yellow chert. BIF and rare quartz.		SWL: 46.49 mbgl (46.94 mbtoc)		
50			CLAY: (44 - 52 mbgl): Soft reddish-brown clay.				
55			BIF: (52 - 58 mbgl): Dark grey BIF, grey yellow and greenish chert.				52 - 64 mbgl, 50mm slotted PVC casing.
60			SHALE: (58 - 64 mbgl): Black shale, moderately weathered, friable.				
65							

MB16MEH0002

HOLE DETAILS

PROJECT: Mesa H PFS 2016
LOCATION: Mesa H
DATE COMMENCED: 10/2/2015
DATE COMPLETED: 11/2/2015

DRILLING DETAILS

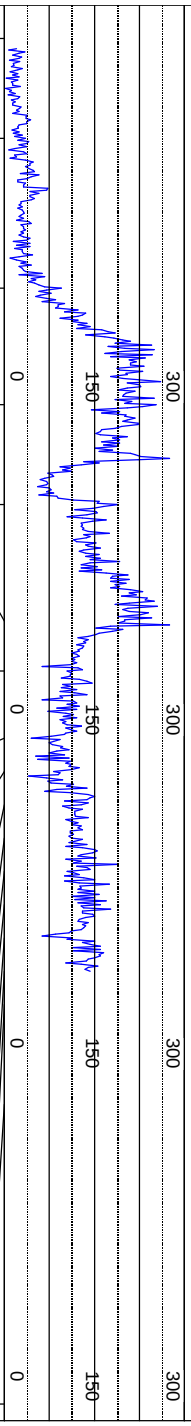
DRILLING COMPANY: Ranger Drilling
DRILLER: Adam Mennell
DRILLING METHOD: RC
HYDROGEOLOGIST: A.Price

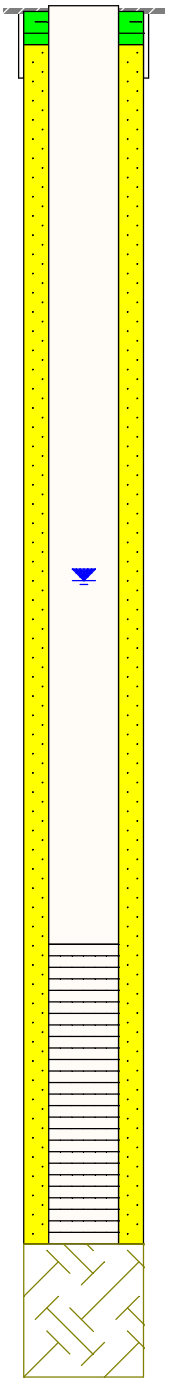
LOCATION

GRID NAME: MGA 94, Zone 50
EASTING: 418342.63
NORTHING: 7595994.38
ELEVATION: 167.57 mRL (TOC)

Peg ID: 16MEH_M08
RC: 7½" diameter 0 - 5 mbgl. 5 - 82 mbgl 5½" diameter.

Depth (mbgl)	Geology	Lithology	Lithological Description	Gamma (0-300cps)	Field Notes	Well Design	Well Construction
0	Robe Pisolite		CID: (0 - 6 mbgl): Blue-grey metallic and brown chips, some pitting in places. Minor hematite and yellow ocherous goethite.				6" PVC collar grouted, 0 - 4 mbgl. Steel stick up 700 mm above natural surface. 1 m x 1 m x 300 mm concrete plinth (200 mm above ground level).
5							
10			CID: (6 - 15 mbgl): Grey and brown, minor yellow goethite, grey vitreous goethite. Moderate weathering, some limonitic clay.				
15	Wittenoom Formation (Bee Gorge)		CLAY: (15 - 22 mbgl): Mottled brown, red and white clay.				0 - 2 mbgl, bentonite seal.
20					Final airlift yield: 1L/s. pH: 8.04 EC: 683 µS/cm Temp: 32.7℃		50mm blank PVC casing, -0.50 - 56 mbgl.
25			CALCRETE: (22 - 28 mbgl): Off white calcrete, some sub-round brown gravel to 2mm.				
30			CLAY: (28 - 35 mbgl): Sticky, off white clay.				2 - 74 mbgl, 3.2 - 6.4 mm graded gravel pack.
35			CLAY: (35 - 38 mbgl): Very dense, sticky dark grey to black clay.		SWL: 34.18 mbgl (34.64 mbtoc)		
40			CLAY: (38 - 42 mbgl): Sticky mottled white, dark grey and red clay.				
45			CLAY: (42 - 44 mbgl): Sticky brown clay.		First water strike at 42 mbgl - very little flow (<0.1L/s).		
50			CLAY: (44 - 46 mbgl): Soft red clay with chips of hematite, red, purple and yellow shale.				
55			SHALE: (46 - 48 mbgl): As above but only minor clay.				56 - 74 mbgl ,50mm slotted PVC casing.
60			CLAY: (48 - 50 mbgl): Sticky purple clay.				
65	Wittenoom Dolomite		CLAY: (50 - 52 mbgl): Off white and grey clay.				
70			CLAY: (52 - 54 mbgl): Dark grey to black sticky clay.		Second water strike at 64 mbgl, 2.5L/s increasing to 3L/s by 70 mbgl.		
75			CLAY: (54 - 56 mbgl): Dark grey and brown sticky clay.				Hole collapsed from 74 to 82 mbgl.
80			CLAY: (56 - 58 mbgl): Grey, white and brown sticky clay.				
			CLAY: (58 - 64 mbgl): Sticky dark grey clay.				
			DOLOMITE: (64 - 80 mbgl): Bluish grey dolomite. Strongly weathered in places. Abundant quartz btwn 70 and 72 mbgl.				





MB16MEH0003

HOLE DETAILS

PROJECT: Mesa H PFS 2016
LOCATION: Mesa H
DATE COMMENCED: 12/2/2015
DATE COMPLETED: 14/2/2015

DRILLING DETAILS

DRILLING COMPANY: Ranger Drilling
DRILLER: Ben Smith
DRILLING METHOD: RC
HYDROGEOLOGIST: A.Price

LOCATION

GRID NAME: MGA 94, Zone 50
EASTING: 419013.90
NORTHING: 7595067.08
ELEVATION: 175.67 mRL (TOC)

Peg ID: 16MEH_M07
RC: 7½" diameter 0 - 5 mbgl. 5 - 84 mbgl 5½" diameter.

Depth (mbgl)	Geology	Lithology	Lithological Description	Gamma (0-300cps)	Field Notes	Well Design	Well Construction
0 - 84	Robe Pisolite / Wittenoom Formation (Bee Gorge)		CID: (0 - 6 mbgl): Dark grey and brown, vitreous goethite, round to sub-round pisolites to 2mm. CID: (6 - 12 mbgl): Grey vitreous goethite, yellow ocherous goethite, moderately weathered. CID: (12 - 31 mbgl): Yellow limonitic clay, yellow ocherous goethite, grey vitreous goethite, rare hematite. CID: (31 - 34 mbgl): Pisolite with red hematite and yellow goethite pisolites in grey vitreous goethite matrix. Yellow ocherous goethite, brown clay. CLAY: (34 - 45 mbgl): Brown clay with minor yellow ocherous and grey vitreous goethite. CHERT: (45 - 47 mbgl): Strongly weathered light grey and light yellow chert. CLAY: (47 - 58 mbgl): Brown clay. QUARTZ: (58 - 65 mbgl): Weathered and unweathered quartz. Strongly fractured and broken. CLAY: (65 - 70 mbgl): Off white clay. CLAY: (70 - 74 mbgl): Brown and grey clay. CLAY: (74 - 76 mbgl): Strongly weathered dark grey shale and grey clay. CLAY: (76 - 84 mbgl): Sticky grey clay.	0 150 300	Final airlift yield: 0.1 - 0.2L/s. pH: 8.36 EC: 606 µS/cm Temp: 32.8℃ SWL: 40.54 mbgl (41.12 mbtoc) First water strike approx 40 mbgl - very little flow (<0.1L/s). No further increase during drilling.	6" PVC collar grouted, 0 - 4 mbgl. Steel stick up 700 mm above natural surface. 1 m x 1 m x 300 mm concrete plinth (200 mm above ground level). 0 - 2 mbgl, bentonite seal. 2 - 84 mbgl, 3.2 - 6.4 mm graded gravel pack. 50mm blank PVC casing, -0.50 - 66 mbgl. 66 - 84 mbgl ,50mm slotted PVC casing.

MB16MEH0004/ MB16MEH0005

HOLE DETAILS

PROJECT: Mesa H PFS 2016
LOCATION: Mesa H
DATE COMMENCED: 15/2/2016
DATE COMPLETED: 16/2/2016

DRILLING DETAILS

DRILLING COMPANY: Bunbury Drilling
DRILLER: Luke Wallace
DRILLING METHOD: Air Hammer
HYDROGEOLOGIST: Ashley Price

LOCATION

GRID NAME: MGA 94, Zone 50
EASTING: 415490.51
NORTHING: 7596140.85
ELEVATION S: 165.24 mRL TOC
ELEVATION D: 165.31 mRL TOC

Peg ID: 16MEH_M15
Hammer Bit: 14¾" diameter 0 - 6 mbgl . 8½" diameter 0 - 78 mbgl.
Shallow piezometer - MB16MEH0004, deep piezometer - MB16MEH0005. Parent hole - HM16MEH0001

Depth (mbgl)	Geology	Lithology	Lithological Description	Gamma (0-200 cps)	Field Notes	Well Design	Well Construction
0	Robe Pisolite		ALLUVIUM: (0 - 2 mbgl): Reddish-brown, sub-round to sub-angular gravel to 3cm. Dark grey angular gravel to 1 cm. Minor yellow ocherous goethite.		Shallow Piezo Final airlift yield - ~10 L/min pH - 8.47 EC - 675 µS/cm Temp - 32.4℃		10" steel collar grouted, 0 - 6 mbgl. Steel stick up 500 mm above natural surface. 1 m x 1 m x 300 mm concrete plinth (200 mm above ground level).
5			CID: (2 - 10 mbgl): Hard cap. Dark grey vitreous goethite, minor red hematite and rare yellow ocherous goethite. Minor white clay btwn 4 and 6 mbgl.				
10							Bentonite seal, 0 - 2 mbgl.
15			CID: (10 - 24 mbgl): Yellow ocherous goethite and limonitic clay. Pisolite, red pisolites in brown matrix. Minor dark grey vitreous goethite.				
20							
25			CID: (24 - 28 mbgl): Fractured and weathered grey vitreous goethite. Vughy pisolite.				
30			CID: (28 - 50 mbgl): Pisolite, strongly weathered to clay in places. Yellow ocherous goethite and limonitic clay. Vughy pisolite, red and yellow pisolites in brown and grey matrix.				3.2 - 6.4 mm graded gravel pack, 0 - 60 mbgl and 64 - 78 mbgl.
35							
40							
45					SWL Shallow - 45.15 m bgl (45.89 m btoc) Deep - 45.11 m bgl (45.92 m btoc)		
50			CID: (50 - 60 mbgl): Strongly weathered vitreous goethite and pisolite. Yellow ocherous goethite and rare off-white clay.				50mm blank PVC casing, -0.50 - 48 mbgl. 50mm slotted PVC casing, 48 - 60 mbgl.
55							
60	Wittenoom Fm		BIF: (60 - 64 mbgl): Strongly weathered red-purple BIF. White and pink clay.		Deep Piezo Final airlift yield - 0.5 L/s pH - 5.31 EC - 609 µS/cm Temp - 31.9℃		Bentonite seal, 60 - 64 mbgl.
65			CLAY: (64 - 69 mbgl): Dark greenish-grey clay.				
70			SHALE: (69 - 76 mbgl): Strongly weathered dark grey shale.				50mm blank PVC casing, -0.50 - 66 mbgl. 50mm slotted PVC casing, 66 - 78 mbgl.
75			BIF: (76 - 78 mbgl): Strongly weathered and fractured BIF, grey chert and shale.				
80							

MB16MEH0006 / MB16MEH0007

HOLE DETAILS

PROJECT: Mesa H PFS 2016
LOCATION: Mesa H
DATE COMMENCED: 14/02/2016
DATE COMPLETED: 29/02/2016

DRILLING DETAILS

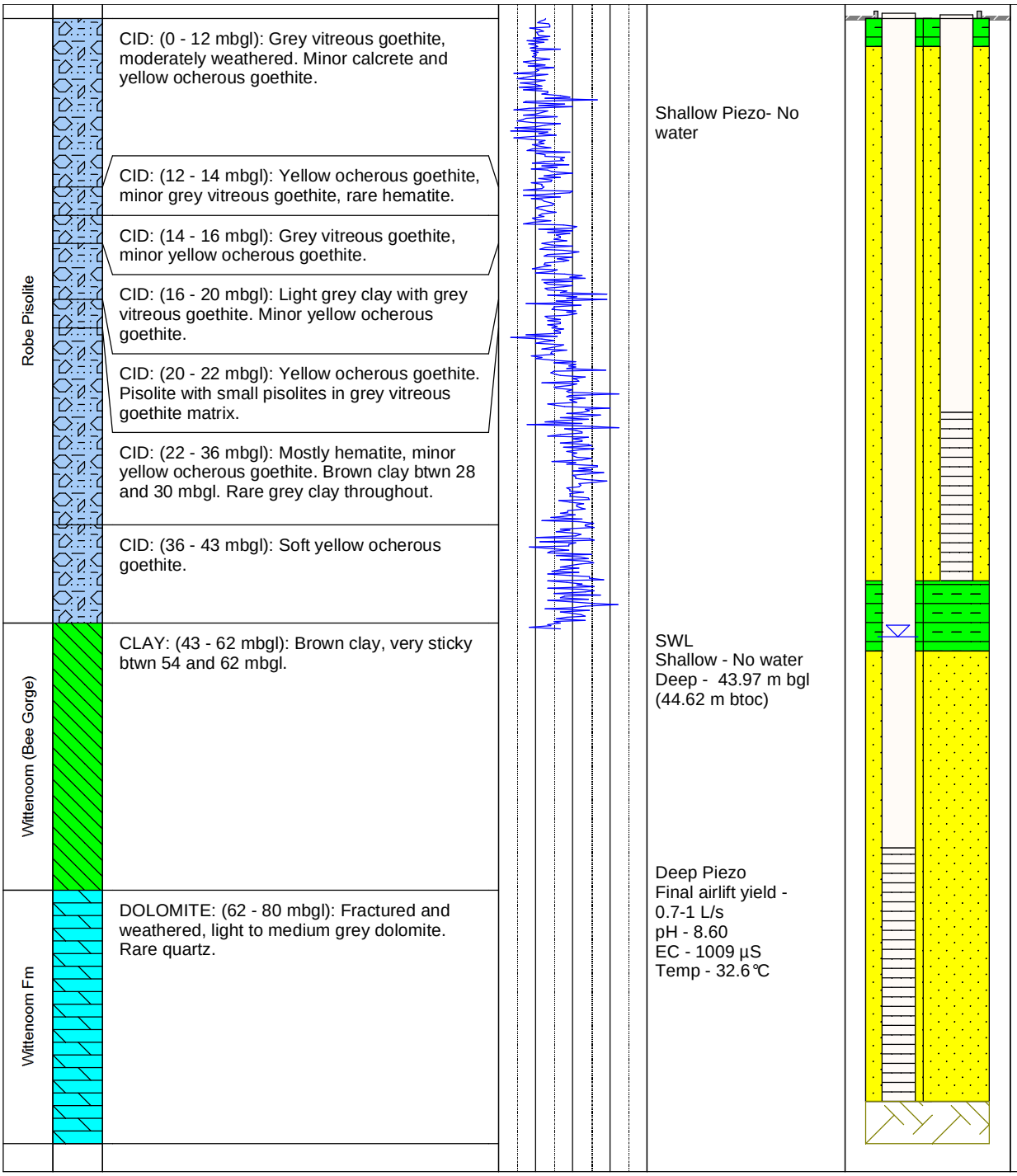
DRILLING COMPANY: Bunbury Drilling
DRILLER: Dan Morris
DRILLING METHOD: Air Hammer
HYDROGEOLOGIST: Ashley Price

LOCATION

GRID NAME: MGA 94, Zone 50
EASTING: 416312.82
NORTHING: 7594795.87
ELEVATION S: 170.5 mRL TOC
ELEVATION D: 170.11 mRL TOC

Peg ID: 16MEH_M02
Hammer Bit: 14¾" diameter 0 - 6 mbgl . 8½" diameter 0 - 80 mbgl.
Shallow piezometer - MB16MEH0006, deep piezometer - MB16MEH0007. Parent hole HM16MEH0002

Depth (mbgl)	Geology	Lithology	Lithological Description	Gamma (0-120 cps)	Field Notes	Well Design	Well Construction
0	Robe Pisolite		CID: (0 - 12 mbgl): Grey vitreous goethite, moderately weathered. Minor calcrete and yellow ocherous goethite.		Shallow Piezo- No water		10" steel collar grouted, 0 - 6 mbgl. Steel stick up 500 mm above natural surface. 1 m x 1 m x 300 mm concrete plinth (200 mm above ground level).
10			CID: (12 - 14 mbgl): Yellow ocherous goethite, minor grey vitreous goethite, rare hematite.				Bentonite seal, 0 - 2 mbgl.
15			CID: (14 - 16 mbgl): Grey vitreous goethite, minor yellow ocherous goethite.				50mm blank PVC casing, -0.50 - 28 mbgl. 50mm slotted PVC casing, 28 - 40 mbgl.
20			CID: (16 - 20 mbgl): Light grey clay with grey vitreous goethite. Minor yellow ocherous goethite.				
25			CID: (20 - 22 mbgl): Yellow ocherous goethite. Pisolite with small pisolites in grey vitreous goethite matrix.				3.2 - 6.4 mm graded gravel pack, 0 - 40 mbgl and 45 - 77 mbgl.
30			CID: (22 - 36 mbgl): Mostly hematite, minor yellow ocherous goethite. Brown clay btwn 28 and 30 mbgl. Rare grey clay throughout.				
35							
40			CID: (36 - 43 mbgl): Soft yellow ocherous goethite.				
45	Wittenoom (Bee Gorge)		CLAY: (43 - 62 mbgl): Brown clay, very sticky btwn 54 and 62 mbgl.		SWL Shallow - No water Deep - 43.97 m bgl (44.62 m btoc)		Bentonite seal, 40 - 45 mbgl.
50							
55							
60					Deep Piezo Final airlift yield - 0.7-1 L/s pH - 8.60 EC - 1009 µS Temp - 32.6℃		50mm blank PVC casing, -0.50 - 59 mbgl. 50mm slotted PVC casing, 59 - 77 mbgl.
65	Wittenoom Fm		DOLOMITE: (62 - 80 mbgl): Fractured and weathered, light to medium grey dolomite. Rare quartz.				
70							
75							
80							Hole collapsed from 77 to 80 mbgl.



MB16MEH0008

HOLE DETAILS

PROJECT: Mesa H PFS 2016
LOCATION: Mesa H
DATE COMMENCED: 15/2/2015
DATE COMPLETED: 16/2/2015

DRILLING DETAILS

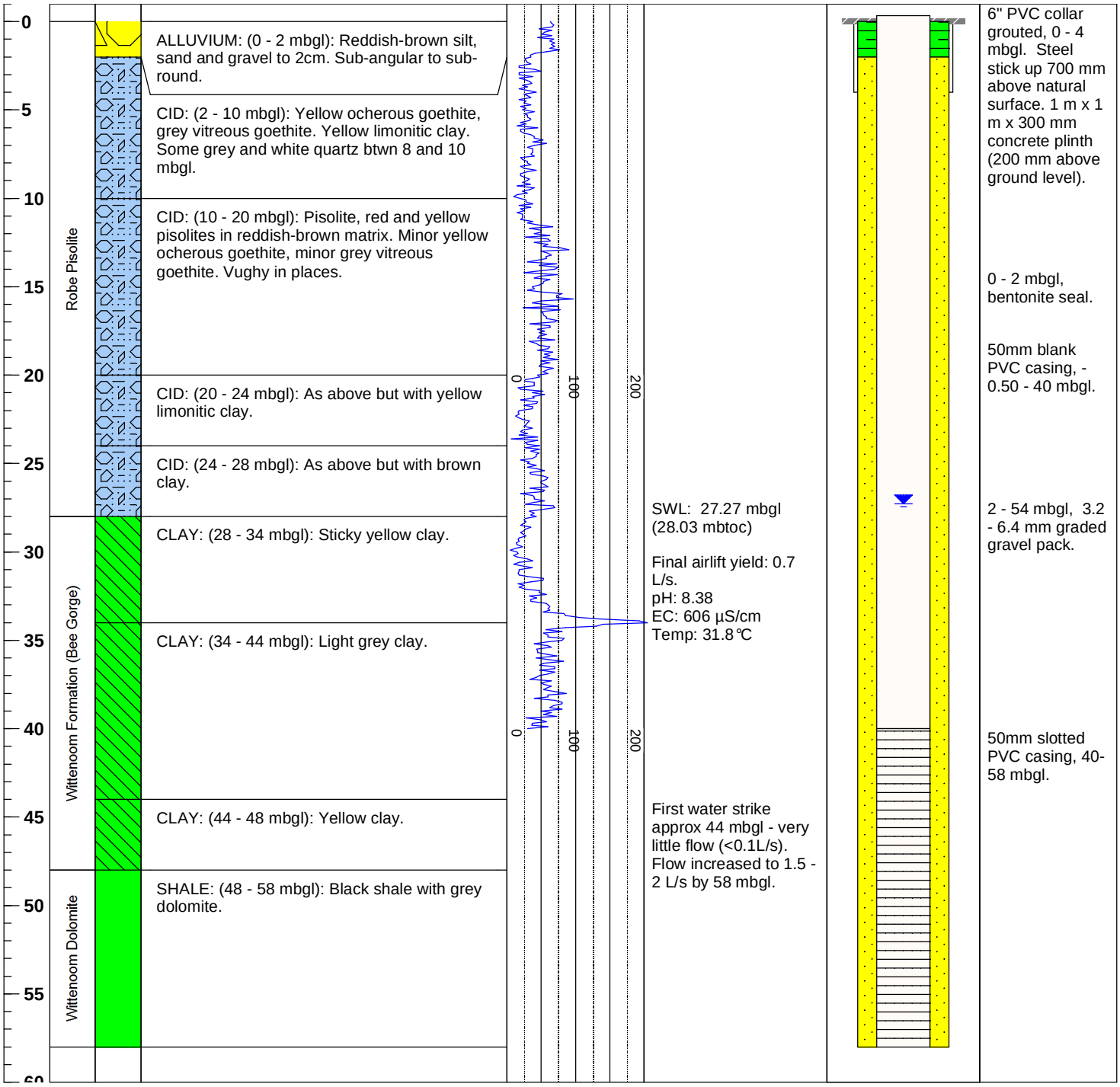
DRILLING COMPANY: Ranger Drilling
DRILLER: Ben Smith
DRILLING METHOD: RC
HYDROGEOLOGIST: A.Price

LOCATION

GRID NAME: MGA 94, Zone 50
EASTING: 418640.88
NORTHING: 7594248.67
ELEVATION: 160.25 mRL (TOC)

Peg ID: 16MEH_M06
RC: 7½" diameter 0 - 4 mbgl. 5 - 58 mbgl 5½" diameter.

Depth (mbgl)	Geology	Lithology	Lithological Description	Gamma (0-200cps)	Field Notes	Well Design	Well Construction
0 - 2	Robe Pisolite		ALLUVIUM: (0 - 2 mbgl): Reddish-brown silt, sand and gravel to 2cm. Sub-angular to sub-round.				6" PVC collar grouted, 0 - 4 mbgl. Steel stick up 700 mm above natural surface. 1 m x 1 m x 300 mm concrete plinth (200 mm above ground level).
2 - 10	Robe Pisolite		CID: (2 - 10 mbgl): Yellow ocherous goethite, grey vitreous goethite. Yellow limonitic clay. Some grey and white quartz btwn 8 and 10 mbgl.				
10 - 20	Robe Pisolite		CID: (10 - 20 mbgl): Pisolite, red and yellow pisolites in reddish-brown matrix. Minor yellow ocherous goethite, minor grey vitreous goethite. Vughy in places.				0 - 2 mbgl, bentonite seal.
20 - 24	Robe Pisolite		CID: (20 - 24 mbgl): As above but with yellow limonitic clay.				50mm blank PVC casing, -0.50 - 40 mbgl.
24 - 28	Robe Pisolite		CID: (24 - 28 mbgl): As above but with brown clay.				
28 - 34	Wittenoom Formation (Bee Gorge)		CLAY: (28 - 34 mbgl): Sticky yellow clay.		SWL: 27.27 mbgl (28.03 mbtoc) Final airlift yield: 0.7 L/s. pH: 8.38 EC: 606 µS/cm Temp: 31.8℃		2 - 54 mbgl, 3.2 - 6.4 mm graded gravel pack.
34 - 44	Wittenoom Formation (Bee Gorge)		CLAY: (34 - 44 mbgl): Light grey clay.				
44 - 48	Wittenoom Formation (Bee Gorge)		CLAY: (44 - 48 mbgl): Yellow clay.		First water strike approx 44 mbgl - very little flow (<0.1L/s). Flow increased to 1.5 - 2 L/s by 58 mbgl.		50mm slotted PVC casing, 40-58 mbgl.
48 - 58	Wittenoom Dolomite		SHALE: (48 - 58 mbgl): Black shale with grey dolomite.				



MB16MEH0009

HOLE DETAILS

PROJECT: Mesa H PFS 2016
LOCATION: Mesa H
DATE COMMENCED: 15/2/2015
DATE COMPLETED: 16/2/2015

DRILLING DETAILS

DRILLING COMPANY: Ranger Drilling
DRILLER: Ben Smith
DRILLING METHOD: RC
HYDROGEOLOGIST: A.Price

LOCATION

GRID NAME: MGA 94, Zone 50
EASTING: 414906.39
NORTHING: 7597496.70
ELEVATION: 161.92 mRL (TOC)

Peg ID: 16MEH_M09.
RC: 7½" diameter 0 - 4 mbgl. 5 - 52 mbgl 5½" diameter.

Depth (mbgl)	Geology	Lithology	Lithological Description	Gamma (0-200cps)	Field Notes	Well Design	Well Construction
0 – 50	Robe Pisolite / Brockman Formation		CID: (0 - 2 mbgl): Pisolite, yellow ocherous goethite, red hematite. Grey vitreous goethite. Minor Quartz. CID: (2 - 6 mbgl): Weathered pisolite, red and yellow clay, rare white clay. Vitreous goethite, hematite. CID: (6 - 10 mbgl): Vitreous goethite matrix, red hematite and yellow goethite pisolites. CID: (10 - 16 mbgl): As above but with pale yellow limonitic clay and more weathered. CLAY: (16 - 19 mbgl): Dense white clay. CID: (19 - 34 mbgl): Brown and grey, weathered. Limonitic clay. CLAY: (34 - 38 mbgl): Red and white clay. Grey shale and weathered BIF. Rare quartz. BIF: (38 - 52 mbgl): BIF. Brown, yellow and red. Minor white clay and grey to black shale.	0 100 200 0 100 200	First water strike approx 28 mbgl - very little flow (<0.1L/s). No flow increase during drilling. No airlift yield during attempted development. SWL: 41.72 mbgl (42.52 mbtoc)		6" PVC collar grouted, 0 - 4 mbgl. Steel stick up 700 mm above natural surface. 1 m x 1 m x 300 mm concrete plinth (200 mm above ground level). 0 - 2 mbgl, bentonite seal. 50mm blank PVC casing, -0.50 - 34 mbgl. 2 - 52 mbgl, 3.2 - 6.4 mm graded gravel pack. 50mm slotted PVC casing, 34-52 mbgl.

MB16MEH0010 / MB16MEH0011

HOLE DETAILS

PROJECT: Mesa H PFS 2016
LOCATION: Mesa H
DATE COMMENCED: 17/2/2016
DATE COMPLETED: 18/02/2016

DRILLING DETAILS

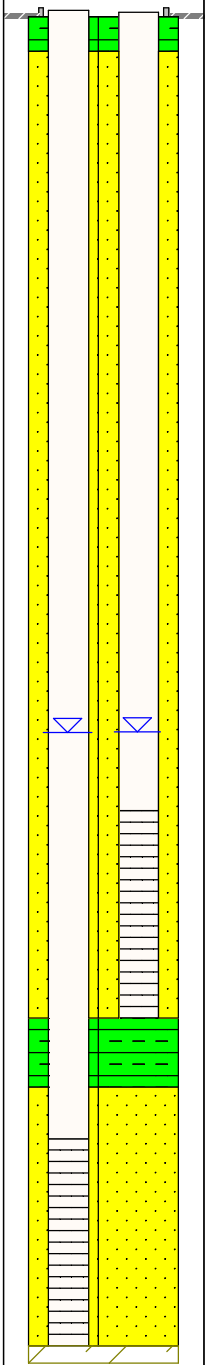
DRILLING COMPANY: Bunbury Drilling
DRILLER: John Nesbitt
DRILLING METHOD: Air Hammer
HYDROGEOLOGIST: Marisa Mochizuki

LOCATION

GRID NAME: MGA 94, Zone 50
EASTING: 417971.10
NORTHING: 7594055.67
ELEVATION S: 175.08 mRL (TOC)
ELEVATION D: 174.96 mRL (TOC)

Peg ID: 16MEH_M14
Hammer Bit: 14¾" diameter 0 - 6 mbgl . 8½" diameter 0 - 78 mbgl.
Shallow piezometer - MB16MEH0010, deep piezometer - MB16MEH0011. Parent hole - HM16MEH0003

Depth (mbgl)	Geology	Lithology	Lithological Description	Gamma (0-80 cps)	Field Notes	Well Design	Well Construction
0	Robe Pisolite		CID: (0 - 8 mbgl): Well weathered grey, brown and red goethite, hematite and vitreous goethite, fragments of cemented pisolites and minor individual pisolites, minor off-white calcrete and yellow limonitic clay.		Shallow Piezo Final airlift yield - 0.25 L/min pH - Not Recorded EC - Not Recorded Temp - °Not Recorded		10" steel collar grouted, 0 - 6 mbgl. Steel stick up 500 mm above natural surface. 1 m x 1 m x 300 mm concrete plinth (200 mm above ground level). Bentonite seal, 0 - 2 mbgl.
5							
10			CID: (8 - 18 mbgl): Well weathered mostly grey vitreous and vuggy goethite, brown and red goethite and hematite and fragments of cemented pisolites, trace individual pisolites, minor off-white calcrete and yellow limonitic clay.				
15							
20			CID: (18 - 26 mbgl): Weathered grey and brown massive vitreous goethite minor to trace limonite and limonitic clay.				50mm blank PVC casing, -0.50 - 46 mbgl. 50mm slotted PVC casing, 46 - 58 mbgl.
25							
30			CID: (26 - 40 mbgl): Weathered grey, brown and red goethite, hematite and vitreous goethite, fragments of cemented pisolites and minor individual pisolites, minor yellow limonitic and grey clay with rounded to subrounded multicoloured fine to coarse sands and fine gravels up to 3 mm.				3.2 - 6.4 mm graded gravel pack, 0 - 58 mbgl and 62 - 78 mbgl.
35					Flow rates during drilling were as follows: 48-60m 2-3 L/sec 60-72m 3-5 L/sec 72-78m 5-6 L/sec SWL Shallow - 41.44 mbgl (42.12 m BTOC) Deep - 41.45 mbgl (42.00 m BTOC)		
40			CID: (40 - 46 mbgl): Well weathered grey, brown and red 1 mm goethite and hematite pisolites in a vitreous goethite matrix, minor to moderate yellow limonitic clay, trace chert and rounded to subrounded sands and fine gravels of quartz. increasing amounts of massive vitreous goethite from 44 - 46 mbgl.				
45							
50			CID: (46 - 48 mbgl): Weathered grey, vitreous goethite with minor pisolite chips as described above minor limonite.		Driller notes bands of harder and soft/lose ground from 62-78m		
55			CID: (48 - 57 mbgl): Weathered grey, vitreous goethite with minor pisolite chips as described above minor limonite and grey clay.				
60	Wittenoom Formation (Bee Gorge)		SHALE: (57 - 62 mbgl): Moderately weathered and fractured grey and black shale, chert and clay, minor brown shale and green chert, chips up to 50 mm.		Deep Piezo Final airlift yield - 1.5 L/s pH - 8.16 EC - 630 µS/cm Temp - 31.9℃		Bentonite seal, 58 - 62 mbgl.
65							50mm blank PVC casing, -0.50 - 65 mbgl. 50mm slotted PVC casing, 65 - 77 mbgl.
70			SHALE: (62 - 78 mbgl): Moderately to well weathered and fractured brown, black and grey shale and chert, minor BIF, green chert and white quartz, chips up to 50 mm. Driller notes alternating bands of hard and soft/loose ground.				
75							Hole collapsed from 77 to 78 mbgl.
80							



MB16MEH0012

HOLE DETAILS

PROJECT: Mesa H PFS 2016
LOCATION: Mesa H
DATE COMMENCED: 19/2/2016
DATE COMPLETED: 22/02/2016

DRILLING DETAILS

DRILLING COMPANY: Bunbury Drilling
DRILLER: Dave Usher
DRILLING METHOD: Air Hammer
HYDROGEOLOGIST: Marisa Mochizuki

LOCATION

GRID NAME: MGA 94, Zone 50
EASTING: 419768.32
NORTHING: 7592737.21
ELEVATION: 165.22 RL (GL)

Peg ID: 16MEH_M01
Mud Rotary Tricone Bit: 14¾" diameter 0 - 8 mbgl . 8½" diameter 8 - 49 mbgl.
Failed nested piezometer

Depth (mbgl)	Geology	Lithology	Lithological Description	Gamma (0-200cps)	Field Notes	Well Design	Well Construction
0	ALLUVIUM		ALLUVIUM: (0 - 6 mbgl): Reddish-brown, sand and silt, sub-rounded to sub-angular gravel to 3 cm of chert, shale and BIF, vuggy goethite, minor round to sub-round goethite and hematite pisolites.		Significant mud loss btwn 0 and 6 mbgl.		10" steel collar grouted, 0 - 8 mbgl. Steel stick up 500 mm above natural surface. 1 m x 1 m x 300 mm concrete plinth (200 mm above ground level).
5			CID: (6 - 8 mbgl): Weathered grey, red and brown goethite and hematite pisolites and chips of vitreous goethite minor yellow limonitic clay/mudstone, moderate fallback/contamination.				
10	PISOLITE		CLAY: (8 - 10 mbgl): Grey, silty clay with gravel (to 3 cm) of chert, shale, BIF, goethite and hematite.				Bentonite seal, 0 - 2 mbgl.
15			CID: (10 - 12 mbgl): Weathered grey vitreous and yellow ochreous goethite, minor pisolites, hematite and grey and yellow limonitic clay.				
20			CLAY: (12 - 14 mbgl): Grey and yellow clay with weathered vitreous to earthy goethite and minor hematite.	0 100 200	Lost circulation from ~26 mbgl with complete lost circ from 32 mbgl (cavaties or fractures). No sample return from 32 mbgl for remainder of hole.		
25			CID: (14 - 16 mbgl): Moderately weathered vitreous and mildly vuggy hematite and goethite, minor yellow ocherous goethite, grey and yellow clay, trace hematite pisolites.				
30			CID: (16 - 20 mbgl): Weathered yellow ochreous goethite and grey vitreous to siliceous goethite, minor hematite and cemented fine (to 1mm) yellow and brown individual pisolites and pisolite clasts.		Minor fractures noted from 30 - 40 mbgl with bands of harder and softer ground btwn 40 and 47 mbgl.		3.2 - 6.4 mm graded gravel pack, 0 - 47 mbgl.
35			CID: (20 - 24 mbgl): Red hematite and yellow ochreous to grey goethite, clasts of fine (to 1mm) cemented pisolites, minor vitreous to highly vitreous goethite. Driller notes slightly harder ground.		SWL: 33.22 mbgl (33.94 mbtoc)		50mm blank PVC casing, -0.50 - 35 mbgl. 50mm slotted PVC casing, 35 - 47 mbgl.
40			NO SAMPLE: (26 - 49 mbgl): No sample, lost circ.	0 100 200	Final airlift yield - 0.25 L/sec pH - 8.65 EC - 583 µS/cm Temp - 32.3℃		
45							
50							

MB16MEH0013

HOLE DETAILS

PROJECT: Mesa H PFS 2016
LOCATION: Mesa H
DATE COMMENCED: 22/02/16
DATE COMPLETED: 23/02/16

DRILLING DETAILS

DRILLING COMPANY: Ranger Drilling
DRILLER: Andrew McPherson
DRILLING METHOD: RC
HYDROGEOLOGIST: Marisa Mochizuki

LOCATION

GRID NAME: MGA 94, Zone 50
EASTING: 419286.91
NORTHING: 7592165.60
ELEVATION: 183.13 mRL (TOC)

Peg ID: 16MEH_M04
RC: 7½" diameter 0 - 5 mbgl. 5 - 76 mbgl 5½" diameter.

Depth (mbgl)	Geology	Lithology	Lithological Description	Gamma (0-200cps)	Field Notes	Well Design	Well Construction
0 - 75	Robe Pisolite / Clay / Wittenoom Formation		CID: (0 - 2 mbgl): Weathered brown and grey chips (to 15 mm) of cemented, fine (to 1 mm) hematite and goethite pisolites, minor linonite and vitreous goethite, minor quartz. CID: (2 - 4 mbgl): Brown and grey vitreous goethite, and clasts of cemented pisolites, moderate limonite. CID: (4 - 13 mbgl): Yellow limonite and grey, highly vitreous and mildly vuggy goethite, minor hematite. CLAY: (13 - 17 mbgl): Red and yellow clay, stiff dark grey clay, minor vitreous goethite and pisolite clasts. CID: (20 - 26 mbgl): Chips (to 20 mm) of vitreous gothite, chert, BIF, and shale, minor grey and yellow clay increasing from 24 - 26 mbgl. CID: (26 - 28 mbgl): Dark chert, goethite, BIF, and shale chips (to 15 mm), substantial yellow and grey clay. CID: (28 - 32 mbgl): Dark chert, goethite, BIF, and shale chips (to 15 mm), minor yellow and grey clay. CLAY: (32 - 42 mbgl): Grey and yellow sticky clay. CLAY: (42 - 50 mbgl): Grey, yellow and white clay with minor purple clay from 44 - 46 mbgl. CLAY: (52 - 54 mbgl): Yellow, grey and purple clay. BIF: (54 - 58 mbgl): Reddish purple shale and chert, minor yellow and grey clay, minor hematite. BIF: (58 - 64 mbgl): Red and grey BIF, hematite, red and brown shale and chert. SHALE: (64 - 70 mbgl): Black shale, minor hematite and goethite, trace secondary silicification along fracture planes, trace to minor brown and red shale. SHALE: (70 - 76 mbgl): Black shale, magnetic, minor hematite and goethite, trace secondary silicification along fracture planes, trace to minor brown and red shale, increase	0 100 200	Final airlift yield: <0.25 L/s. pH: 8.77 EC:725 µS/cm Temp: 29 ℃ First water strike approx 50 mbgl - no significant flow. SWL: 51.12 mbgl (51.80 mbtoc)		6" PVC collar grouted, 0 - 5 mbgl. Steel stick up 700 mm above natural surface. 1 m x 1 m x 300 mm concrete plinth (200 mm above ground level). 0 - 2 mbgl, bentonite seal. 50mm blank PVC casing, -0.50 - 64 mbgl. 2 - 40 mbgl, 3.2 - 6.4 mm graded gravel pack. 40 - 44 mbgl, bentonite seal. 40 - 44 mbgl, 3.2 - 6.4 mm graded gravel pack. 64 - 76 mbgl ,50mm slotted PVC casing.

MB16MEH0014

HOLE DETAILS

PROJECT: Mesa H PFS 2016
LOCATION: Mesa H
DATE COMMENCED: 18/02/2016
DATE COMPLETED: 18/02/2016

DRILLING DETAILS

DRILLING COMPANY: Ranger Drilling
DRILLER: Andrew McPherson
DRILLING METHOD: RC
HYDROGEOLOGIST: Marisa Mochizuki

LOCATION

GRID NAME: MGA 94, Zone 50
EASTING: 418861.54
NORTHING: 7598680.02
ELEVATION: 139.33 mRL (TOC)

Peg ID: 16MEH_M11
RC: 7½" diameter 0 - 5 mbgl. 5 - 64 mbgl 5½" diameter.

Depth (mbgl)	Geology	Lithology	Lithological Description	Gamma (0-200cps)	Field Notes	Well Design	Well Construction
0	Alluvium		ALLUVIUM: (0 - 18 mbgl): Strongly weathered reddish-brown, sub-rounded to sub-angular gravel to 30mm of chert and BIF, sand and silt, minor clay 10 - 12 and 16 - 18 mbgl.		SWL: 8.88 mbgl (9.44 mbtoc)		6" PVC collar grouted, 0 - 4 mbgl. Steel stick up 700 mm above natural surface. 1 m x 1 m x 300 mm concrete plinth (200 mm above ground level).
15			ALLUVIUM: (18 - 19 mbgl): Strongly weathered reddish-brown, sub-round to sub-angular gravel to 30 mm of chert and BIF, sand and silt, minor red clay, vitreous goethite and pisolites.				0 - 2 and 34-38 mbgl, bentonite seal.
20	Robe Pisolite		CID: (19- 21 mbgl): Reddish-brown, silt and clay with grey vitreous goethite, cemented pisolites minor angular chert and BIF.	0 100 200			50mm blank PVC casing, -0.50 - 40 mbgl.
25			CLAY: (21- 26 mbgl): Brown and grey clay with fragments (to 10 mm) of vuggy vitreous goethite and hematite, cherts and shale.				
30			CLAY: (26- 31 mbgl): Pale brown and grey clay with minor weathered fragments of shale, chert, quartz and weathered goethite.				2 - 34 and 38-64 mbgl, 3.2 - 6.4 mm graded gravel pack.
35			CID: (31- 45 mbgl): Strongly weathered reddish brown shale, chert, massive, vuggy goethite becoming more grey and enriched with depth, moderate limonitic clay that increases with depth, trace to minor botryoidal goethite and pisolites.	0 100 200	Final airlift yield: 2.5 L/s. pH: 8.08 EC: 1096 µS/cm Temp: 31.6 ℃		
40							
45			CLAY: (45- 48 mbgl): Brown to yellow clay transition zone, minor shale chert and goethite.				50mm slottedPVC casing, 40-64 mbgl.
50	Wittenoom Formation		DOLOMITE: (48- 52 mbgl): Fresh bluish grey, crystalline, silicified dolomite.		First water strike approx 12 mbgl - very little flow (<0.1L/s). flow increased to 1L/sec at 30 m then to 2.5 L/sec around 40 - 50 m.		
55			DOLOMITE: (52- 54 mbgl): Mildly weathered bluish grey, crystalline, silicified dolomite, minor red shale and pale brown clay.	0 100 200			
60			DOLOMITE: (54- 64 mbgl): Fresh bluish grey, crystalline, silicified dolomite, minor red shale and pale brown clay from 60 - 62 mbgl.				
65							

MB16MEH0015

HOLE DETAILS	DRILLING DETAILS	LOCATION
PROJECT: Mesa H PFS 2016	**DRILLING COMPANY:** Ranger Drilling	**GRID NAME:** MGA 94, Zone 50
LOCATION: Mesa H	**DRILLER:** Andrew McPherson	**EASTING:** Not Surveyed
DATE COMMENCED: 19/02/2016	**DRILLING METHOD:** RC	**NORTHING:** Not Surveyed
DATE COMPLETED: 19/02/2016	**HYDROGEOLOGIST:** Marisa Mochizuki	**ELEVATION:** Not Surveyed

Peg ID: 16MEH_M11
RC: 7½" diameter 0 - 5 mbgl. 5 - 40 mbgl 5½ diameter.

Depth (mbgl)	Geology	Lithology	Lithological Description	Gamma (0-200cps)	Field Notes	Well Design	Well Construction
0	Alluvium		ALLUVIUM: (0 - 18 mbgl): Strongly weathered reddish-brown, sub-rounded to sub-angular gravel to 30mm of chert and BIF, sand and silt, minor clay 10 - 12 and 16 - 18 mbgl.		First water strike approx 12 mbgl. Flow increased to 0.75L/sec at ~20m.		Hole not constructed and abandoned due to surface casing blow out and hole collapse.
5							
10							
15							
20	Robe Pisolite		CID: (18 - 24 mbgl): A mix of alluvium as above with minor to moderate brown and red clay, vitreous, vuggy goethite with botryoidal formation and pisolites.				
25			CLAY: (24 - 30 mbgl): Pale yellow, brown to grey, silty clay with minor chert and quartz, vuggy vitreous goethite and red to brown shale. Clay content decreases from 28 - 30 mbgl.				
30			CID: (30 - 32 mbgl): Well weathered brown shale and vuggy goethite trace limonite and silty clay.		Surface casing blew out and broke. The hole collapsed and could not be stabilised. It was then back filled and abandoned.		
35			CLAY: (32 - 34 mbgl): Pale brown and grey clay with minor weathered fragments of shale and weathered goethite.				
40			PISOLITE: (34- 40 mbgl): Well weathered reddish brown shale, vuggy goethite, some botryoidal goethite and hematite, white quartz vein at 36 - 38 mbgl and increased limonitic clay from 38 - 40 mbgl.				

MB16MEH0016

HOLE DETAILS

PROJECT: Mesa H PFS 2016
LOCATION: Mesa H
DATE COMMENCED: 19/02/2016
DATE COMPLETED: 19/02/2016

DRILLING DETAILS

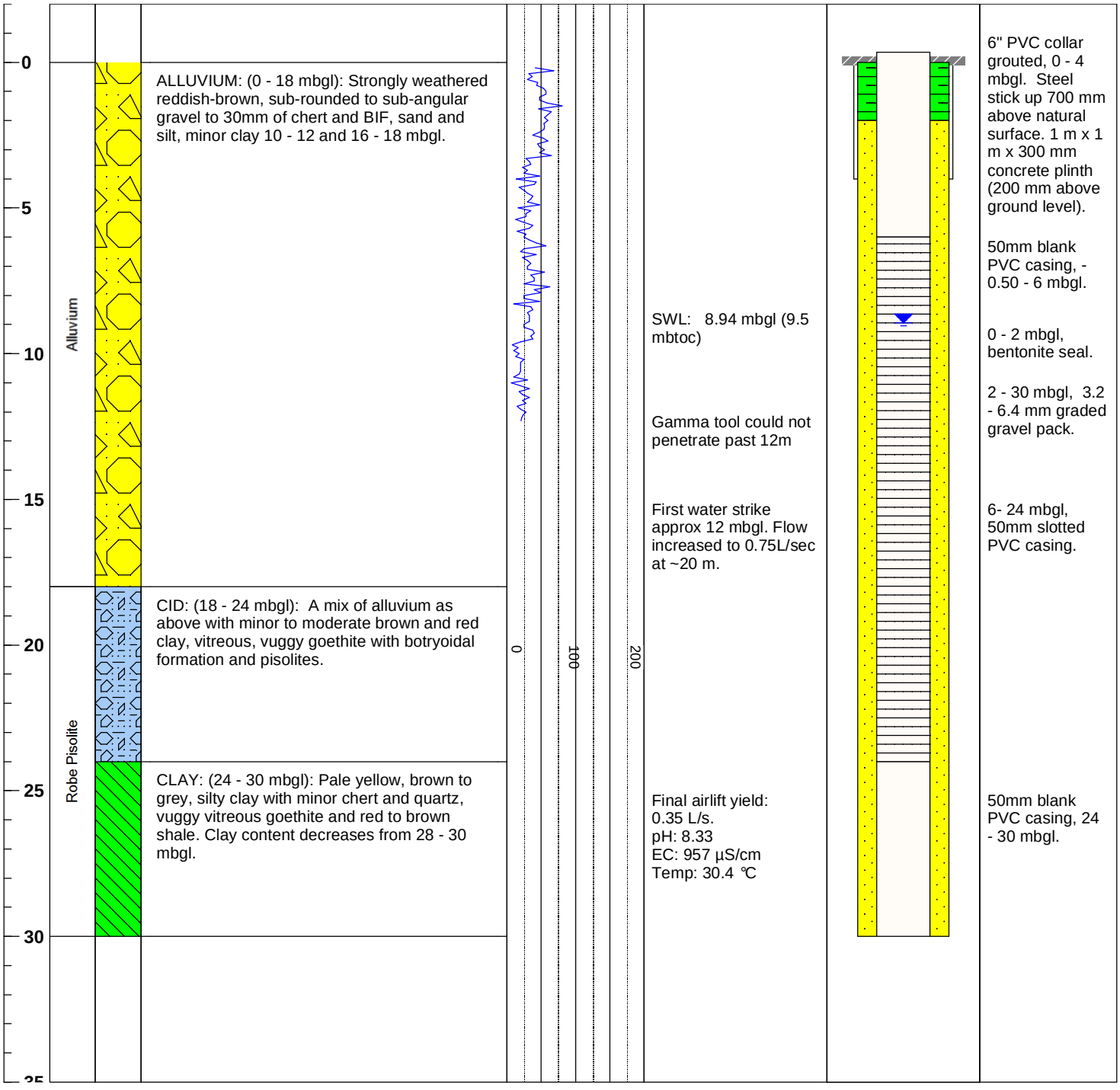
DRILLING COMPANY: Ranger Drilling
DRILLER: Andrew McPherson
DRILLING METHOD: RC
HYDROGEOLOGIST: Marisa Mochizuki

LOCATION

GRID NAME: MGA 94, Zone 50
EASTING: 418854.63
NORTHING: 7598682.99
ELEVATION: 139.44 mRL (TOC)

Peg ID: 16MEH_M11
RC: 7½" diameter 0 - 5 mbgl. 5 - 30 mbgl 5½ diameter.

Depth (mbgl)	Geology	Lithology	Lithological Description	Gamma (0-200cps)	Field Notes	Well Design	Well Construction
0 - 18	Alluvium		ALLUVIUM: (0 - 18 mbgl): Strongly weathered reddish-brown, sub-rounded to sub-angular gravel to 30mm of chert and BIF, sand and silt, minor clay 10 - 12 and 16 - 18 mbgl.		SWL: 8.94 mbgl (9.5 mbtoc) Gamma tool could not penetrate past 12m First water strike approx 12 mbgl. Flow increased to 0.75L/sec at ~20 m.		6" PVC collar grouted, 0 - 4 mbgl. Steel stick up 700 mm above natural surface. 1 m x 1 m x 300 mm concrete plinth (200 mm above ground level). 50mm blank PVC casing, -0.50 - 6 mbgl. 0 - 2 mbgl, bentonite seal. 2 - 30 mbgl, 3.2 - 6.4 mm graded gravel pack. 6- 24 mbgl, 50mm slotted PVC casing.
18 - 24	Robe Pisolite		CID: (18 - 24 mbgl): A mix of alluvium as above with minor to moderate brown and red clay, vitreous, vuggy goethite with botryoidal formation and pisolites.				
24 - 30	Robe Pisolite		CLAY: (24 - 30 mbgl): Pale yellow, brown to grey, silty clay with minor chert and quartz, vuggy vitreous goethite and red to brown shale. Clay content decreases from 28 - 30 mbgl.		Final airlift yield: 0.35 L/s. pH: 8.33 EC: 957 µS/cm Temp: 30.4 ℃		50mm blank PVC casing, 24 - 30 mbgl.



MB16MEH0017

HOLE DETAILS

PROJECT: Mesa H PFS 2016
LOCATION: Mesa H
DATE COMMENCED: 19/02/2016
DATE COMPLETED: 21/02/2016

DRILLING DETAILS

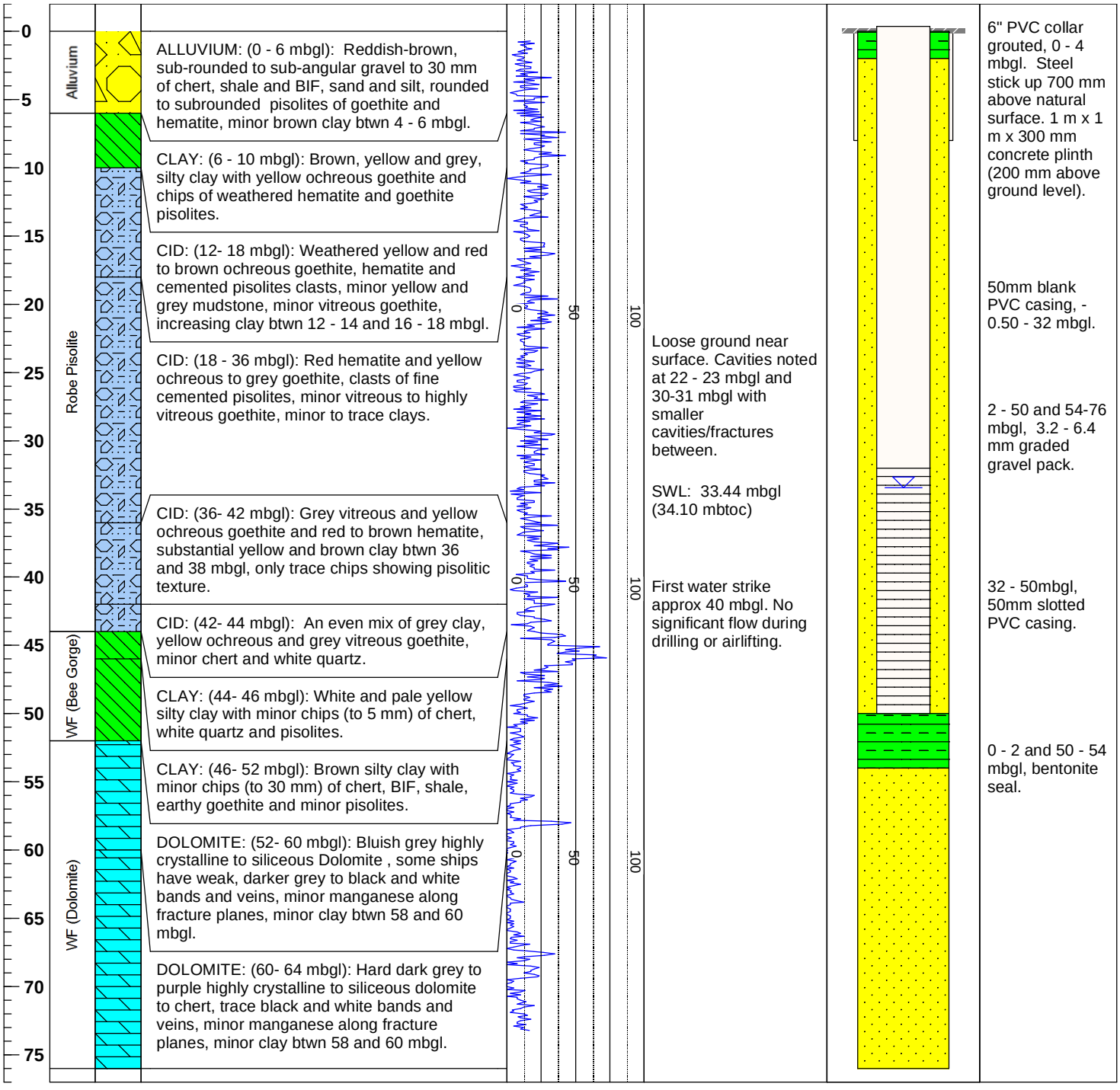
DRILLING COMPANY: Ranger Drilling
DRILLER: Andrew McPherson
DRILLING METHOD: RC
HYDROGEOLOGIST: Marisa Mochizuki

LOCATION

GRID NAME: MGA 94, Zone 50
EASTING: 419597.88
NORTHING: 7592744.90
ELEVATION: 165.68 mRL (TOC)

Peg ID: 16MEH_M13
RC: 7½" diameter 0 - 8 mbgl. 8 - 76 mbgl 5½ diameter.

Depth (mbgl)	Geology	Lithology	Lithological Description	Gamma (0-100cps)	Field Notes	Well Design	Well Construction
0 - 6	Alluvium		ALLUVIUM: (0 - 6 mbgl): Reddish-brown, sub-rounded to sub-angular gravel to 30 mm of chert, shale and BIF, sand and silt, rounded to subrounded pisolites of goethite and hematite, minor brown clay btwn 4 - 6 mbgl.				6" PVC collar grouted, 0 - 4 mbgl. Steel stick up 700 mm above natural surface. 1 m x 1 m x 300 mm concrete plinth (200 mm above ground level).
6 - 10	Robe Pisolite		CLAY: (6 - 10 mbgl): Brown, yellow and grey, silty clay with yellow ochreous goethite and chips of weathered hematite and goethite pisolites.				
10 - 18			CID: (12- 18 mbgl): Weathered yellow and red to brown ochreous goethite, hematite and cemented pisolites clasts, minor yellow and grey mudstone, minor vitreous goethite, increasing clay btwn 12 - 14 and 16 - 18 mbgl.				50mm blank PVC casing, -0.50 - 32 mbgl.
18 - 36			CID: (18 - 36 mbgl): Red hematite and yellow ochreous to grey goethite, clasts of fine cemented pisolites, minor vitreous to highly vitreous goethite, minor to trace clays.		Loose ground near surface. Cavities noted at 22 - 23 mbgl and 30-31 mbgl with smaller cavities/fractures between. SWL: 33.44 mbgl (34.10 mbtoc)		2 - 50 and 54-76 mbgl, 3.2 - 6.4 mm graded gravel pack.
36 - 42			CID: (36- 42 mbgl): Grey vitreous and yellow ochreous goethite and red to brown hematite, substantial yellow and brown clay btwn 36 and 38 mbgl, only trace chips showing pisolitic texture.				
42 - 44			CID: (42- 44 mbgl): An even mix of grey clay, yellow ochreous and grey vitreous goethite, minor chert and white quartz.		First water strike approx 40 mbgl. No significant flow during drilling or airlifting.		32 - 50mbgl, 50mm slotted PVC casing.
44 - 46	WF (Bee Gorge)		CLAY: (44- 46 mbgl): White and pale yellow silty clay with minor chips (to 5 mm) of chert, white quartz and pisolites.				
46 - 52			CLAY: (46- 52 mbgl): Brown silty clay with minor chips (to 30 mm) of chert, BIF, shale, earthy goethite and minor pisolites.				0 - 2 and 50 - 54 mbgl, bentonite seal.
52 - 60	WF (Dolomite)		DOLOMITE: (52- 60 mbgl): Bluish grey highly crystalline to siliceous Dolomite , some ships have weak, darker grey to black and white bands and veins, minor manganese along fracture planes, minor clay btwn 58 and 60 mbgl.				
60 - 64			DOLOMITE: (60- 64 mbgl): Hard dark grey to purple highly crystalline to siliceous dolomite to chert, trace black and white bands and veins, minor manganese along fracture planes, minor clay btwn 58 and 60 mbgl.				



MB16MEH0018

HOLE DETAILS

PROJECT: Mesa H PFS 2016
LOCATION: Mesa H
DATE COMMENCED: 23/02/2016
DATE COMPLETED: 23/02/2016

DRILLING DETAILS

DRILLING COMPANY: Ranger Drilling
DRILLER: Andrew McPherson
DRILLING METHOD: RC
HYDROGEOLOGIST: Marisa Mochizuki

LOCATION

GRID NAME: MGA 94, Zone 50
EASTING: 418273.51
NORTHING: 7593072.81
ELEVATION: 168.34 mRL (TOC)

Peg ID: 16MEH_M05
RC: 7½" diameter 0 - 5 mbgl. 5 - 52 mbgl 5½ diameter.

Depth (mbgl)	Geology	Lithology	Lithological Description	Gamma (0-150cps)	Field Notes	Well Design	Well Construction
0 - 5	Robe Pisolite		CID: (0 - 6 mbgl): Weathered red and grey hematite and goethite pisolites and chips of pisolite clasts, red silt, minor shale and sands decreasing with depth.				6" PVC collar grouted, 0 - 4 mbgl. Steel stick up 700 mm above natural surface. 1 m x 1 m x 300 mm concrete plinth (200 mm above ground level).
5 - 10	Robe Pisolite		CID: (6 - 10 mbgl): As above but with minor shale, minor limonite and yellow and grey clay and increasing amounts of vitreous goethite from 6- 10 mbgl.				
10 - 15	Marra Mamba Formation		BIF: (10 - 14 mbgl): Even mix of silty yellow and grey clay, multi coloured chert and BIF, minor vitreous goethite.				0 - 2 mbgl, bentonite seal.
15 - 20	Marra Mamba Formation		BIF: (14- 16 mbgl): Pale and multi coloured chert and minor shale/siltstone/silty yellow and grey clay.				
20 - 25	Marra Mamba Formation		BIF: (16 - 24 mbgl): Pale and multi coloured chert and minor shale/siltstone/silty white with minor yellow clay.	0 75 150			50mm blank PVC casing, - 0.50 - 36 mbgl.
25 - 30	Marra Mamba Formation		BIF: (24- 28 mbgl):Yellow red, and grey chert, minor shale and clay.				
30 - 35	Marra Mamba Formation		SHALE: (28- 29 mbgl): Black shale, significant black yellow and red chert.				2 - 52 mbgl, 3.2 - 6.4 mm graded gravel pack.
35 - 40	Marra Mamba Formation		BIF: (29- 31 mbgl): Black yellow and red chert, minor black shale.				
40 - 45	Marra Mamba Formation		SHALE: (31- 36 mbgl): Mildly weathered black shale, dark red, black and orange chert, minor grey and yellow clay.		SWL: 35.22 mbgl (36.01 mbtoc)		
45 - 50	Marra Mamba Formation		SHALE: (36- 38 mbgl): Black shale dark red and black chert, minor grey clay.				
40 - 45	Marra Mamba Formation		CHERT: (38 - 42 mbgl): Fresh black and dark grey chert with significant shale, minor colourless quartz.	0 75 150	First water strike approx 40 mbgl. No significant flow during drilling or airlifting.		36 - 48 mbgl, 50mm slotted PVC casing.
45 - 50	Marra Mamba Formation		SHALE: (42- 47 mbgl): Black and dark grey shale with significant chert.				
50	Marra Mamba Formation		CHERT: (47- 52 mbgl): Black and dark grey chert with minor shale.				

MB16MEH0019

HOLE DETAILS

PROJECT: Mesa H PFS 2016
LOCATION: Mesa H
DATE COMMENCED: 23/02/2016
DATE COMPLETED: 24/02/2016

DRILLING DETAILS

DRILLING COMPANY: Ranger Drilling
DRILLER: Andrew McPherson
DRILLING METHOD: RC
HYDROGEOLOGIST: Marisa Mochizuki

LOCATION

GRID NAME: MGA 94, Zone 50
EASTING: 419938.38
NORTHING: 7591715.26
ELEVATION: 178.53 mRL (TOC)

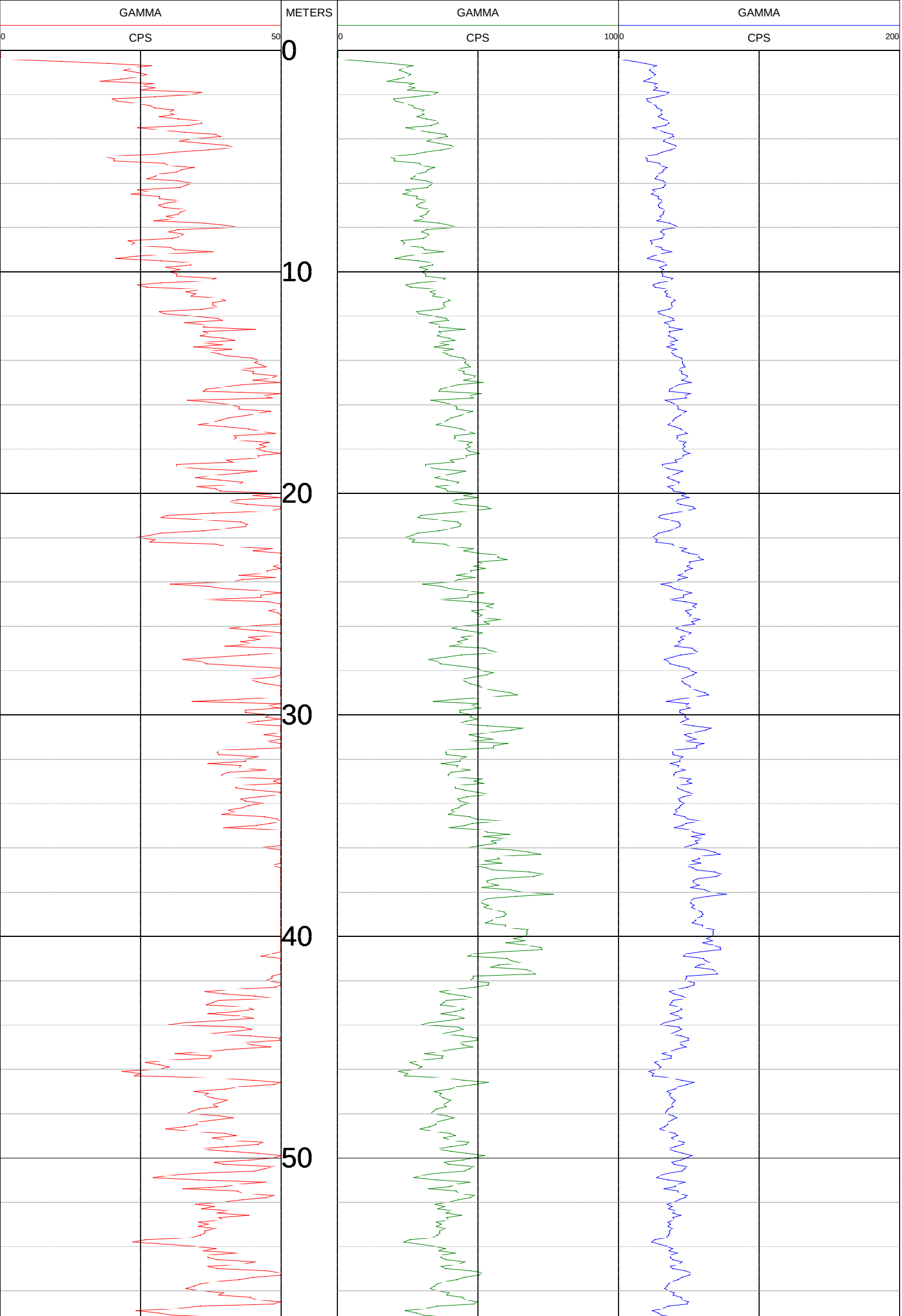
Peg ID: 16MEH_M03
RC: 7½" diameter 0 - 5 mbgl. 5 - 70 mbgl 5½ diameter.

Depth (mbgl)	Geology	Lithology	Lithological Description	Gamma (0-150cps)	Field Notes	Well Design	Well Construction
0 - 70	Robe Pisolite; Clay (Bee Gorge); Wittenoom Formation		CID: (0 - 2 mbgl): Well weathered clasts of cemented red and grey fine (to 1mm) pisolites and goethite, red silt. CID: (2 - 4 mbgl): Weathered grey and brown vitreous goethite, minor limonite and yellow clay. CID: (4 - 7 mbgl): Weathered grey and brown vitreous goethite, minor limonite and yellow clay with substantial yellow chert. SHALE: (7 - 9 mbgl): Yellow shale, minor chert, vitreous goethite and grey clay. CID: (9 - 14 mbgl): Weathered massive vitreous goethite, minor grey and trace yellow and red clay and limonite. Increased red clay from 8 - 10 mbgl. Becoming slightly more weathered from 12 - 14 mbgl. CID: (14- 16 mbgl): Grey and yellow clay with significant weathered vitreous goethite and hematite. CLAY: (16- 21 mbgl): Stiff grey clay with minor silty red clay, trace to minor vitreous goethite and hematite. CID: (21- 23 mbgl): Weathered vitreous goethite and hematite with significant stiff grey and silty red to purple clay. CLAY: (23- 26 mbgl): Stiff dark grey clay, minor silty red clay. CID: (26- 28 mbgl): Stiff grey and silty red and yellow clay, minor vitreous goethite. CID: (28 - 35 mbgl): Weathered vitreous to yellow and brown ocherous goethite, minor hematite and limonite, minor clasts of hematite and goethite pisolites in a vitreous goethite matrix, minor grey and yellow clay from 30 - 36 mbgl. CLAY: (36 - 53 mbgl):Off white clay, minor red silty clay from 38 - 42 mbgl, minor yellow silty clay from 42 - 48 mbgl, trace silty purple clay from 48 - 50 mbgl, trace red silty clay 50 - 52 mbgl. SHALE: (53 - 70 mbgl): Soft black shale, pulverized with only trace chips (to 3 mm)	0 75 150	First water strike approx 40 mbgl. No significant flow during drilling or airlifting. SWL: 42.82 mbgl (13.50 mbtoc)	6" PVC collar grouted, 0 - 4 mbgl. Steel stick up 700 mm above natural surface. 1 m x 1 m x 300 mm concrete plinth (200 mm above ground level). 0 - 2 mbgl, bentonite seal. 50mm blank PVC casing, -0.50 - 40 mbgl. 2 - 70 mbgl, 3.2 - 6.4 mm graded gravel pack. 40 - 64 mbgl, 50mm slotted PVC casing.

WB16MEH0001

COMPANY	:	RTIO			OTHER SERVICES:		
WELL	:	WB16MEH000			PEG#		
LOCATION/FIELD	:	MEH			16MEH		
COUNTY	:	MEGDC0202			_P02		
LOCATION	:	MEH					
SECTION	:		TOWNSHIP	:		RANGE	:
DATE	:	03/13/16	PERMANENT DATUM	:	GL		
DEPTH DRILLER	:	84				KB	:
LOG BOTTOM	:	83.50	LOG MEASURED FROM	:	GL	DF	:
LOG TOP	:	-0.80	DRL MEASURED FROM	:	GL	GL	:
CASING DIAMETER	:	10.	LOGGING UNIT	:	SV10		
CASING TYPE	:	STEEL	FIELD OFFICE	:	SURTRON		
CASING THICKNESS	:		RECORDED BY	:	CJ		
BIT SIZE	:	31	BOREHOLE FLUID	:		FILE	: PROCESSED
MAGNETIC DECL.	:	1.438	RM	:		TYPE	: 9238AA
MATRIX DENSITY	:	2.65	RM TEMPERATURE	:		LGDATE	: 03/13/16
NEUTRON MATRIX	:	SANDSTONE	MATRIX DELTA T	:	177		
						THRESH	: 90000

ALL SERVICES PROVIDED SUBJECT TO STANDARD TERMS AND CONDITIONS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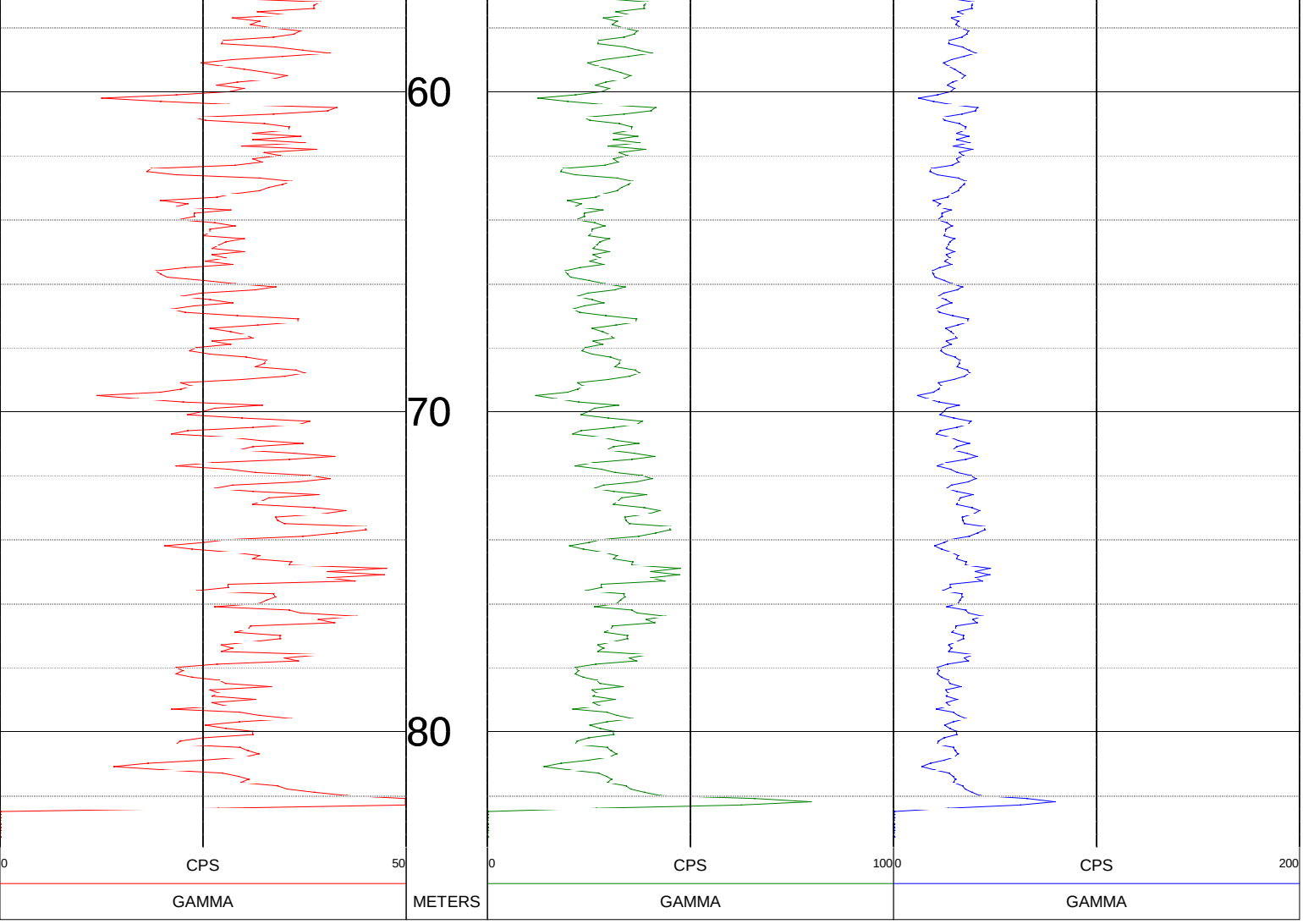
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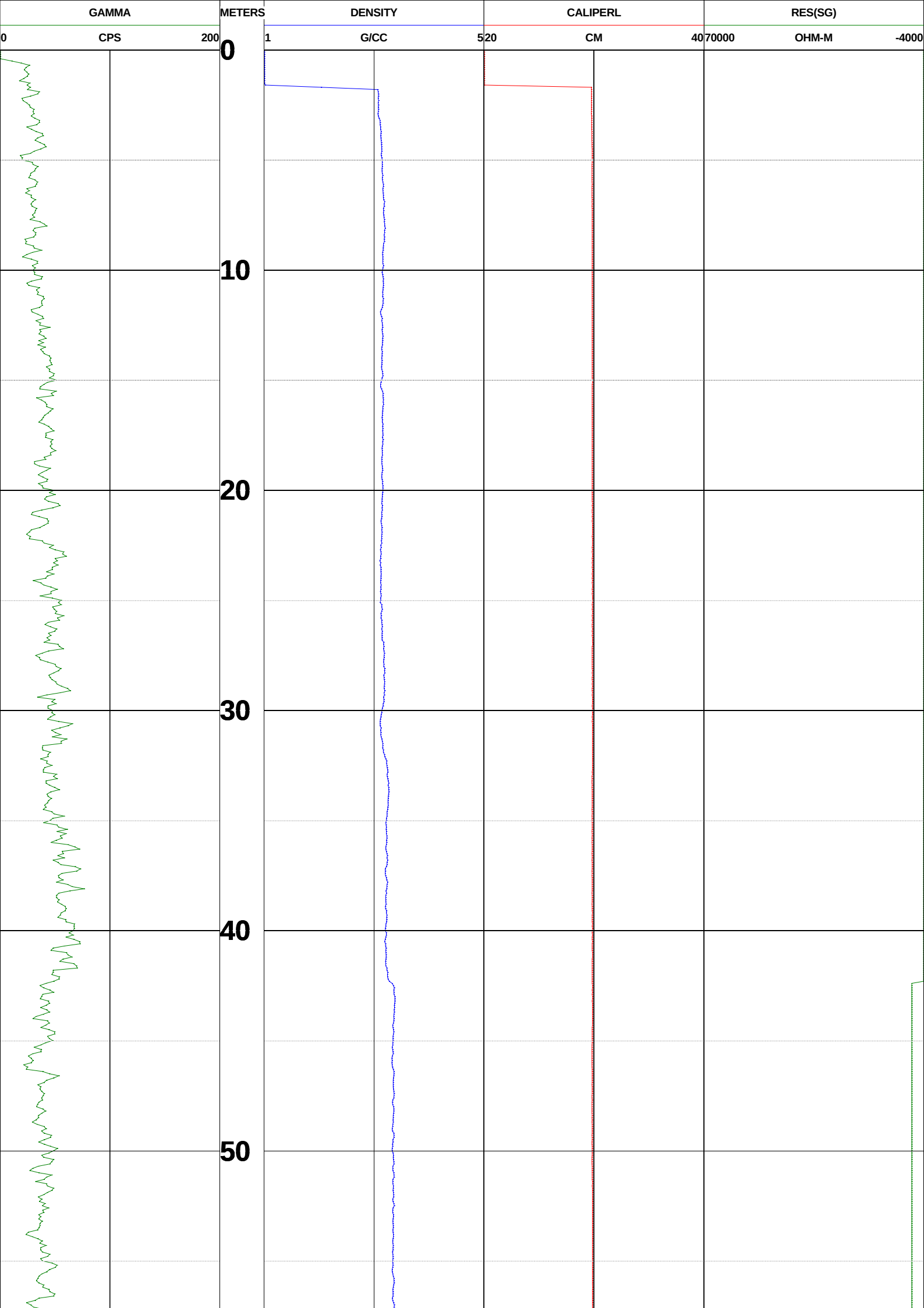
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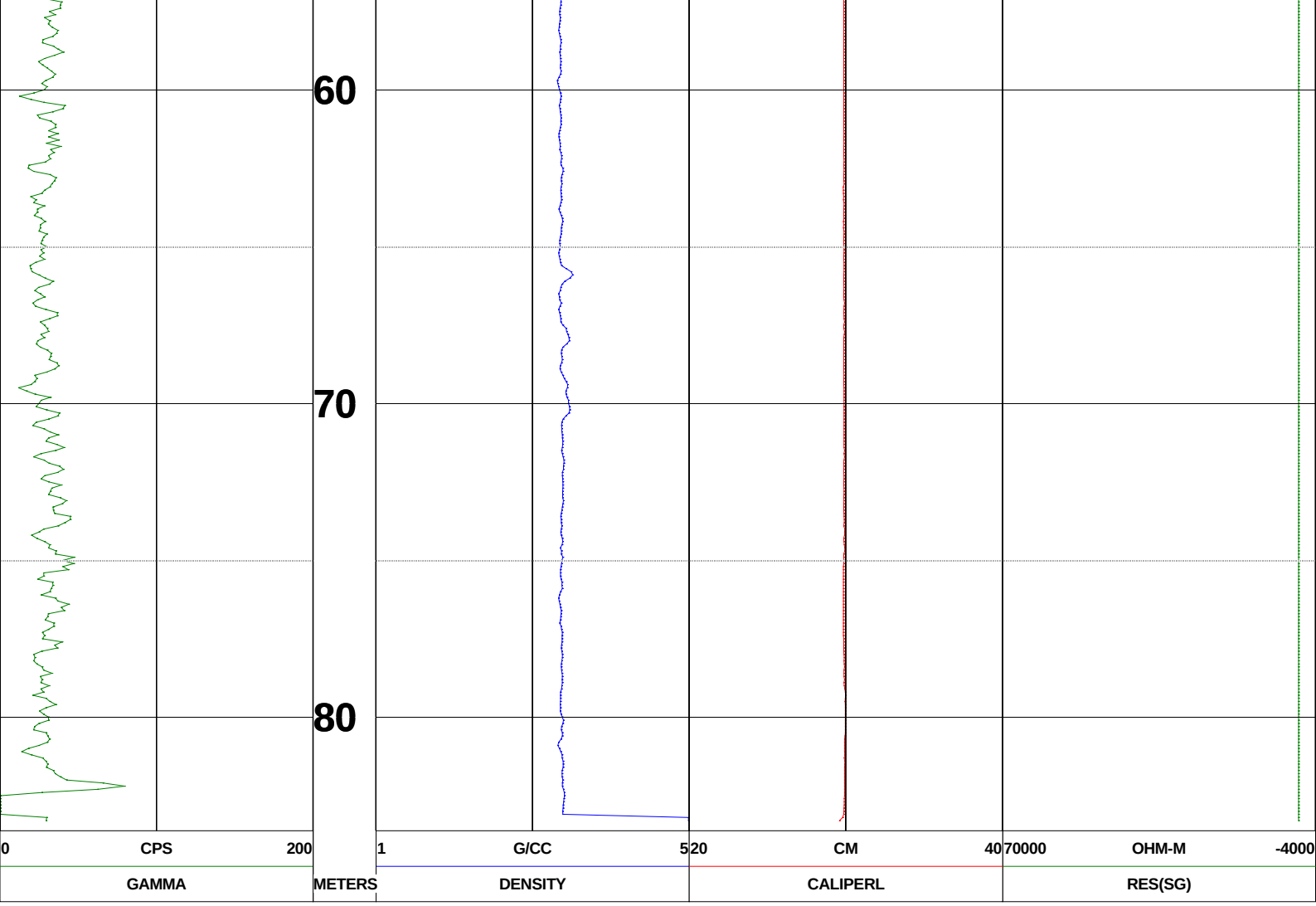
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OHM-M
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RES(SG)

WB16MEH0002

COMPANY	:	RTIO			OTHER SERVICES:		
WELL	:	WB16MEH000			PEG#		
LOCATION/FIELD	:	MEH			16-MEH		
COUNTY	:	MEGDC0202			P01		
LOCATION	:	MEH					
SECTION	:		TOWNSHIP	:		RANGE	:
DATE	:	02/29/16	PERMANENT DATUM	:	GL		
DEPTH DRILLER	:	57				KB	:
LOG BOTTOM	:	55.60	LOG MEASURED FROM	:	GL	DF	:
LOG TOP	:	0.10	DRL MEASURED FROM	:	GL	GL	:
CASING DIAMETER	:	10.	LOGGING UNIT	:	SV10		
CASING TYPE	:	OPEN	FIELD OFFICE	:	SURTRON		
CASING THICKNESS:			RECORDED BY	:	RP		
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NEUTRON MATRIX	:	SANDSTONE	MATRIX DELTA T	:	177		
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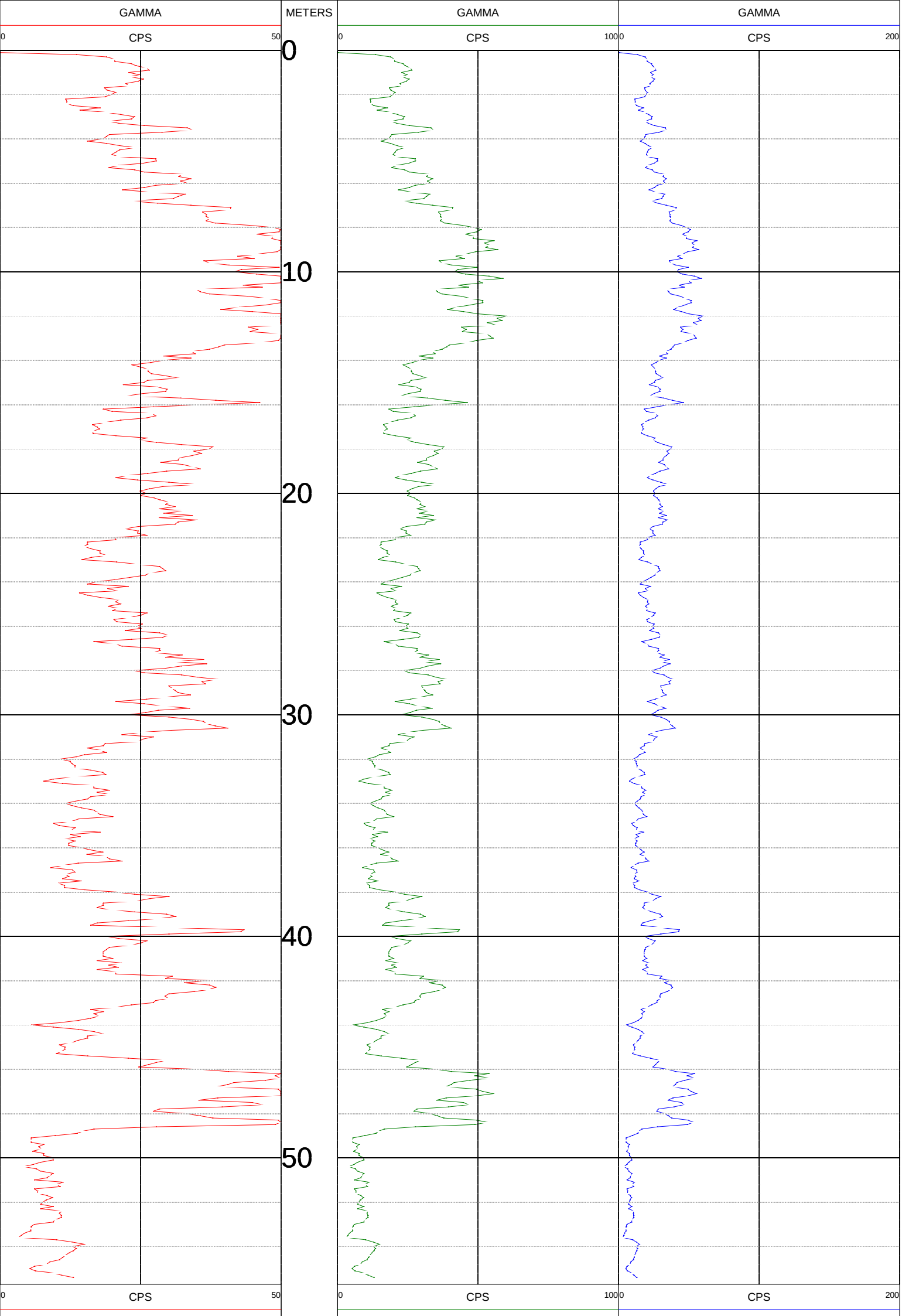
ALL SERVICES PROVIDED SUBJECT TO STANDARD TERMS AND CONDITIONS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CPS
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GAMMA	METERS	GAMMA	GAMMA

WB16MEH0002

COMPANY	:	RTIO			OTHER SERVICES:		
WELL	:	WB16MEH000			PEG#		
LOCATION/FIELD	:	MEH			16MEH		
COUNTY	:	MEGDC0202			_P01		
LOCATION	:	MEH					
SECTION	:		TOWNSHIP	:		RANGE	:
DATE	:	03/04/16	PERMANENT DATUM	:	GL		
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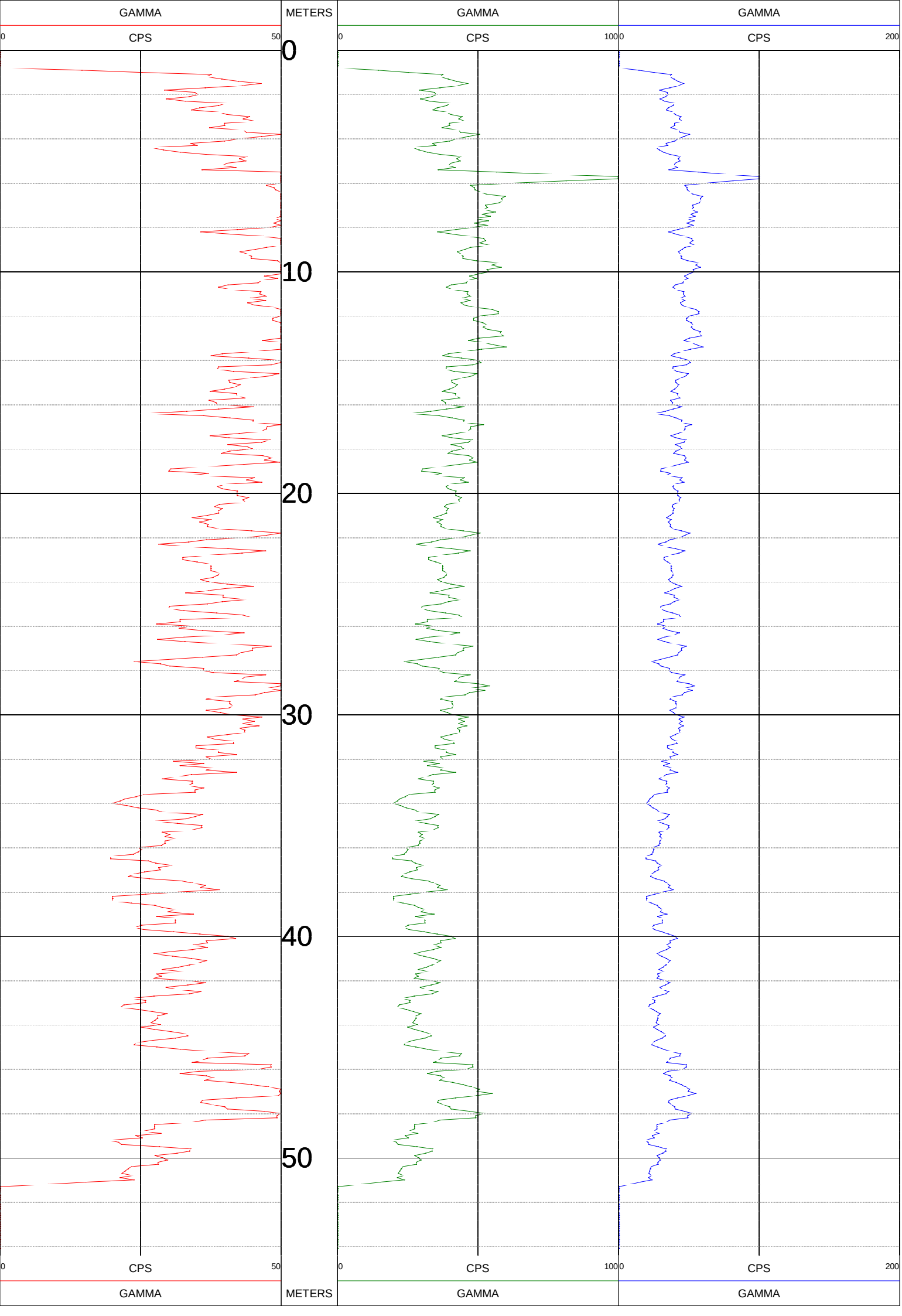
CASING TYPE	:	STEEL	FIELD OFFICE	:	SURTRON		
CASING THICKNESS	:		RECORDED BY	:	CJ		
BIT SIZE	:	31	BOREHOLE FLUID	:		FILE	: PROCESSED
MAGNETIC DECL.	:	1.438	RM	:		TYPE	: 9238AA
MATRIX DENSITY	:	2.65	RM TEMPERATURE	:		LGDATE	: 03/04/16
NEUTRON MATRIX	:	SANDSTONE	MATRIX DELTA T	:	177		
						THRESH	: 90000

ALL SERVICES PROVIDED SUBJECT TO STANDARD TERMS AND CONDITIONS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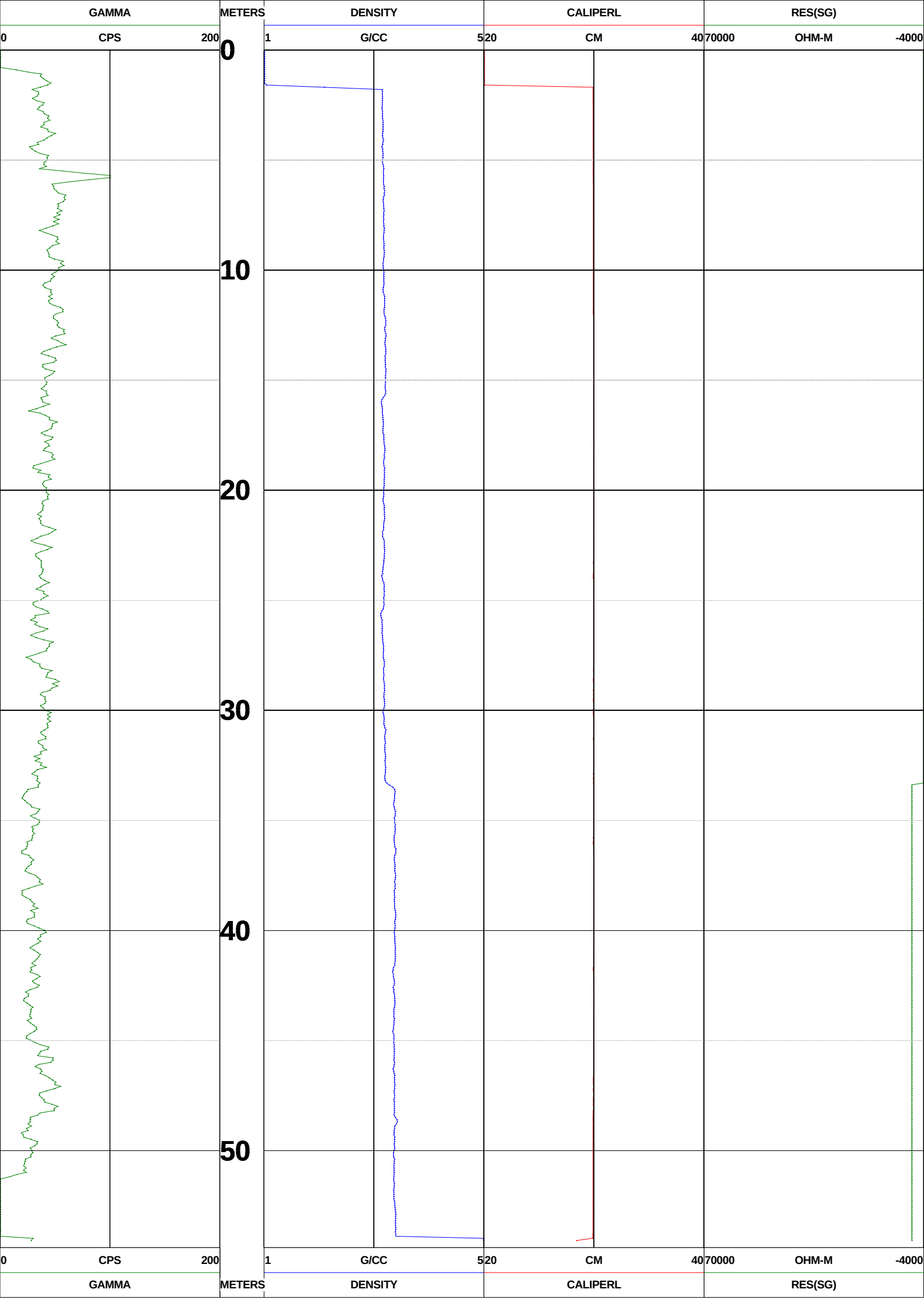
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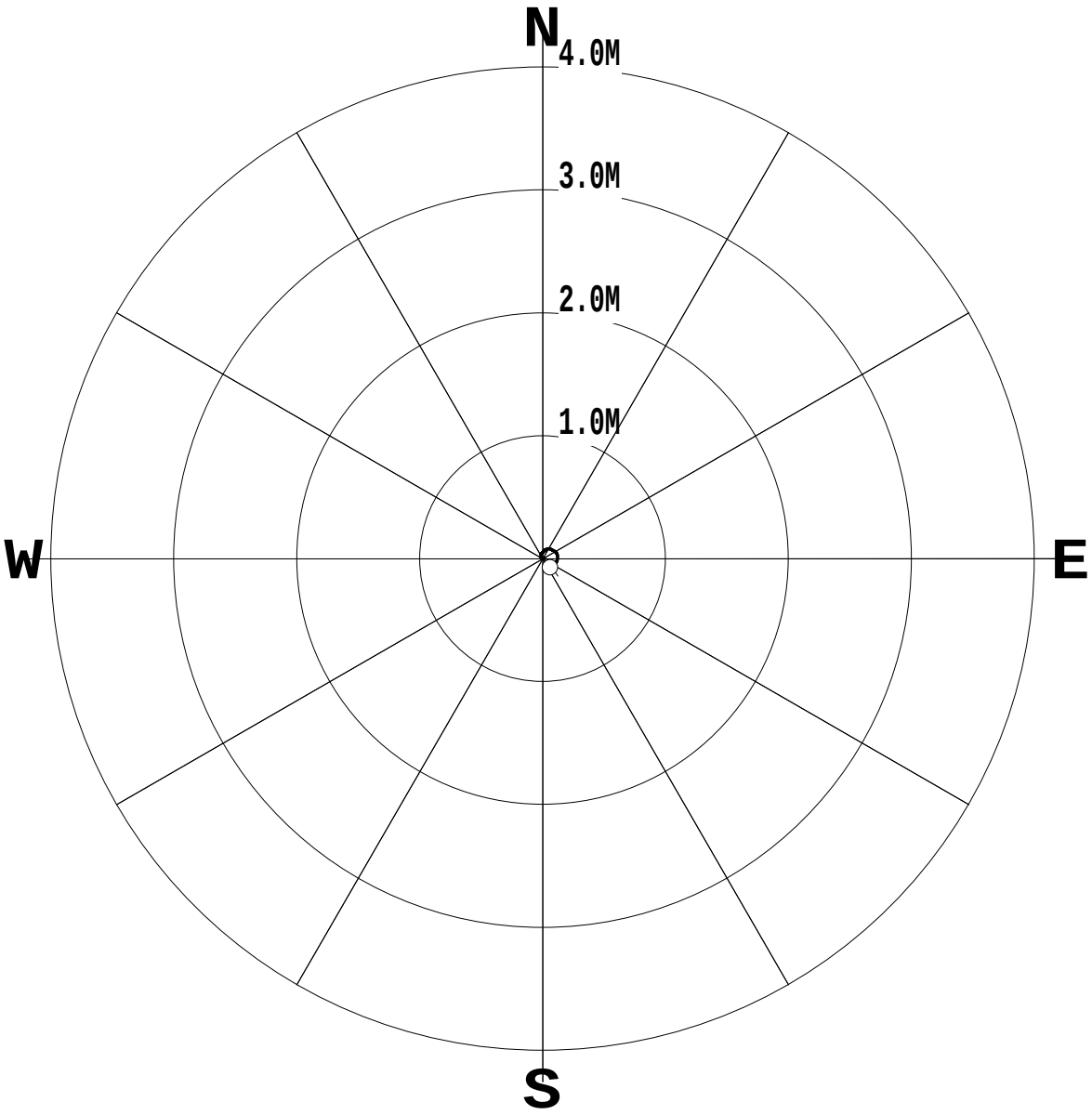
DENSITY
CALIPERL
RES(SG)

PLAN VIEW
COMPU-LOG DEVIATION

CLIENT: RTIO
LOCATION: MEH
HOLE ID: WB16MEH0002
DATE OF LOG: 03/04/16
PROBE: 9098C 1217

MAG DECL: 1.4

SCALE: 1 M/CM
TRUE DEPTH: 51.30 M
AZIMUTH: 137.6
DISTANCE: 0.1 M
+ = 50 M INCR
○ = BOTTOM OF HOLE



* * * * * * * COMPU-LOG - VERTICAL DEVIATION * * * * * * *

CLIENT : RTIO HOLE ID. : WB16MEH0002
FIELD OFFICE : SURTRON DATE OF LOG : 03/04/16
DATA FROM : PROBE : 9098C , 1217
MAG. DECL. : 1.438 DEPTH UNITS : METERS
LOG: WB16MEH0002_GYRO.log

CABLE DEPTH	TRUE DEPTH	NORTH DEV.	EAST DEV.	DISTANCE	AZIMUTH	SANG	SANGB
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10.00	10.00	0.04	-0.01	0.0	341.2	0.3	23.1
20.00	20.00	0.07	0.02	0.1	15.8	0.3	54.3
30.00	30.00	0.08	0.07	0.1	42.0	0.3	121.0
40.00	40.00	0.02	0.12	0.1	78.5	0.6	171.1
50.00	50.00	-0.06	0.07	0.1	130.6	0.6	246.3
51.30	51.30	-0.07	0.06	0.1	137.6	0.6	254.4

WB16MEH0003

COMPANY	:	RTIO			OTHER SERVICES:		
WELL	:	WB16MEH000			PEG#		
LOCATION/FIELD	:	MEH			16MEH		
COUNTY	:	MEGDC0202			_P03		
LOCATION	:	MEH					
SECTION	:		TOWNSHIP	:		RANGE	:
DATE	:	03/11/16	PERMANENT DATUM	:	GL		
DEPTH DRILLER	:	70				KB	:
LOG BOTTOM	:	69.50	LOG MEASURED FROM	:	GL	DF	:
LOG TOP	:	-0.80	DRL MEASURED FROM	:	GL	GL	:
CASING DIAMETER	:	10.	LOGGING UNIT	:	SV10		
CASING TYPE	:	STEEL	FIELD OFFICE	:	SURTRON		
CASING THICKNESS:			RECORDED BY	:	CJ		
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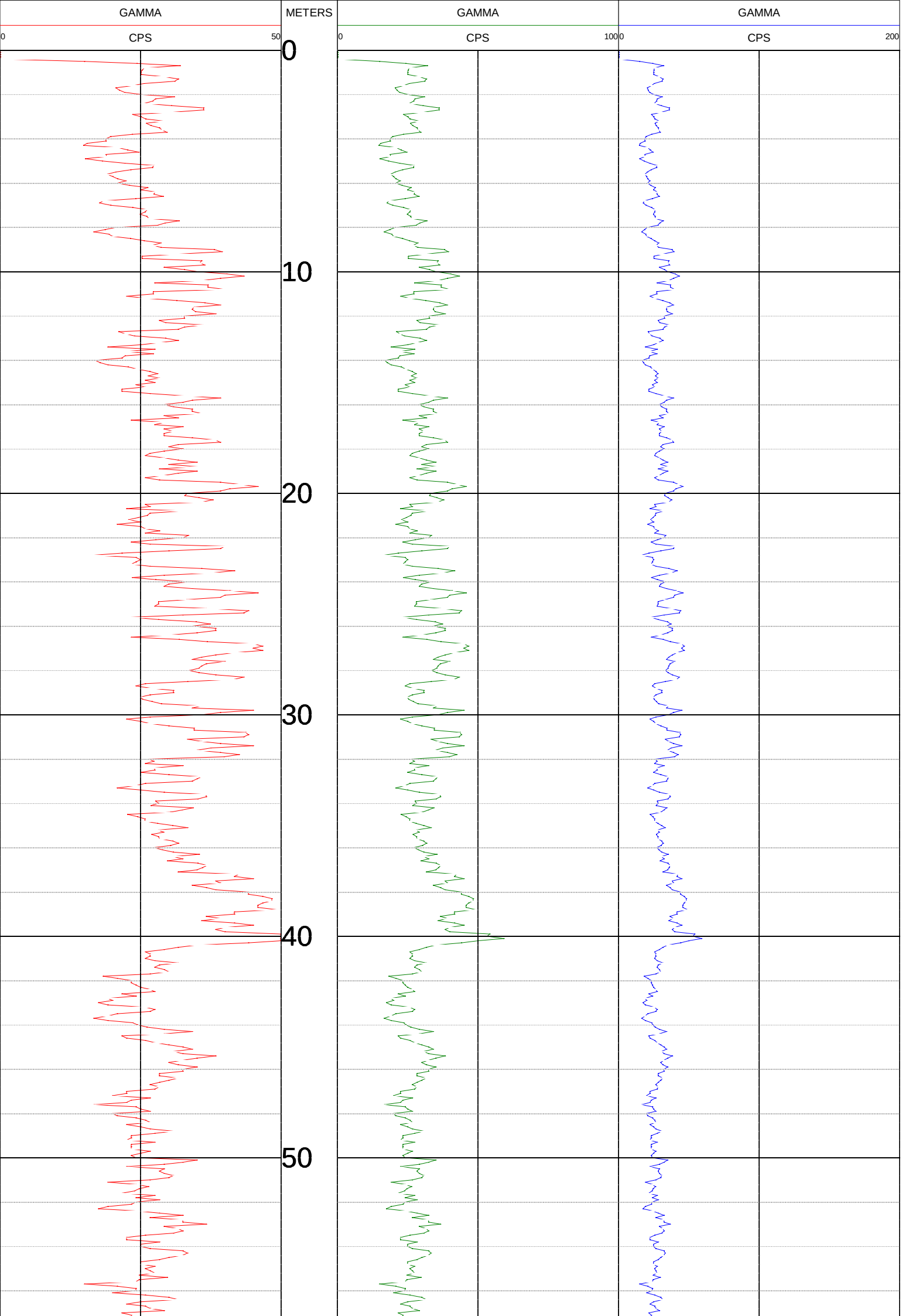
MATRIX DENSITY	:	2.65	RM TEMPERATURE	:		LGDATE	: 03/11/16
NEUTRON MATRIX	:	SANDSTONE	MATRIX DELTA T	:	177		
						THRESH	: 90000

ALL SERVICES PROVIDED SUBJECT TO STANDARD TERMS AND CONDITIONS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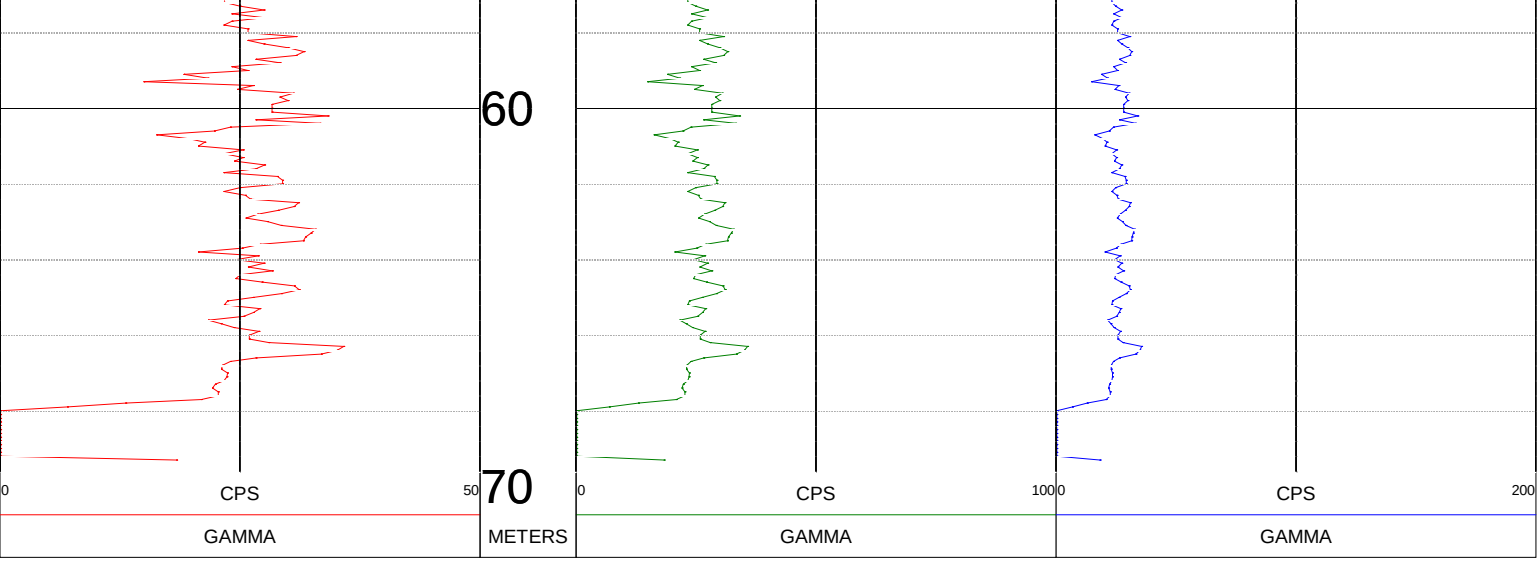
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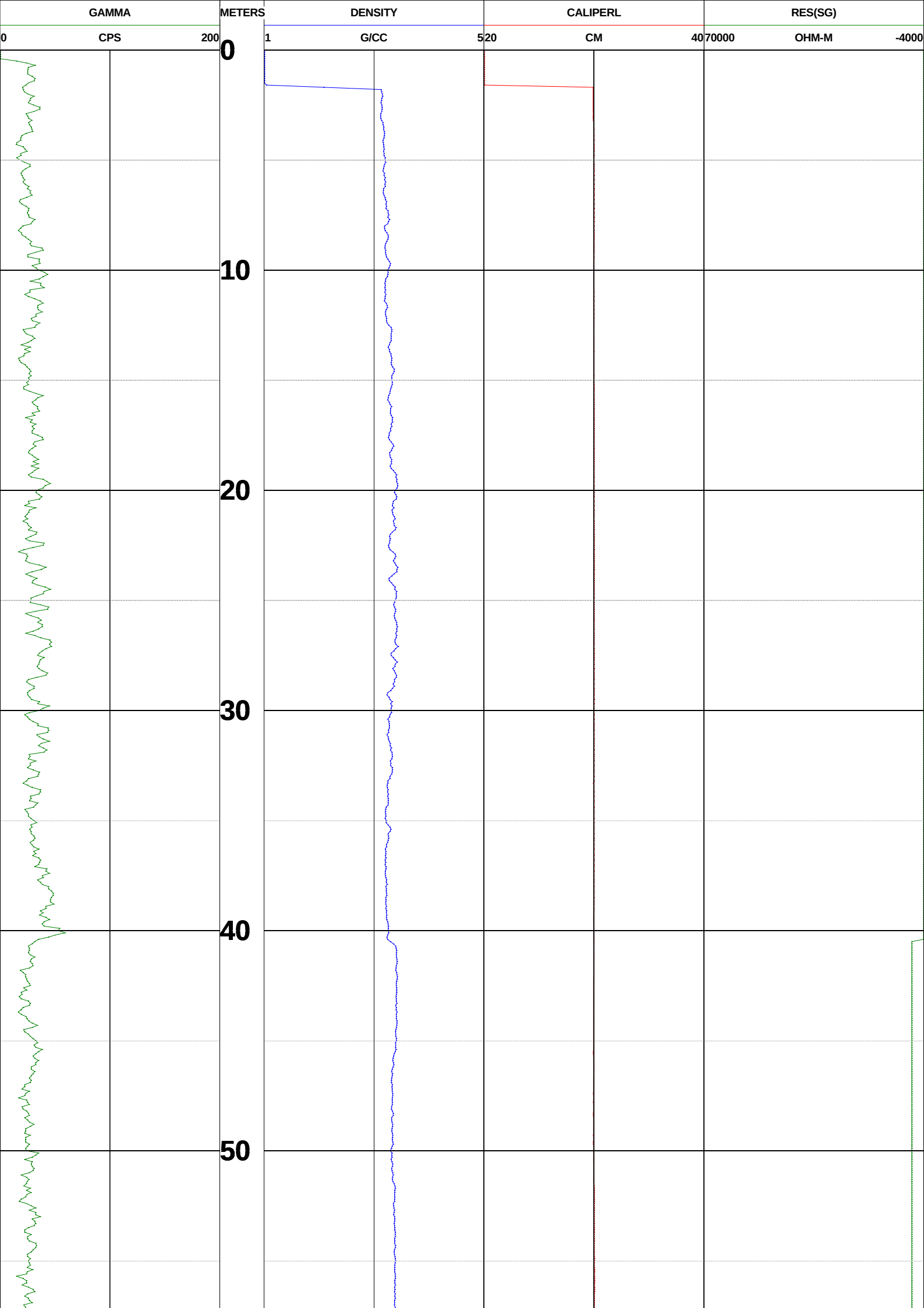
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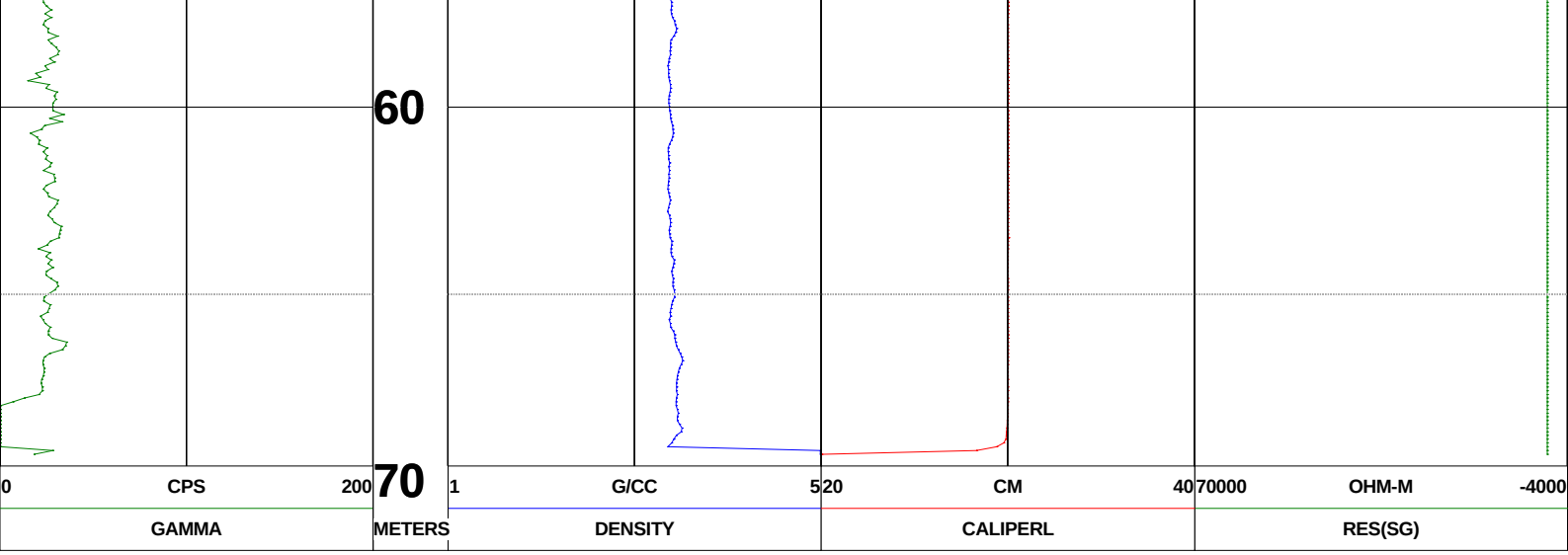
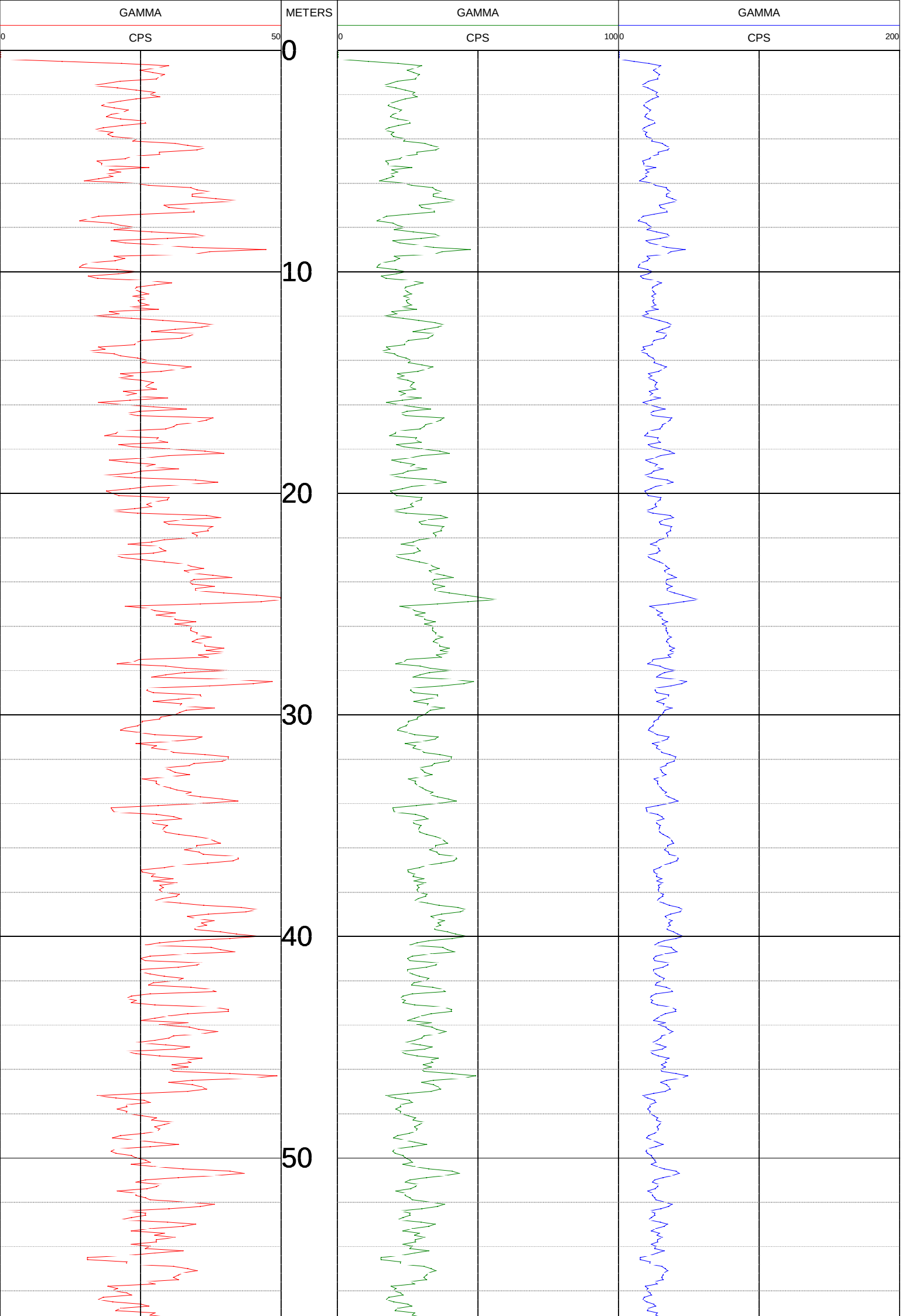

60
70
0
CPS
200
GAMMA
METERS
1
G/CC
5
DENSITY
20
CM
40
CALIPERL
70000
OHM-M
-4000
RES(SG)

WB16MEH0004

COMPANY	:	RTIO			OTHER SERVICES:		
WELL	:	WB16MEH000			PEG#		
LOCATION/FIELD	:	MEH			16MEH		
COUNTY	:	MEGDC0202			_P04		
LOCATION	:	MEH					
SECTION	:		TOWNSHIP	:		RANGE	:
DATE	:	03/14/16	PERMANENT DATUM	:	GL		
DEPTH DRILLER	:	76				KB	:
LOG BOTTOM	:	75.00	LOG MEASURED FROM:		GL	DF	:
LOG TOP	:	-0.80	DRL MEASURED FROM:		GL	GL	:
CASING DIAMETER	:	10.	LOGGING UNIT	:	SV10		
CASING TYPE	:	STEEL	FIELD OFFICE	:	SURTRON		
CASING THICKNESS:			RECORDED BY	:	CJ		
BIT SIZE	:	31	BOREHOLE FLUID	:		FILE	: PROCESSED
MAGNETIC DECL.	:	1.438	RM	:		TYPE	: 9238AA
MATRIX DENSITY	:	2.65	RM TEMPERATURE	:		LGDATE	: 03/14/16
NEUTRON MATRIX	:	SANDSTONE	MATRIX DELTA T	:	177		
						THRESH	: 90000

ALL SERVICES PROVIDED SUBJECT TO STANDARD TERMS AND CONDITIONS


GAMMA
METERS
GAMMA
GAMMA
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CPS
50
0
CPS
100
0
CPS
200
0
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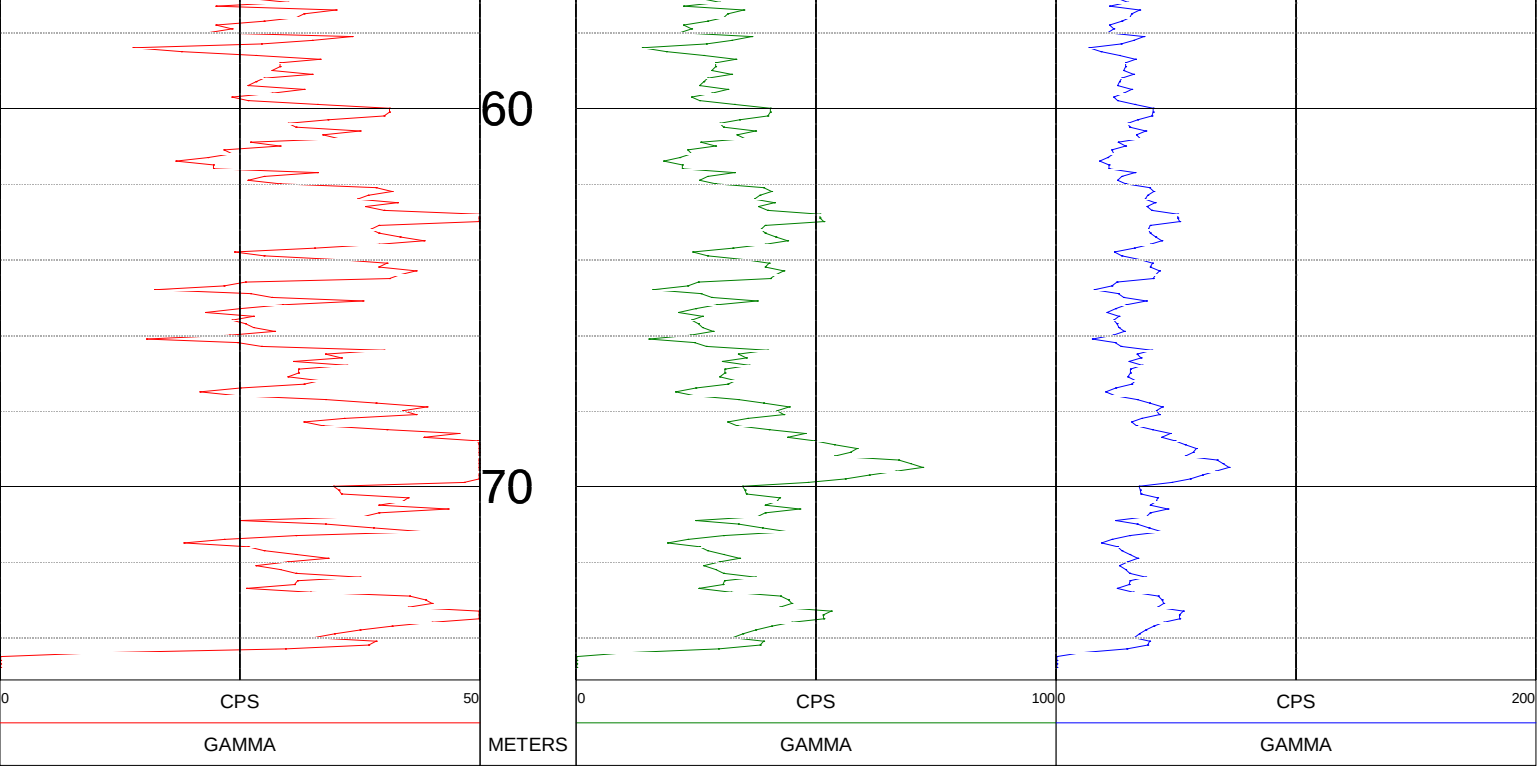
20
30
40
50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CPS
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GAMMA
METERS
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CPS
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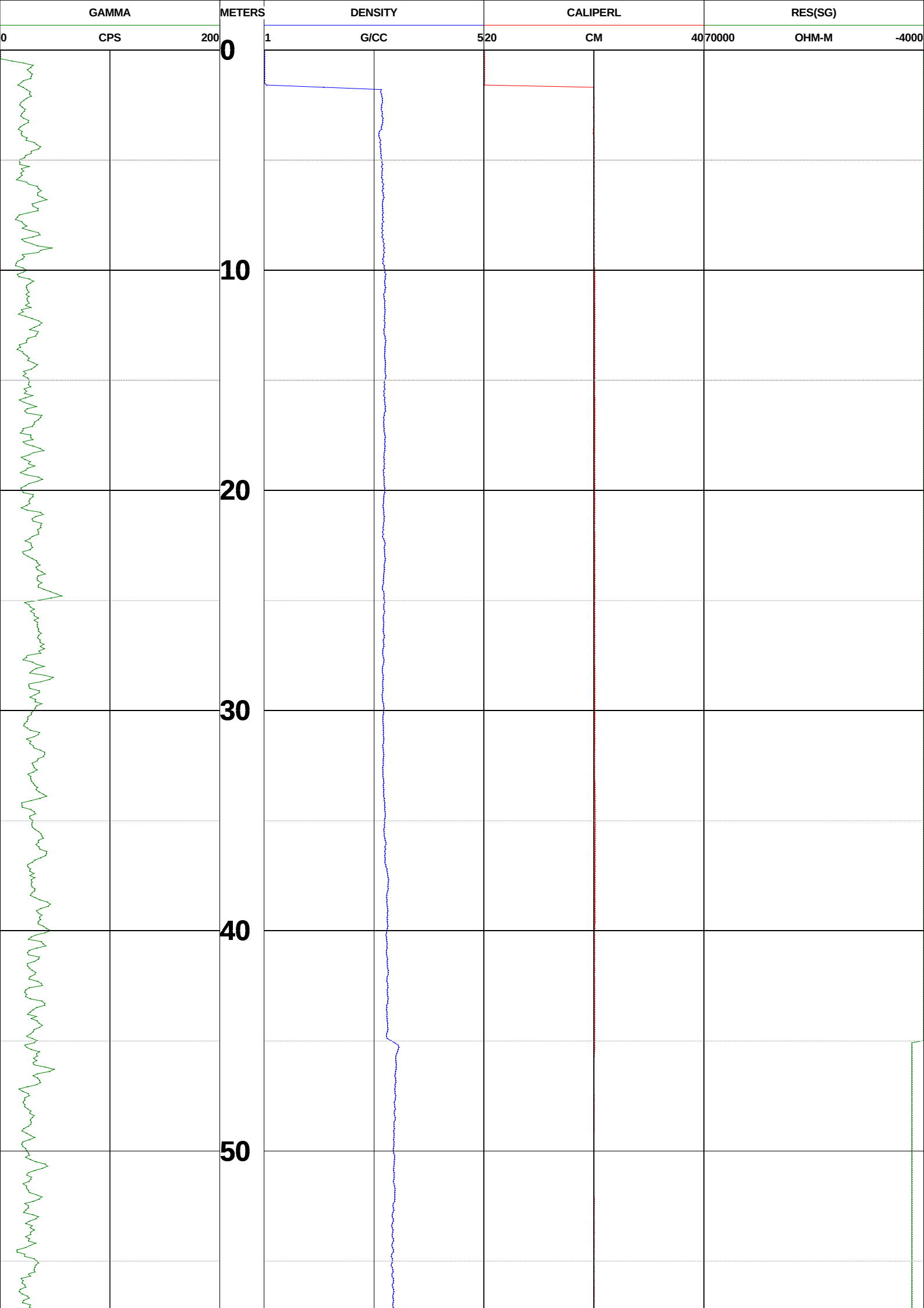
GAMMA
0
CPS
200
GAMMA


GAMMA
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CPS
200
METERS
0
10
20
30
40
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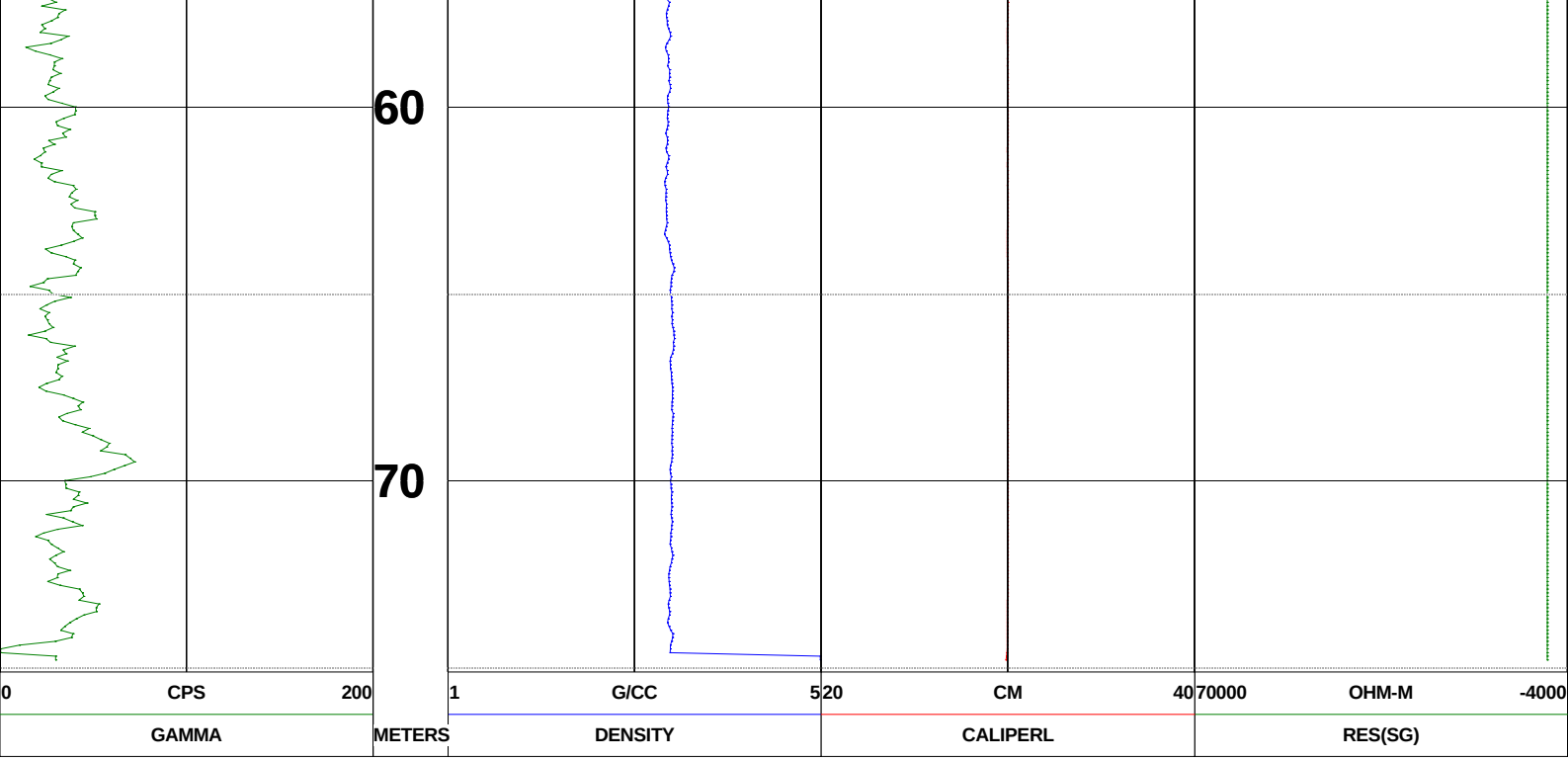
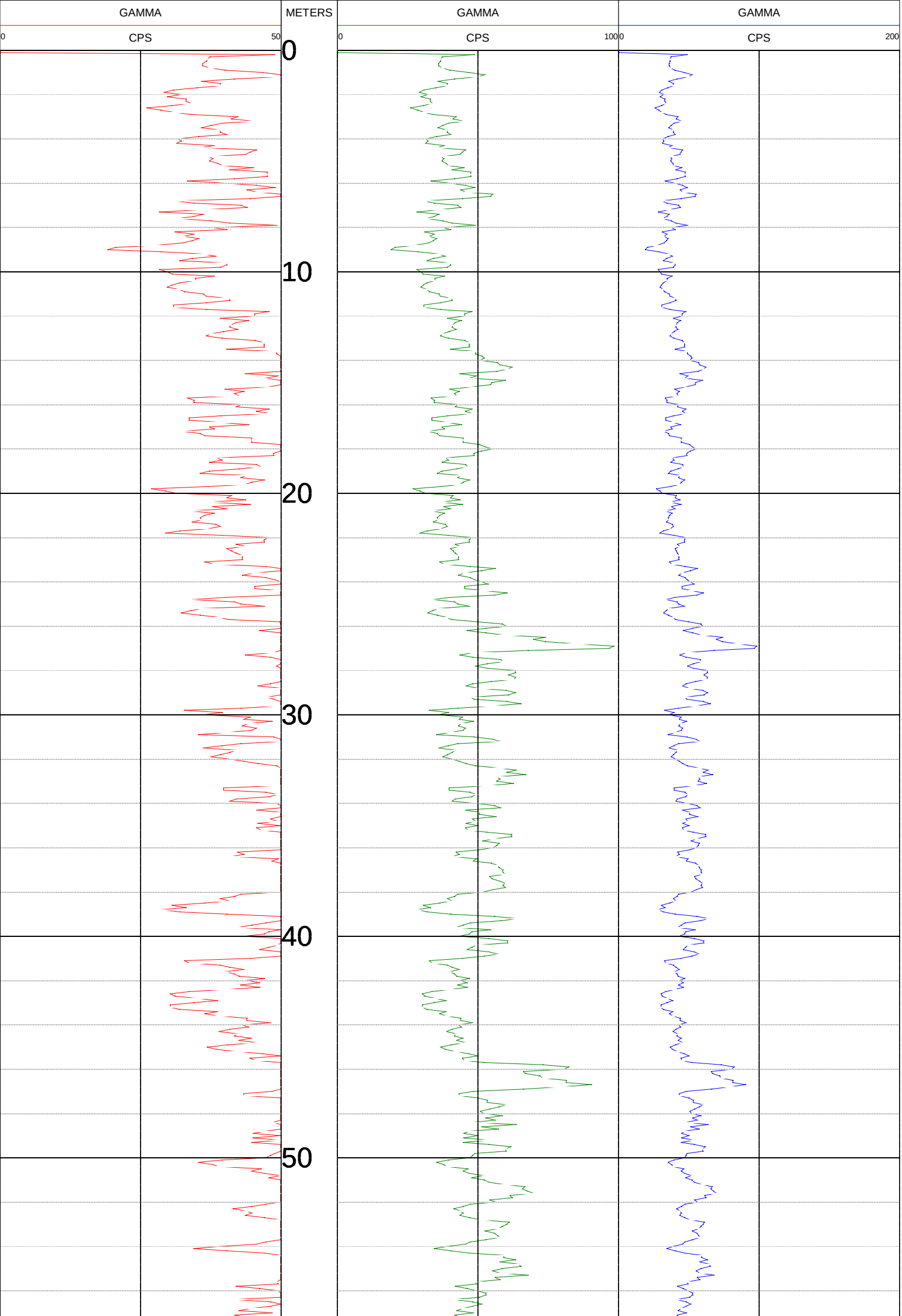
DENSITY
1
G/CC
5
CALIPERL
20
CM
40
RES(SG)
70000
OHM-M
-4000


60
70
0
CPS
200
GAMMA
METERS
1
G/CC
5
DENSITY
20
CM
40
CALIPERL
70000
OHM-M
-4000
RES(SG)

HM16MEH0001

COMPANY	:	RTIO			OTHER SERVICES:		
WELL	:	HM16MEH000			PEG#		
LOCATION/FIELD	:	MEH			16MEH		
COUNTY	:	MEGDC0202			_M15		
LOCATION	:	MEH					
SECTION	:		TOWNSHIP	:		RANGE	:
DATE	:	03/04/16	PERMANENT DATUM	:	GL		
DEPTH DRILLER	:	78				KB	:
LOG BOTTOM	:	77.70	LOG MEASURED FROM	:	GL	DF	:
LOG TOP	:	0.10	DRL MEASURED FROM	:	GL	GL	:
CASING DIAMETER	:	10.	LOGGING UNIT	:	SV10		
CASING TYPE	:	PVC	FIELD OFFICE	:	SURTRON		
CASING THICKNESS:			RECORDED BY	:	CJ		
BIT SIZE	:	31	BOREHOLE FLUID	:		FILE	: ORIGINAL
MAGNETIC DECL.	:	1.438	RM	:		TYPE	: 9012C
MATRIX DENSITY	:	2.65	RM TEMPERATURE	:		LGDATE	: 03/04/16
NEUTRON MATRIX	:	SANDSTONE	MATRIX DELTA T	:	177		
						THRESH	: 90000

ALL SERVICES PROVIDED SUBJECT TO STANDARD TERMS AND CONDITIONS


GAMMA
METERS
GAMMA
GAMMA
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CPS
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0
CPS
100
0
CPS
200
0
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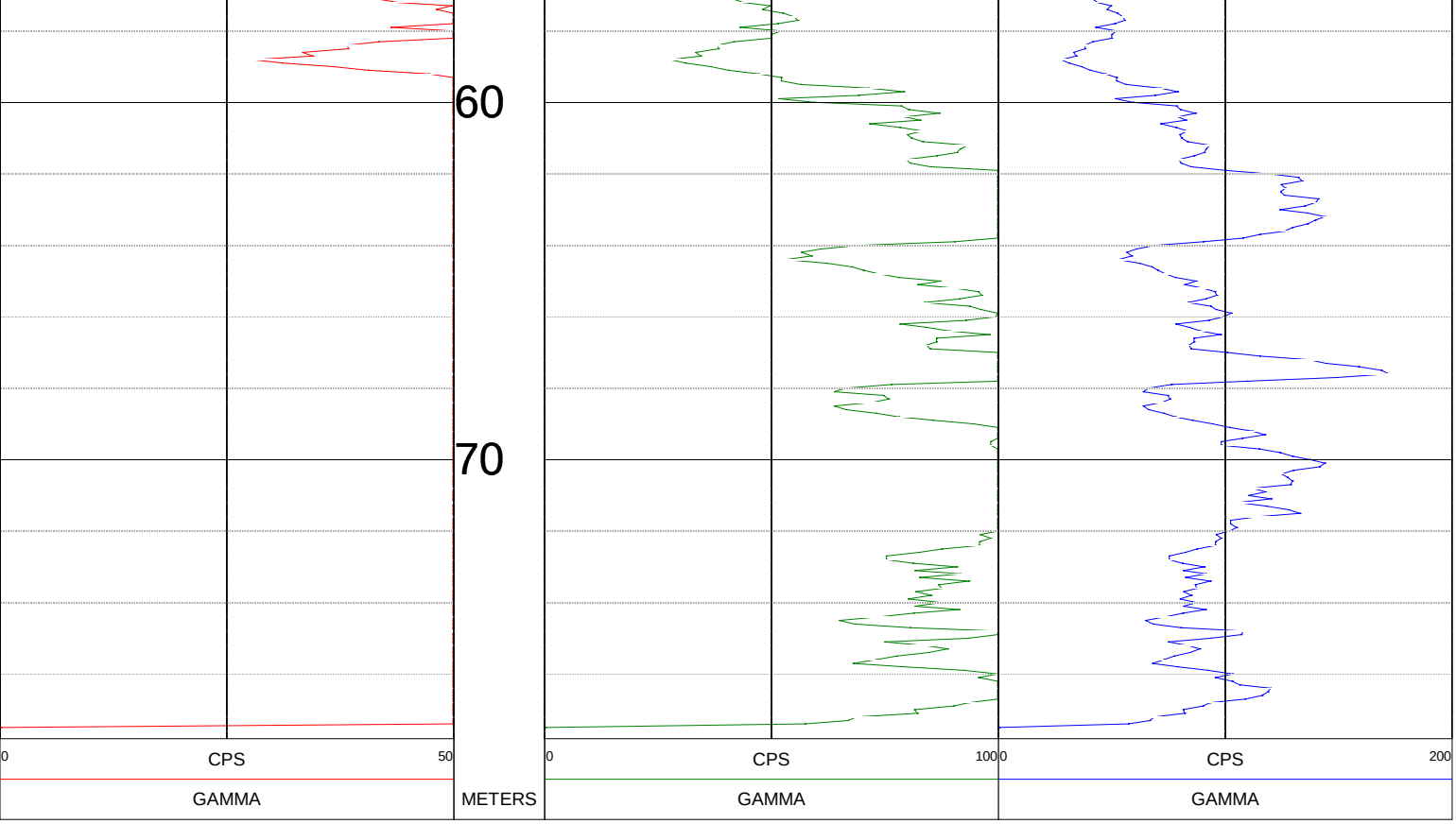
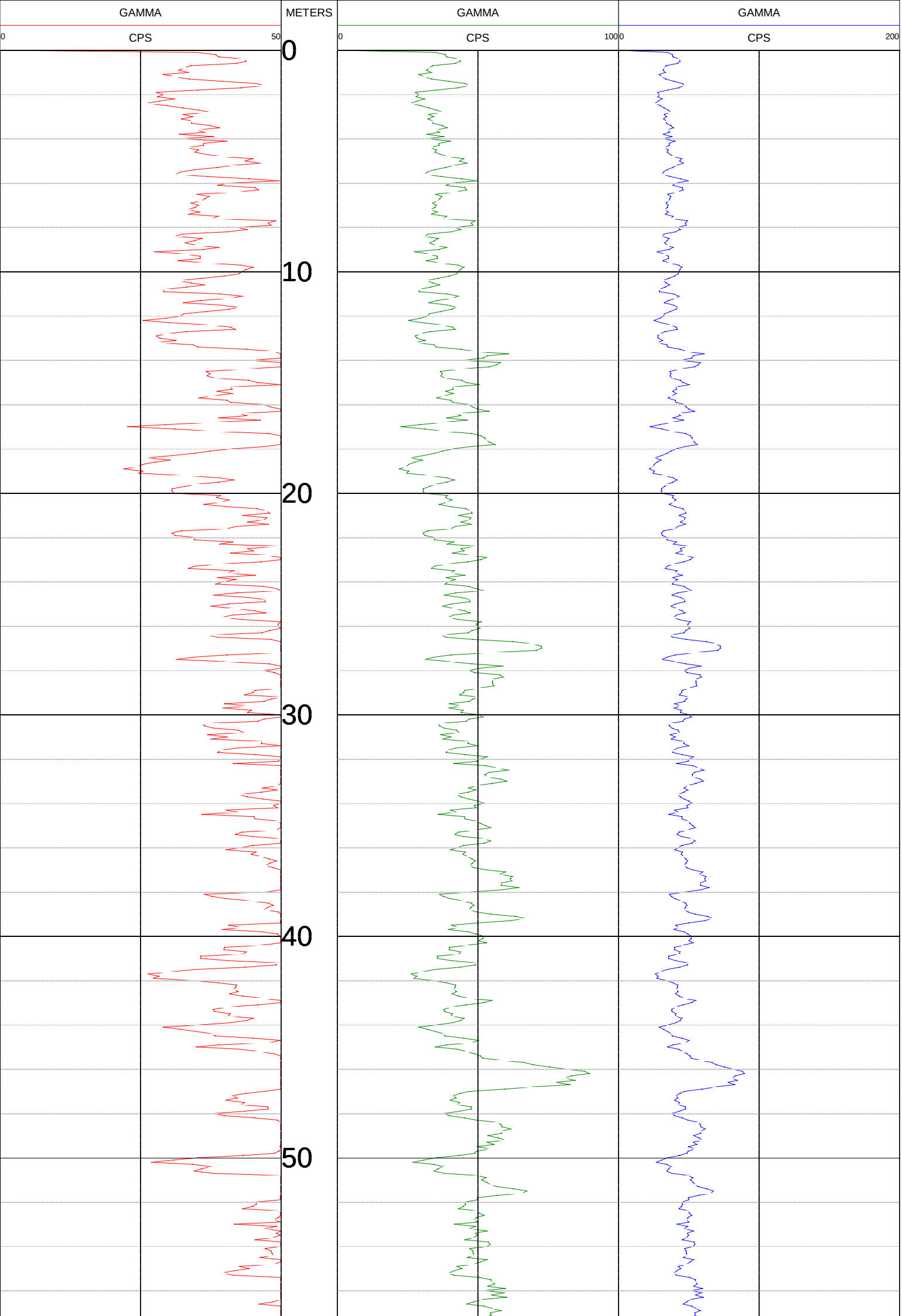
20
30
40
50


60
70
0
CPS
50
GAMMA
METERS
0
CPS
100
GAMMA
0
CPS
200
GAMMA

HM16MEH0001

COMPANY	: RTIO			OTHER SERVICES:			
WELL	: HM16MEH000			16MEH			
LOCATION/FIELD	:			_M15			
COUNTY	: MEGDC0202						
LOCATION	: MEH						
SECTION	: MEH	TOWNSHIP	:		RANGE	:	
DATE	: 02/17/16	PERMANENT DATUM	: GL				
DEPTH DRILLER	: 78				KB	:	
LOG BOTTOM	: 59.50	LOG MEASURED FROM:	GL		DF	:	
LOG TOP	: 0.00	DRL MEASURED FROM:	GL		GL	:	
CASING DIAMETER	: 10.	LOGGING UNIT	: SV25				
CASING TYPE	: PVC	FIELD OFFICE	: SURTRON				
CASING THICKNESS:		RECORDED BY	: CJ				
BIT SIZE	: 12.5	BOREHOLE FLUID	:		FILE	: ORIGINAL	
MAGNETIC DECL.	: 1.438	RM	:		TYPE	: 9012C	
MATRIX DENSITY	: 2.65	RM TEMPERATURE	:		LGDATE	: 02/17/16	
NEUTRON MATRIX	: SANDSTONE	MATRIX DELTA T	: 177				
					THRESH	: 90000	

ALL SERVICES PROVIDED SUBJECT TO STANDARD TERMS AND CONDITIONS


GAMMA
METERS
GAMMA
GAMMA
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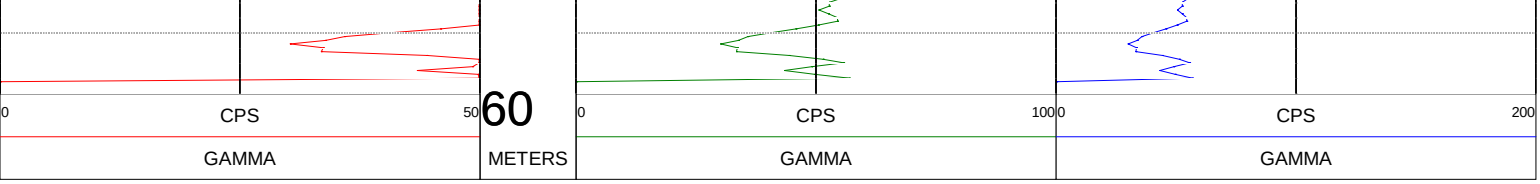
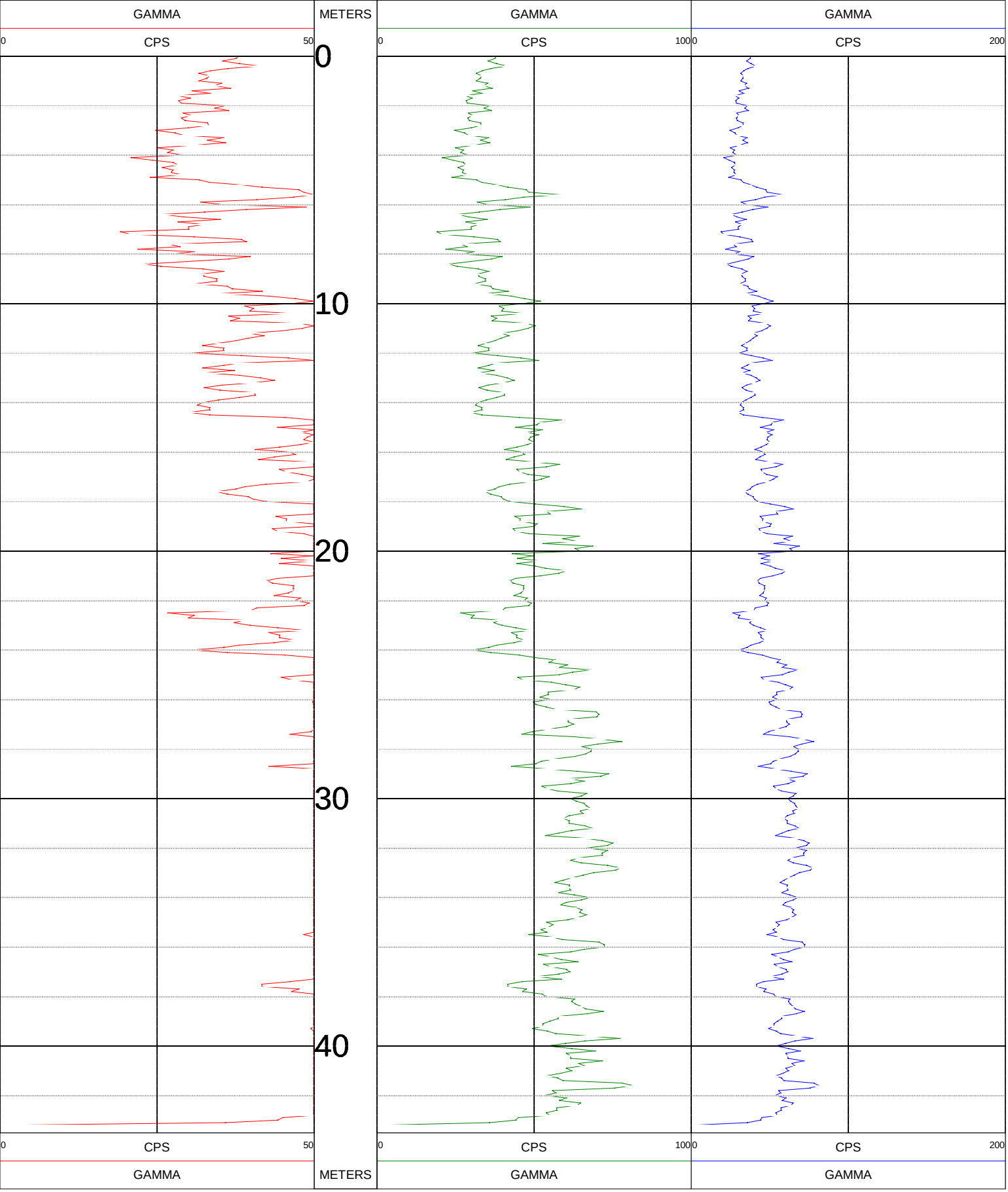
CPS
50
0
CPS
100
0
CPS
200
0
10
20
30
40
50


0
CPS
50
GAMMA
60
METERS
0
CPS
100
GAMMA
0
CPS
200
GAMMA

HM16MEH0002

COMPANY	:	RTIO			OTHER SERVICES:		
WELL	:	HM16MEH000			PEG#		
LOCATION/FIELD	:	MEH			16MEH		
COUNTY	:	MEGDC0202			_M02		
LOCATION	:	MEH					
SECTION	:		TOWNSHIP	:		RANGE	:
DATE	:	03/04/16	PERMANENT DATUM	:	GL		
DEPTH DRILLER	:	77				KB	:
LOG BOTTOM	:	43.40	LOG MEASURED FROM	:	GL	DF	:
LOG TOP	:	-0.10	DRL MEASURED FROM	:	GL	GL	:
CASING DIAMETER	:	10.	LOGGING UNIT	:	SV10		
CASING TYPE	:	PVC	FIELD OFFICE	:	SURTRON		
CASING THICKNESS	:		RECORDED BY	:	CJ		
BIT SIZE	:	31	BOREHOLE FLUID	:		FILE	: ORIGINAL
MAGNETIC DECL.	:	1.438	RM	:		TYPE	: 9012C
MATRIX DENSITY	:	2.65	RM TEMPERATURE	:		LGDATE	: 03/04/16
NEUTRON MATRIX	:	SANDSTONE	MATRIX DELTA T	:	177		
						THRESH	: 90000

ALL SERVICES PROVIDED SUBJECT TO STANDARD TERMS AND CONDITIONS


GAMMA
METERS
GAMMA
GAMMA
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CPS
50
0
CPS
100
0
CPS
200
0
10
20
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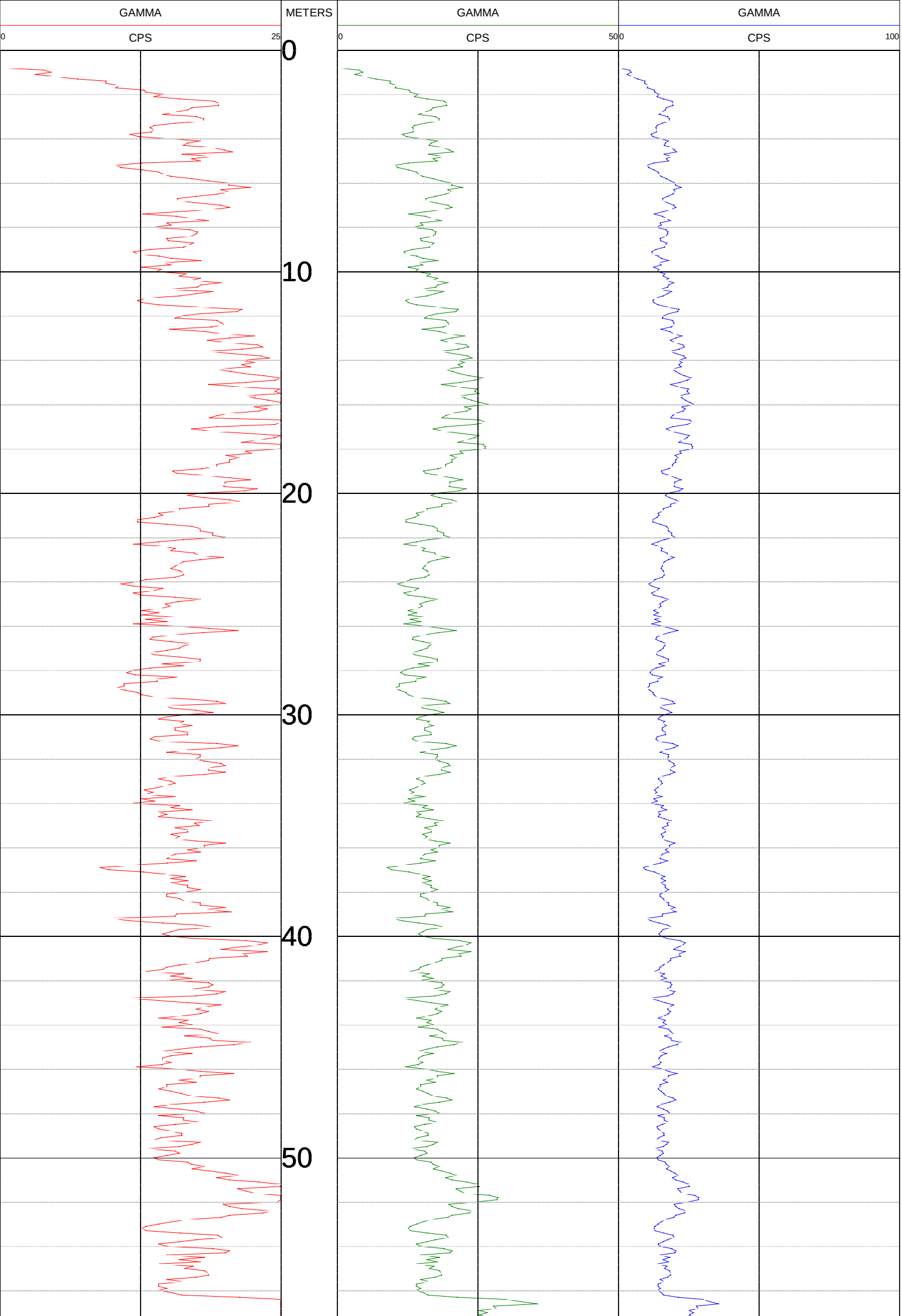
40
0
CPS
50
0
CPS
100
0
CPS
200
GAMMA
METERS
GAMMA
GAMMA

HM16MEH0003

COMPANY	: RTIO			OTHER SERVICES:			
WELL	: HM16MEH000			16MEH			
LOCATION/FIELD	:			_M14			
COUNTY	: MEGDC0202						
LOCATION	: MEH						
SECTION	: MEH	TOWNSHIP	:		RANGE	:	
DATE	: 02/18/16	PERMANENT DATUM	: GL				
DEPTH DRILLER	: 77				KB	:	
LOG BOTTOM	: 76.60	LOG MEASURED FROM:	GL		DF	:	
LOG TOP	: 0.80	DRL MEASURED FROM:	GL		GL	:	
CASING DIAMETER	: 10.	LOGGING UNIT	: SV25				
CASING TYPE	: PVC	FIELD OFFICE	: SURTRON				
CASING THICKNESS:		RECORDED BY	: CJ				
BIT SIZE	: 12.5	BOREHOLE FLUID	:		FILE	: ORIGINAL	
MAGNETIC DECL.	: 1.438	RM	:		TYPE	: 9060C	
MATRIX DENSITY	: 2.65	RM TEMPERATURE	:		LGDATE	: 02/18/16	
NEUTRON MATRIX	: SANDSTONE	MATRIX DELTA T	: 177				
					THRESH	: 90000	

ALL SERVICES PROVIDED SUBJECT TO STANDARD TERMS AND CONDITIONS


GAMMA
METERS
GAMMA
GAMMA
0
CPS
25
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CPS
50
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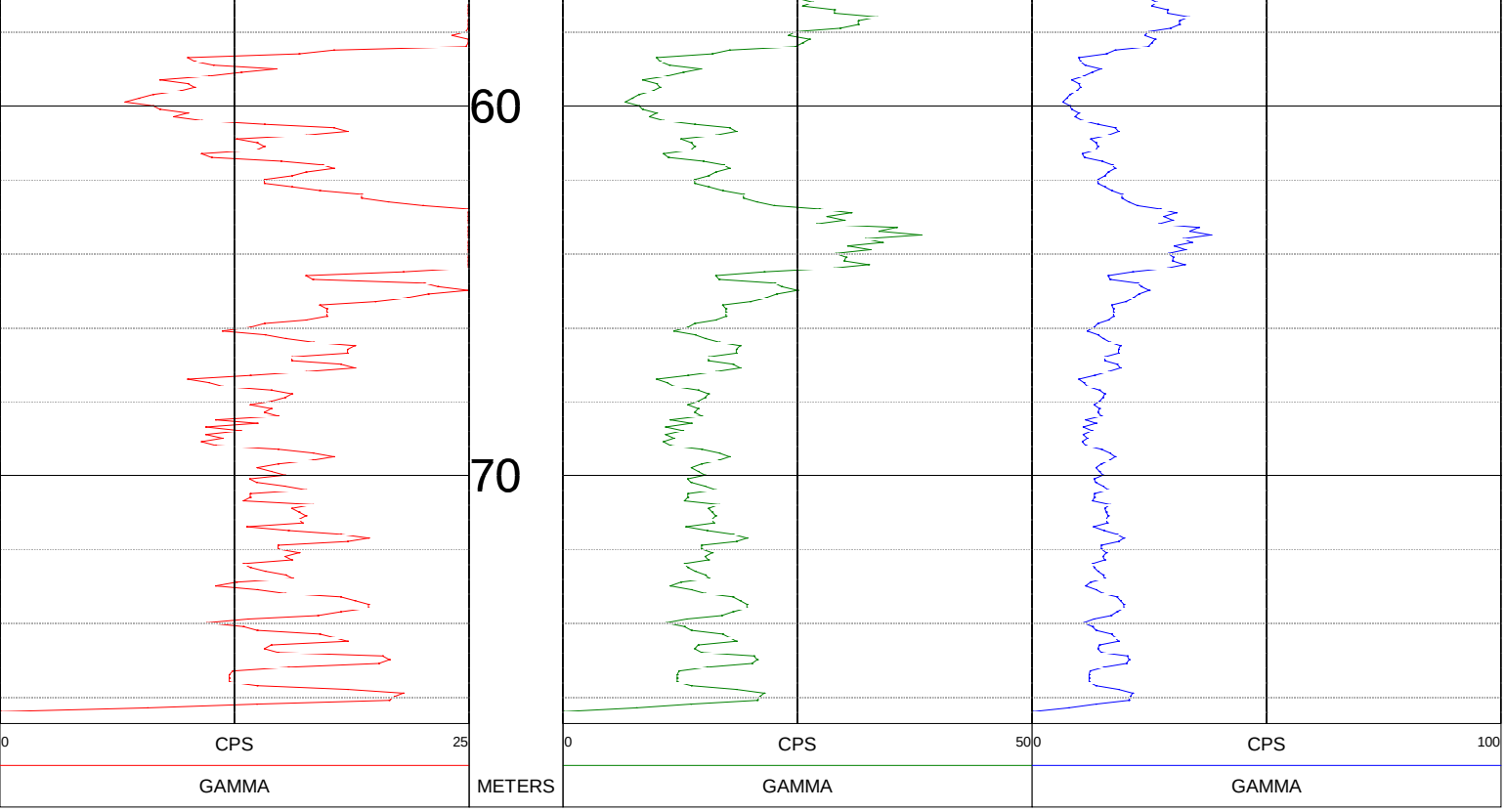
CPS
100
0
10
20
30
40
50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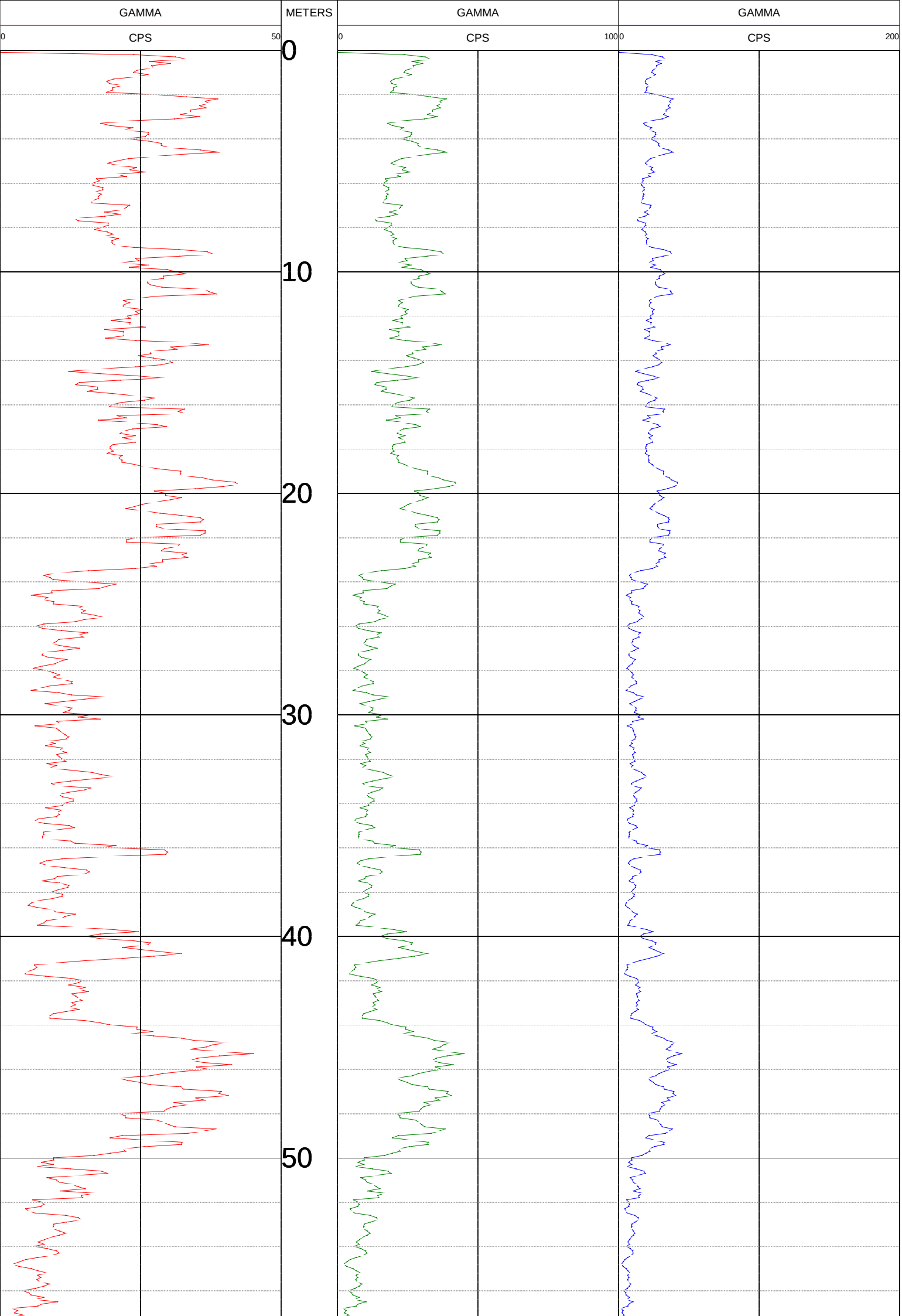
70
0
CPS
25
GAMMA
METERS
0
CPS
500
GAMMA
0
CPS
100
GAMMA

MB16MEH0001

COMPANY	:	RTIO			OTHER SERVICES:		
WELL	:	MB16MEH000			PEG#		
LOCATION/FIELD	:				16MEH_		
COUNTY	:	MEGDC0202			M16		
LOCATION	:	MEH					
SECTION	:	MEH	TOWNSHIP	:		RANGE	:
DATE	:	02/10/16	PERMANENT DATUM	:	GL		
DEPTH DRILLER	:	64				KB	:
LOG BOTTOM	:	63.20	LOG MEASURED FROM	:	GL	DF	:
LOG TOP	:	-0.30	DRL MEASURED FROM	:	GL	GL	:
CASING DIAMETER	:	10.	LOGGING UNIT	:	SV10		
CASING TYPE	:	PVC	FIELD OFFICE	:	SURTRON		
CASING THICKNESS:			RECORDED BY	:	DP		
BIT SIZE	:	12.5	BOREHOLE FLUID	:		FILE	: PROCESSED
MAGNETIC DECL.	:	1.438	RM	:		TYPE	: 9012C
MATRIX DENSITY	:	2.65	RM TEMPERATURE	:		LGDATE	: 02/10/16
NEUTRON MATRIX	:	SANDSTONE	MATRIX DELTA T	:	177		
						THRESH	: 90000

ALL SERVICES PROVIDED SUBJECT TO STANDARD TERMS AND CONDITIONS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METERS
GAMMA
GAMMA
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CPS
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CPS
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CPS
200
0
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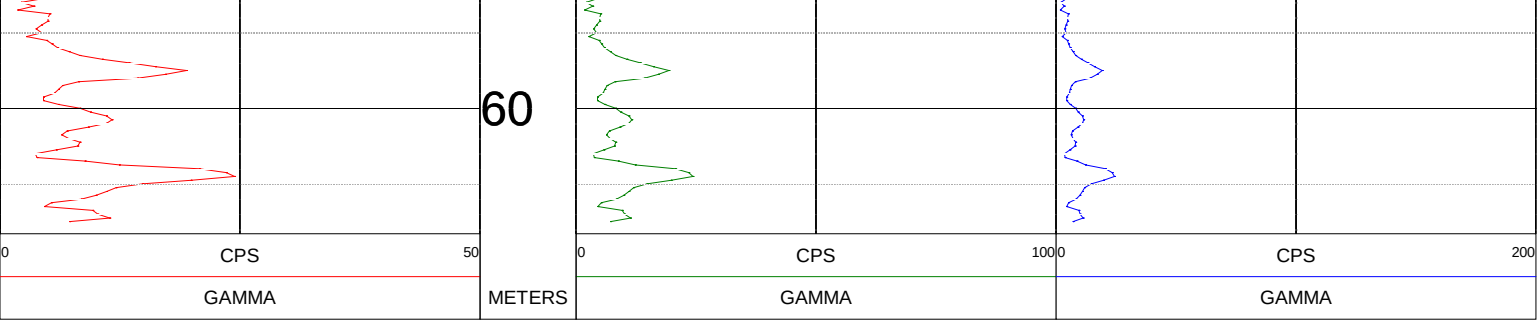
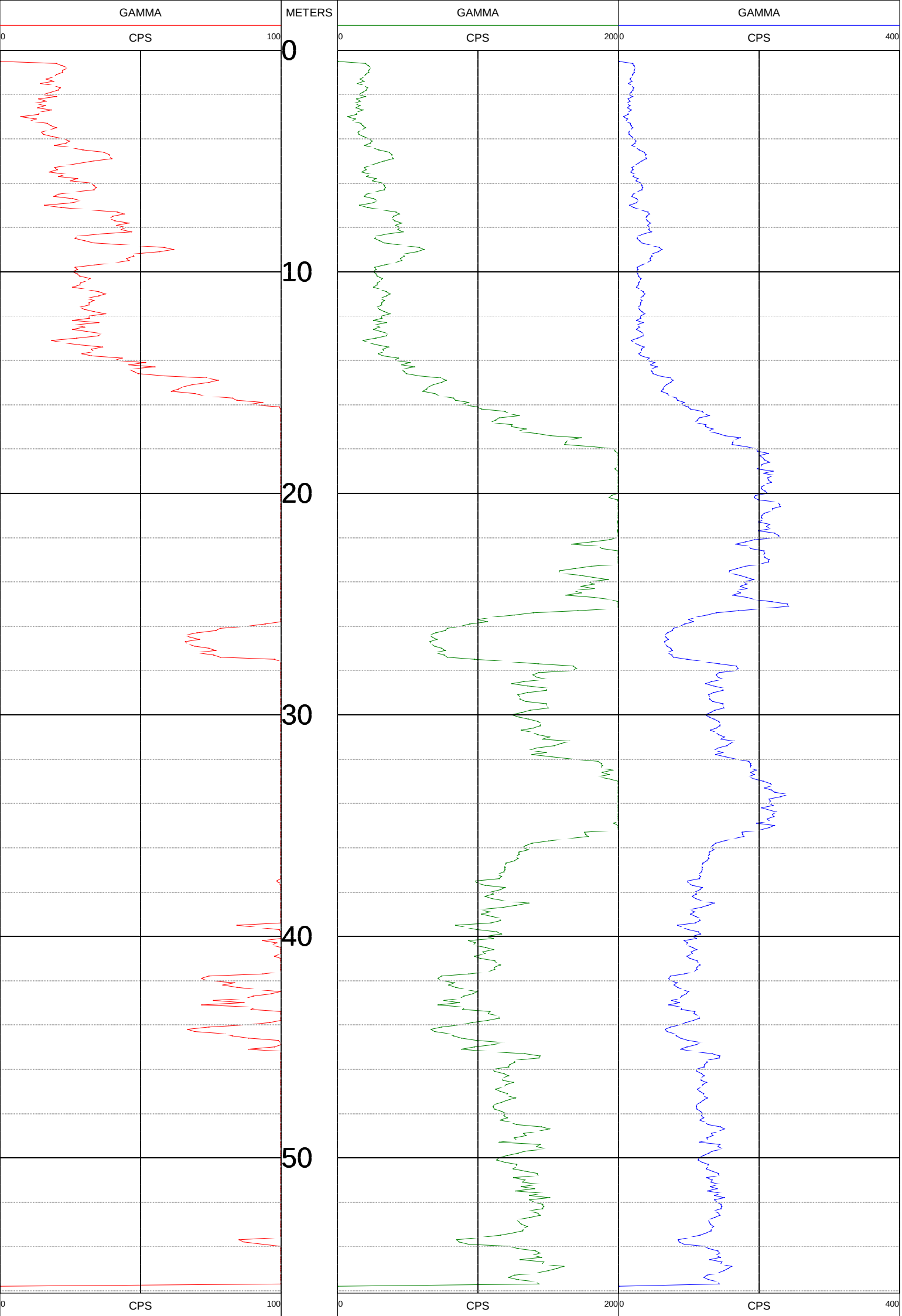
20
30
40
50


60
0
CPS
50
GAMMA
METERS
0
CPS
100
GAMMA
0
CPS
200
GAMMA

MB16MEH0002

COMPANY	: RTIO			OTHER SERVICES:			
WELL	: MB16MEH000			16MEH_			
LOCATION/FIELD	:			M08			
COUNTY	: MEGDC0202						
LOCATION	: MEH						
SECTION	: MEH	TOWNSHIP	:		RANGE	:	
DATE	: 02/12/16	PERMANENT DATUM	: GL				
DEPTH DRILLER	: 80				KB	:	
LOG BOTTOM	: 56.00	LOG MEASURED FROM:	GL		DF	:	
LOG TOP	: 0.50	DRL MEASURED FROM:	GL		GL	:	
CASING DIAMETER	: 10.	LOGGING UNIT	: SV25				
CASING TYPE	: PVC	FIELD OFFICE	: SURTRON				
CASING THICKNESS:		RECORDED BY	: CJ				
BIT SIZE	: 12.5	BOREHOLE FLUID	:		FILE	: ORIGINAL	
MAGNETIC DECL.	: 1.438	RM	:		TYPE	: 9012C	
MATRIX DENSITY	: 2.65	RM TEMPERATURE	:		LGDATE	: 02/12/16	
NEUTRON MATRIX	: SANDSTONE	MATRIX DELTA T	: 177				
					THRESH	: 90000	

ALL SERVICES PROVIDED SUBJECT TO STANDARD TERMS AND CONDITIONS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METERS
GAMMA
GAMMA
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CPS
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0
CPS
200
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CPS
400
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10
20
30
40
50
0
CPS
100
0
CPS
200
0
CPS
400

GAMMA	METERS	GAMMA	GAMMA

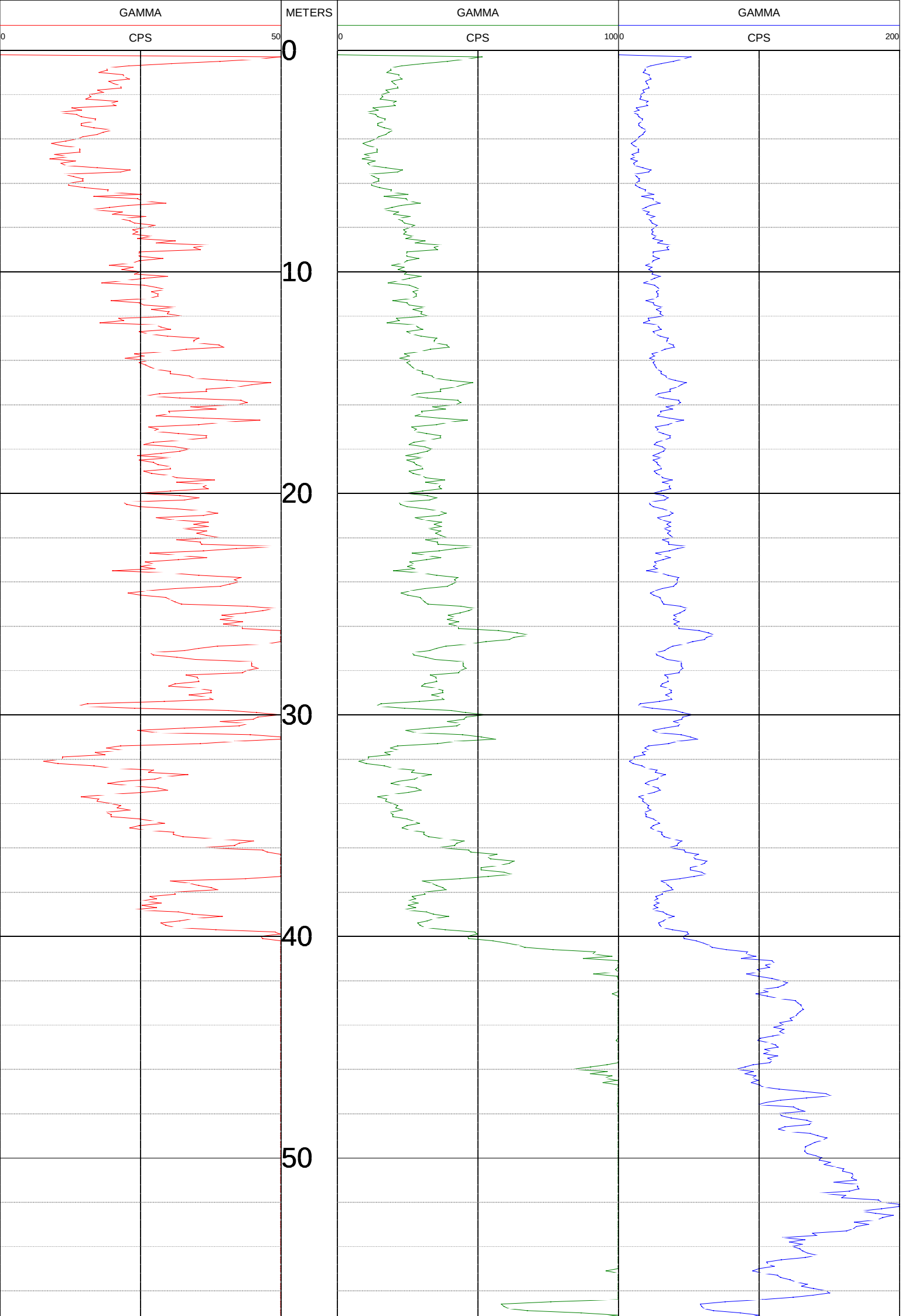
SURTRON

WIRELINE SERVICES

MB16MEH0003

COMPANY	: RTIO			OTHER SERVICES:	
WELL	: MB16MEH000			16MEH	
LOCATION/FIELD	:			_M07	
COUNTY	: MEGDC0202				
LOCATION	: MEH				
SECTION	: MEH	TOWNSHIP	:	RANGE	:
DATE	: 02/15/16	PERMANENT DATUM	: GL		
DEPTH DRILLER	: 84			KB	:
LOG BOTTOM	: 66.00	LOG MEASURED FROM:	GL	DF	:
LOG TOP	: 0.20	DRL MEASURED FROM:	GL	GL	:
CASING DIAMETER	: 10.	LOGGING UNIT	: SV25		
CASING TYPE	: PVC	FIELD OFFICE	: SURTRON		
CASING THICKNESS:		RECORDED BY	: CJ		
BIT SIZE	: 12.5	BOREHOLE FLUID	:	FILE	: ORIGINAL
MAGNETIC DECL.	: 1.438	RM	:	TYPE	: 9012C
MATRIX DENSITY	: 2.65	RM TEMPERATURE	:	LGDATE	: 02/15/16
NEUTRON MATRIX	: SANDSTONE	MATRIX DELTA T	: 177		
				THRESH	: 90000

ALL SERVICES PROVIDED SUBJECT TO STANDARD TERMS AND CONDITIONS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METERS
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CPS
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CPS
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CPS
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20
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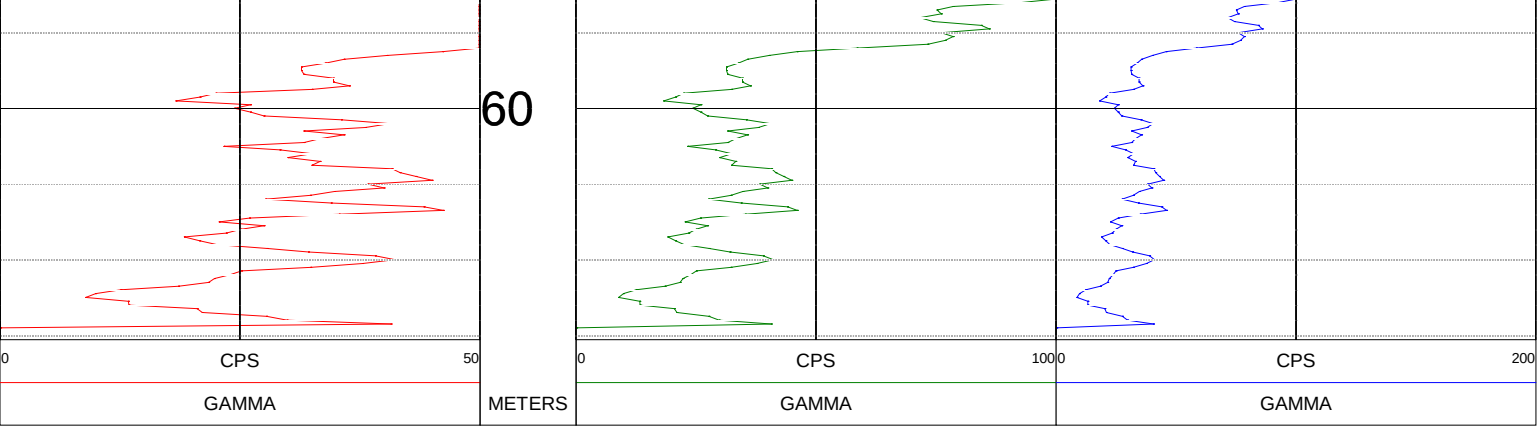
40
50


60
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CPS
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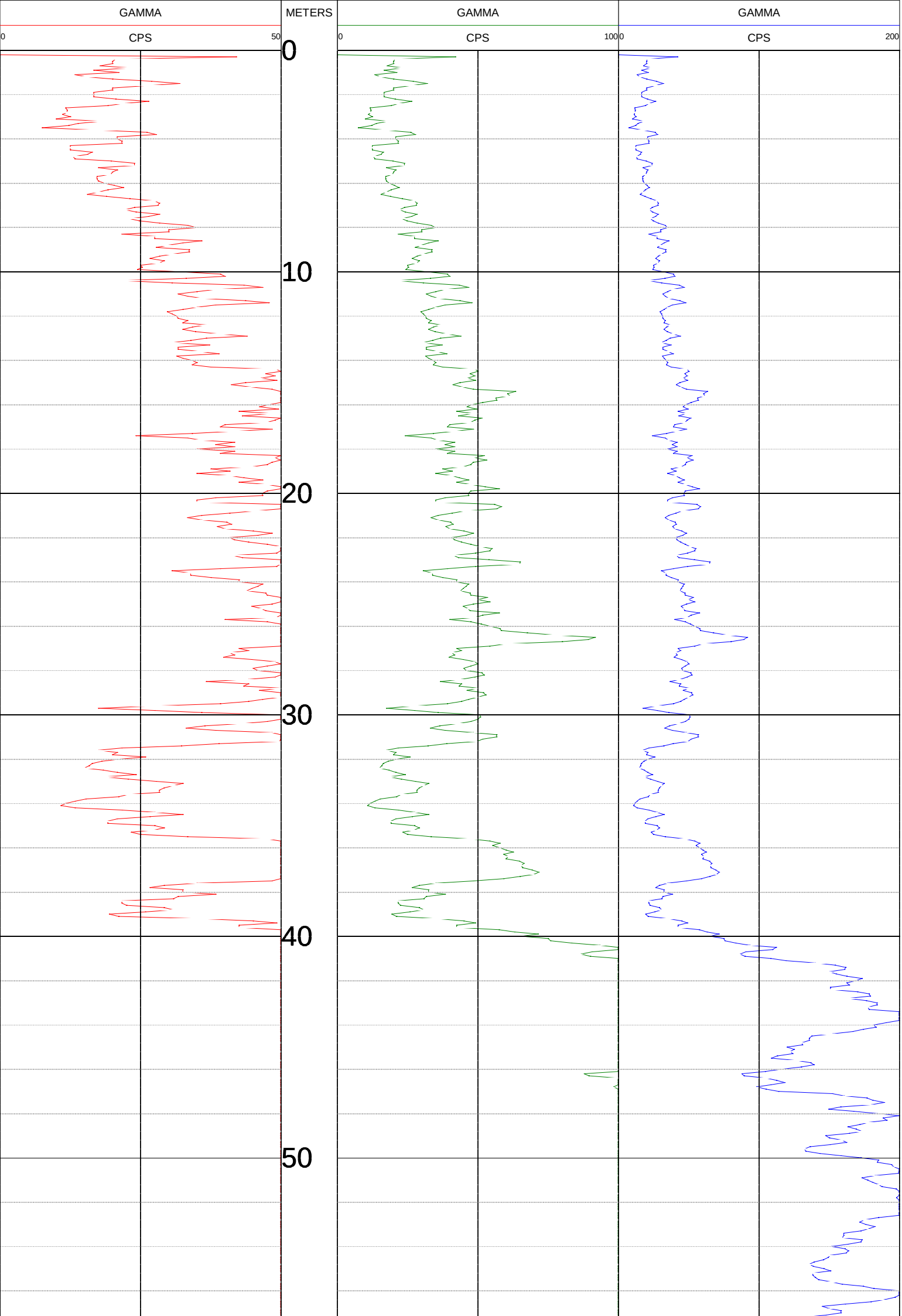
GAMMA
METERS
0
CPS
100
GAMMA
0
CPS
200
GAMMA

MB16MEH0003

COMPANY	: RTIO			OTHER SERVICES:	
WELL	: MB16MEH000			16MEH	
LOCATION/FIELD	:			_M07	
COUNTY	: MEGDC0202				
LOCATION	: MEH				
SECTION	: MEH	TOWNSHIP	:	RANGE	:
DATE	: 02/13/16	PERMANENT DATUM	: GL		
DEPTH DRILLER	: 84			KB	:
LOG BOTTOM	: 65.40	LOG MEASURED FROM:	GL	DF	:
LOG TOP	: 0.20	DRL MEASURED FROM:	GL	GL	:
CASING DIAMETER	: 10.	LOGGING UNIT	: SV25		
CASING TYPE	: IROD	FIELD OFFICE	: SURTRON		
CASING THICKNESS:		RECORDED BY	: CJ		
BIT SIZE	: 12.5	BOREHOLE FLUID	:	FILE	: ORIGINAL
MAGNETIC DECL.	: 1.438	RM	:	TYPE	: 9012C
MATRIX DENSITY	: 2.65	RM TEMPERATURE	:	LGDATE	: 02/13/16
NEUTRON MATRIX	: SANDSTONE	MATRIX DELTA T	: 177		
				THRESH	: 90000

ALL SERVICES PROVIDED SUBJECT TO STANDARD TERMS AND CONDITIONS


GAMMA
METERS
GAMMA
GAMMA
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CPS
50
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CPS
100
0
CPS
200
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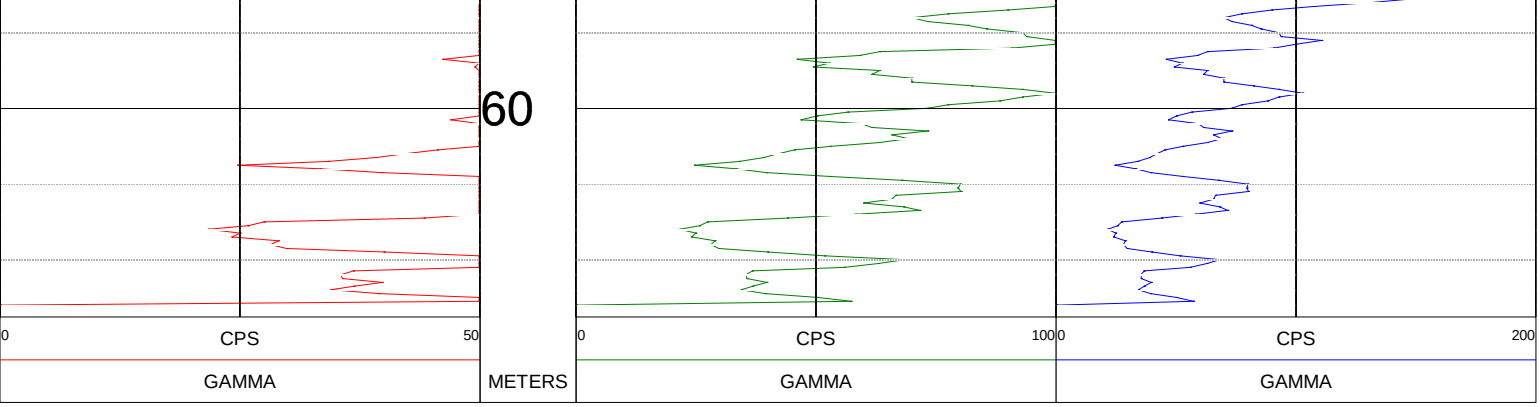
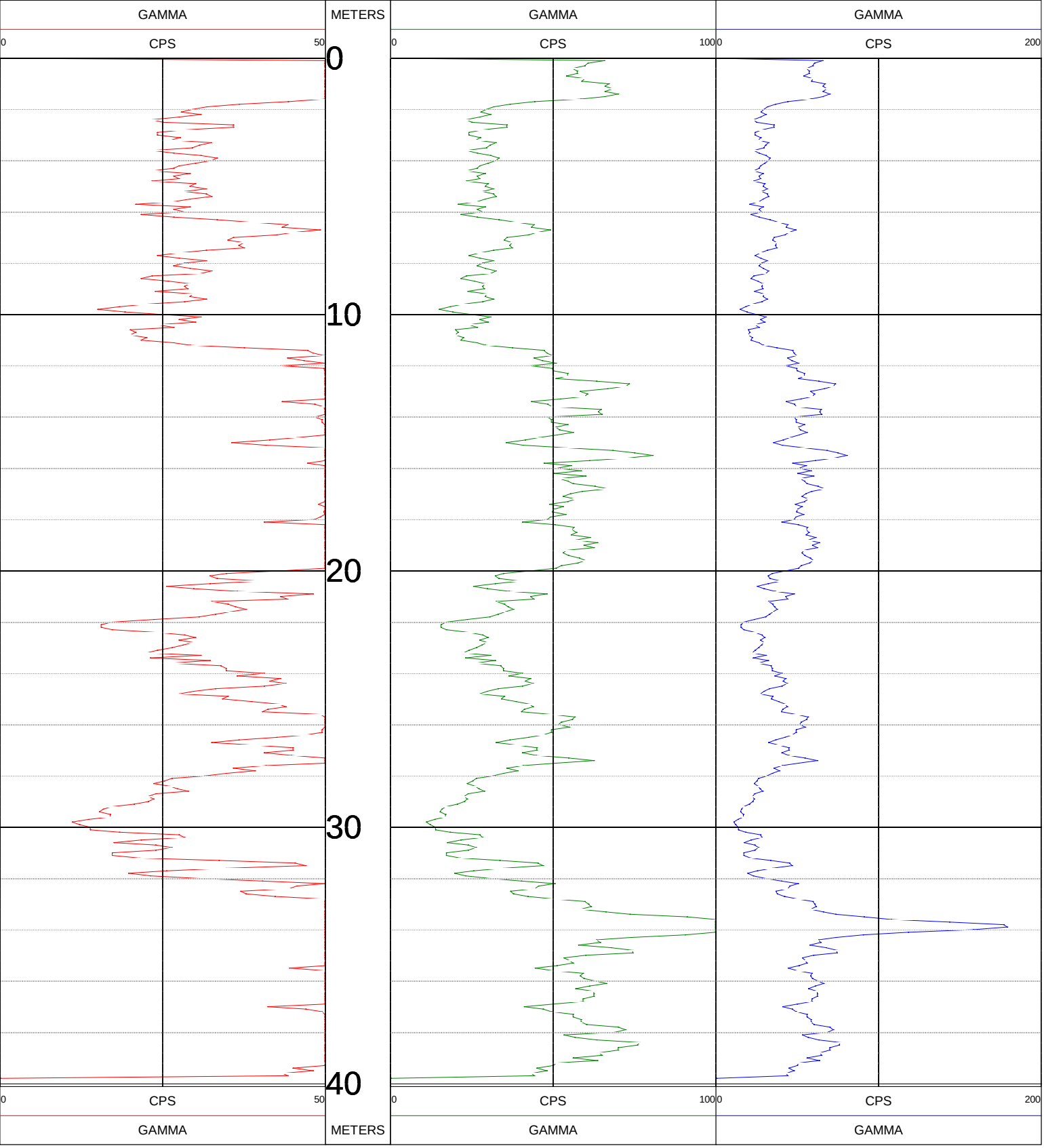
20
30
40
50


60
0
CPS
50
GAMMA
METERS
0
CPS
100
GAMMA
0
CPS
200
GAMMA

MB16MEH0008

COMPANY	: RTIO			OTHER SERVICES:	
WELL	: MB16MEH000			16MEH	
LOCATION/FIELD	:			_M06	
COUNTY	: MEGDC0202				
LOCATION	: MEH				
SECTION	: MEH	TOWNSHIP	:	RANGE	:
DATE	: 02/17/16	PERMANENT DATUM	: GL		
DEPTH DRILLER	: 58			KB	:
LOG BOTTOM	: 40.00	LOG MEASURED FROM:	GL	DF	:
LOG TOP	: 0.00	DRL MEASURED FROM:	GL	GL	:
CASING DIAMETER	: 10.	LOGGING UNIT	: SV25		
CASING TYPE	: PVC	FIELD OFFICE	: SURTRON		
CASING THICKNESS:		RECORDED BY	: CJ		
BIT SIZE	: 12.5	BOREHOLE FLUID	:	FILE	: ORIGINAL
MAGNETIC DECL.	: 1.438	RM	:	TYPE	: 9012C
MATRIX DENSITY	: 2.65	RM TEMPERATURE	:	LGDATE	: 02/17/16
NEUTRON MATRIX	: SANDSTONE	MATRIX DELTA T	: 177		
				THRESH	: 90000

ALL SERVICES PROVIDED SUBJECT TO STANDARD TERMS AND CONDITIONS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METERS
GAMMA
GAMMA
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CPS
50
0
CPS
100
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CPS
200
0
10
20
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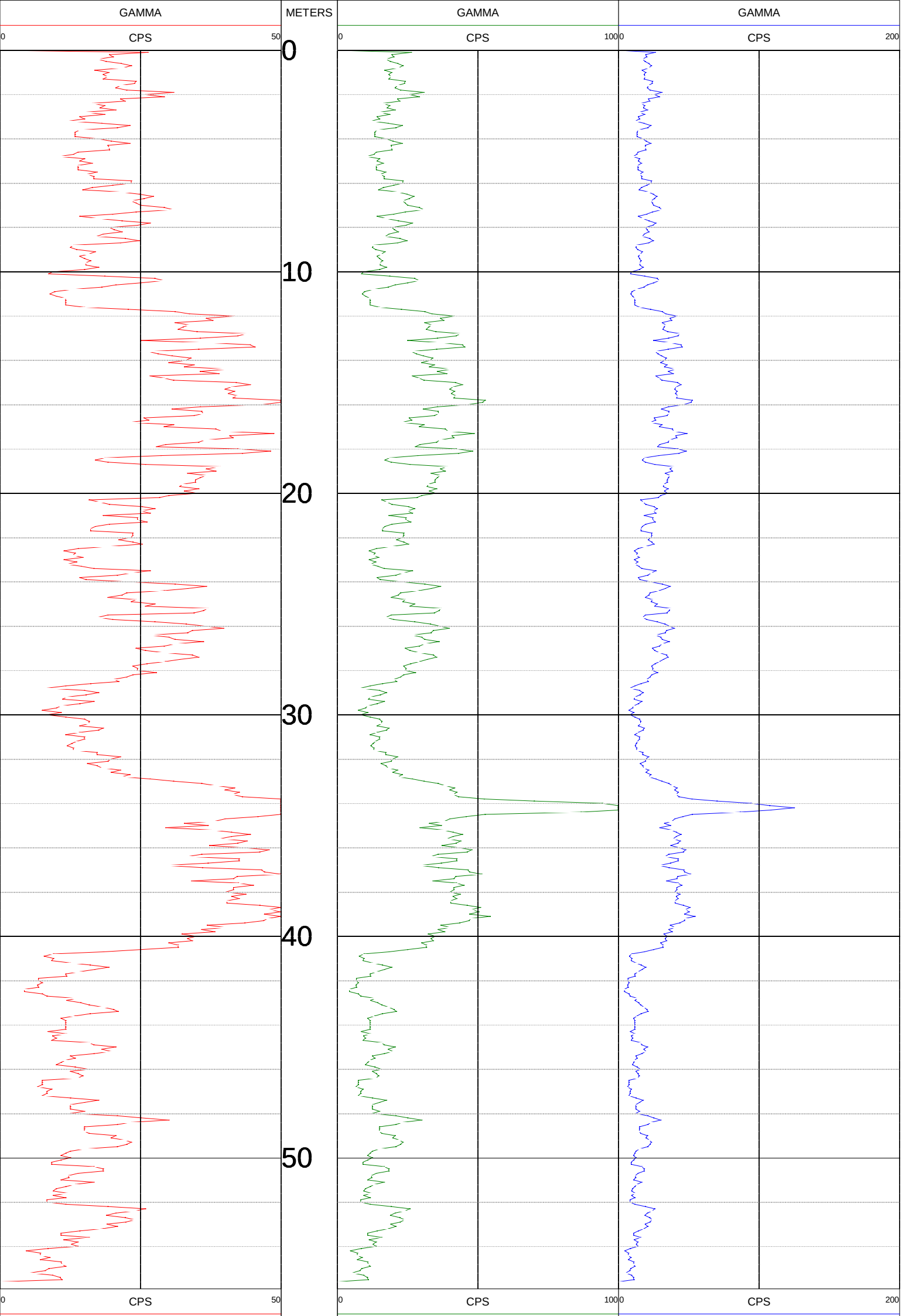
CPS
50
0
CPS
100
0
CPS
200
GAMMA
METERS
GAMMA
GAMMA

MB16MEH0008

COMPANY	: RTIO			OTHER SERVICES:			
WELL	: MB16MEH000			16MEH			
LOCATION/FIELD	:			_M06			
COUNTY	: MEGDC0202						
LOCATION	: MEH						
SECTION	: MEH	TOWNSHIP	:		RANGE	:	
DATE	: 02/15/16	PERMANENT DATUM	: GL				
DEPTH DRILLER	: 58				KB	:	
LOG BOTTOM	: 55.80	LOG MEASURED FROM:	GL		DF	:	
LOG TOP	: 0.00	DRL MEASURED FROM:	GL		GL	:	
CASING DIAMETER	: 10.	LOGGING UNIT	: SV25				
CASING TYPE	: RODS	FIELD OFFICE	: SURTRON				
CASING THICKNESS:		RECORDED BY	: CJ				
BIT SIZE	: 12.5	BOREHOLE FLUID	:		FILE	: ORIGINAL	
MAGNETIC DECL.	: 1.438	RM	:		TYPE	: 9012C	
MATRIX DENSITY	: 2.65	RM TEMPERATURE	:		LGDATE	: 02/15/16	
NEUTRON MATRIX	: SANDSTONE	MATRIX DELTA T	: 177				
					THRESH	: 90000	

ALL SERVICES PROVIDED SUBJECT TO STANDARD TERMS AND CONDITIONS


GAMMA
METERS
GAMMA
GAMMA
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CPS
50
0
CPS
100
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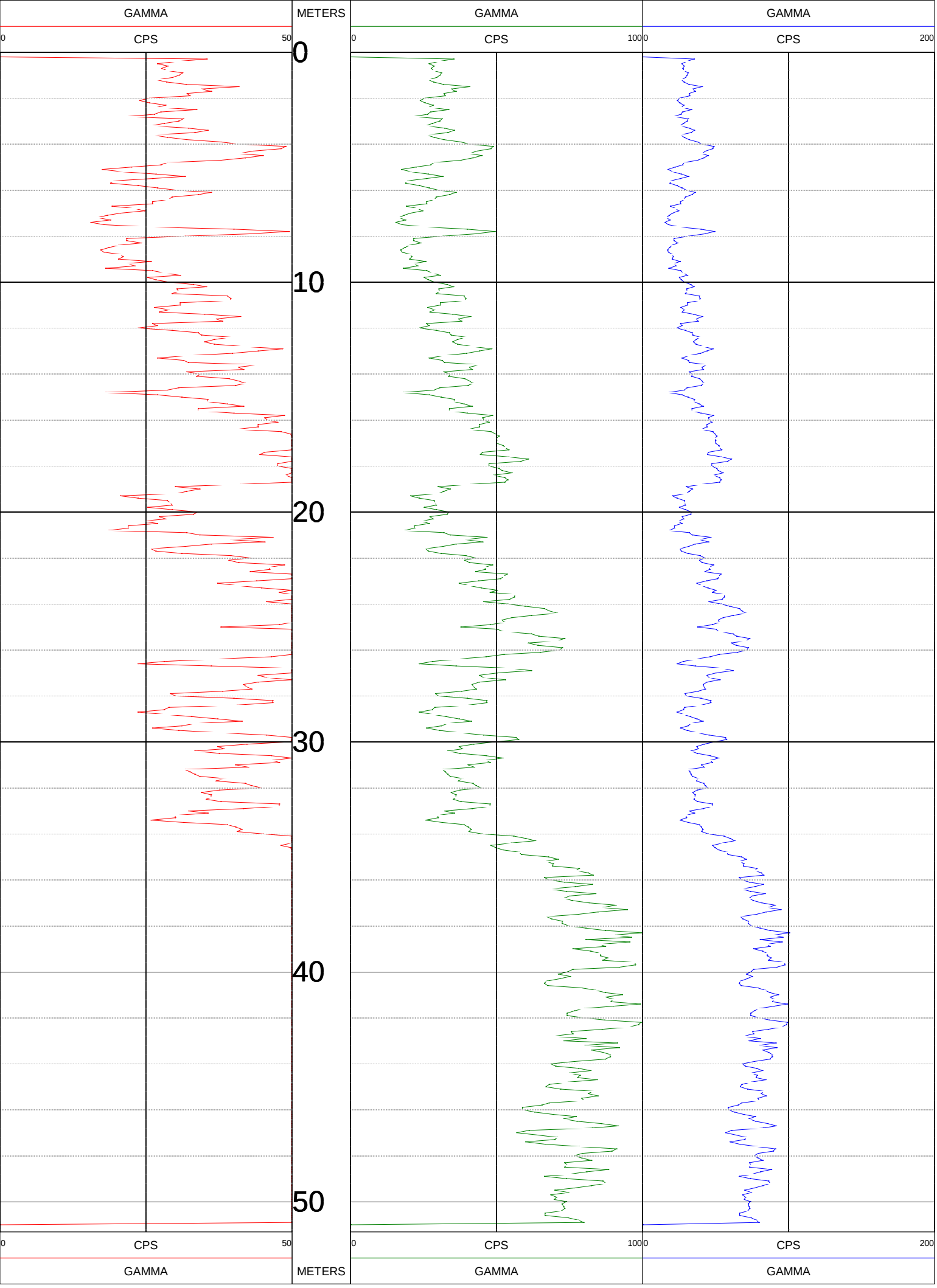
CPS
200
0
10
20
30
40
50
0
CPS
50
0
CPS
100
0
CPS
200

GAMMA	METERS	GAMMA	GAMMA

MB16MEH0009

COMPANY	:	RTIO			OTHER SERVICES:		
WELL	:	MB16MEH000			PEG#		
LOCATION/FIELD	:	MEH			16MEH		
COUNTY	:	MEGDC0202			_M09		
LOCATION	:	MEH					
SECTION	:		TOWNSHIP	:		RANGE	:
DATE	:	03/03/16	PERMANENT DATUM	:	GL		
DEPTH DRILLER	:	52				KB	:
LOG BOTTOM	:	51.20	LOG MEASURED FROM	:	GL	DF	:
LOG TOP	:	0.20	DRL MEASURED FROM	:	GL	GL	:
CASING DIAMETER	:	10.	LOGGING UNIT	:	SV10		
CASING TYPE	:	PVC	FIELD OFFICE	:	SURTRON		
CASING THICKNESS	:		RECORDED BY	:	CJ		
BIT SIZE	:	31	BOREHOLE FLUID	:		FILE	: ORIGINAL
MAGNETIC DECL.	:	1.438	RM	:		TYPE	: 9012C
MATRIX DENSITY	:	2.65	RM TEMPERATURE	:		LGDATE	: 03/03/16
NEUTRON MATRIX	:	SANDSTONE	MATRIX DELTA T	:	177		
						THRESH	: 90000

ALL SERVICES PROVIDED SUBJECT TO STANDARD TERMS AND CONDITIONS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GAMMA
GAMMA
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CPS
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CPS
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CPS
200
0
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20
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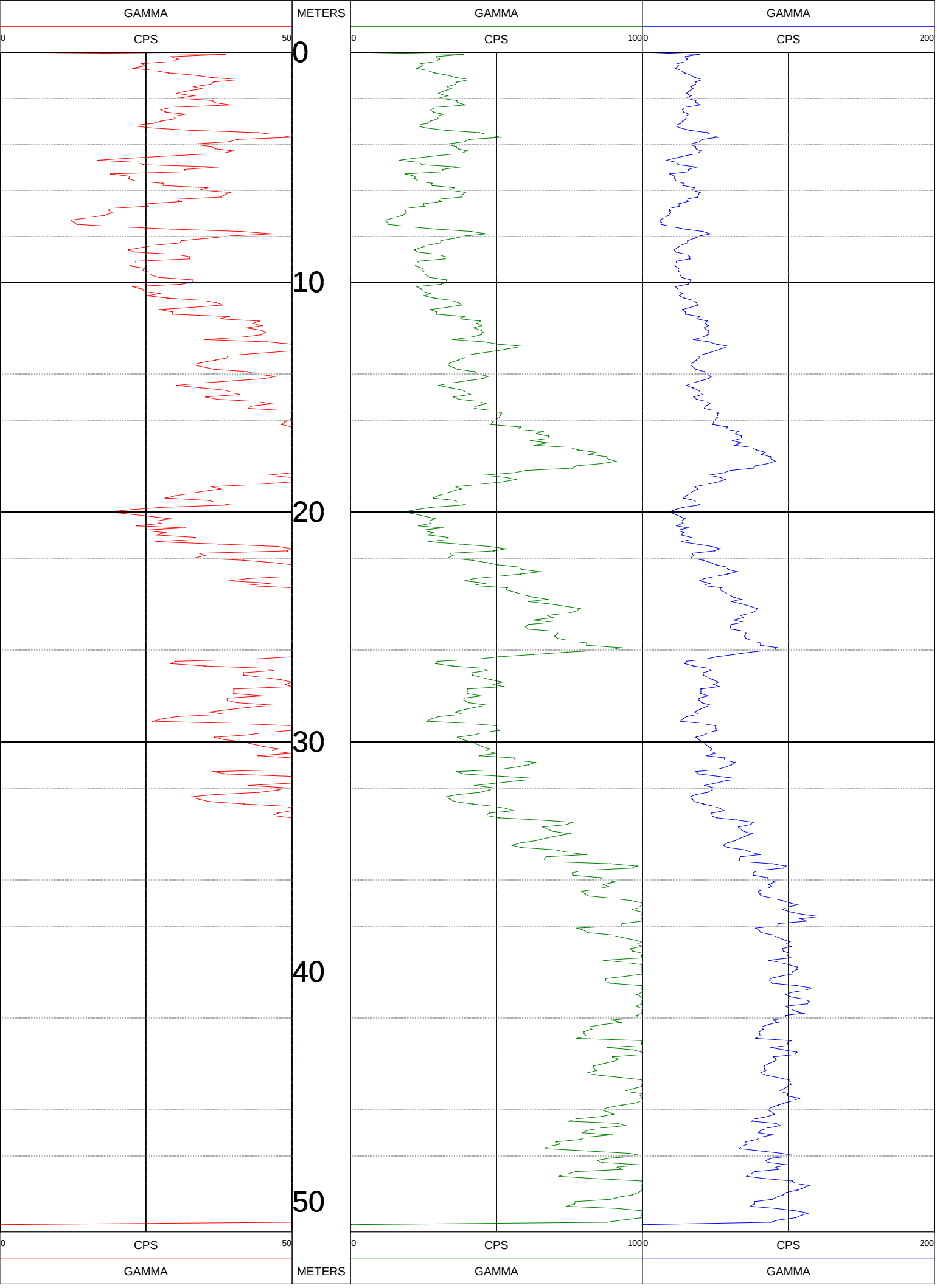
0
CPS
50
0
CPS
100
0
CPS
200
GAMMA
METERS
GAMMA
GAMMA

MB16MEH0009

COMPANY	: RTIO			OTHER SERVICES:			
WELL	: MB16MEH000			16MEH			
LOCATION/FIELD	:			_M09			
COUNTY	: MEGDC0202						
LOCATION	: MEH						
SECTION	: MEH	TOWNSHIP	:		RANGE	:	
DATE	: 02/17/16	PERMANENT DATUM	: GL				
DEPTH DRILLER	: 52				KB	:	
LOG BOTTOM	: 51.20	LOG MEASURED FROM:	GL		DF	:	
LOG TOP	: 0.00	DRL MEASURED FROM:	GL		GL	:	
CASING DIAMETER	: 10.	LOGGING UNIT	: SV25				
CASING TYPE	: RODS	FIELD OFFICE	: SURTRON				
CASING THICKNESS:		RECORDED BY	: CJ				
BIT SIZE	: 12.5	BOREHOLE FLUID	:		FILE	: ORIGINAL	
MAGNETIC DECL.	: 1.438	RM	:		TYPE	: 9012C	
MATRIX DENSITY	: 2.65	RM TEMPERATURE	:		LGDATE	: 02/17/16	
NEUTRON MATRIX	: SANDSTONE	MATRIX DELTA T	: 177				
					THRESH	: 90000	

ALL SERVICES PROVIDED SUBJECT TO STANDARD TERMS AND CONDITIONS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METERS
GAMMA
GAMMA
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CPS
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CPS
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20
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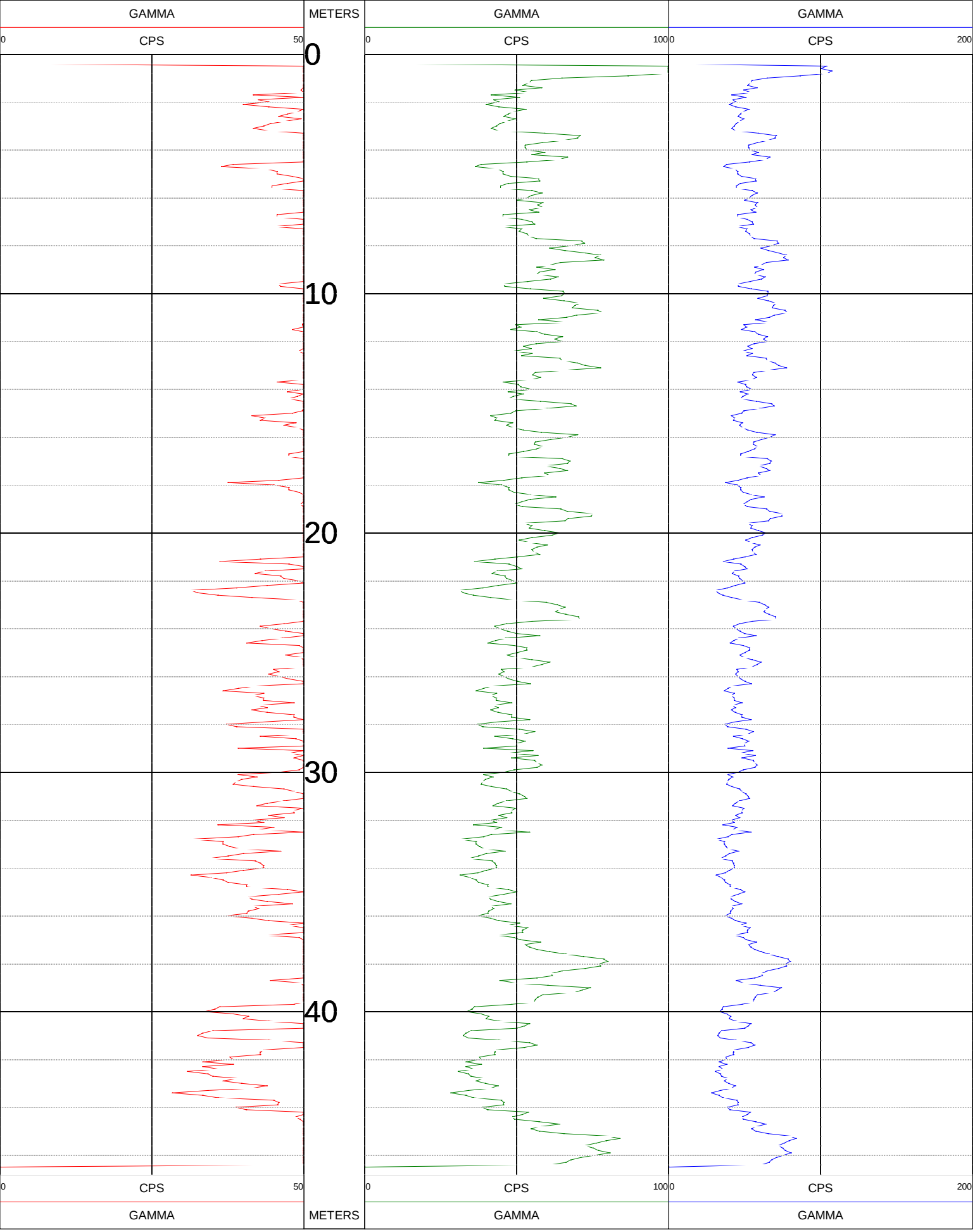
0
CPS
50
0
CPS
100
0
CPS
200
GAMMA
METERS
GAMMA
GAMMA

MB16MEH0012

COMPANY	: RTIO			OTHER SERVICES:			
WELL	: MB16MEH001			16MEH			
LOCATION/FIELD	:			_M01			
COUNTY	: MEGDC0202						
LOCATION	: MEH						
SECTION	: MEH	TOWNSHIP	:		RANGE	:	
DATE	: 02/22/16	PERMANENT DATUM	: GL				
DEPTH DRILLER	: 49				KB	:	
LOG BOTTOM	: 46.70	LOG MEASURED FROM:	GL		DF	:	
LOG TOP	: 0.40	DRL MEASURED FROM:	GL		GL	:	
CASING DIAMETER	: 10.	LOGGING UNIT	: SV25				
CASING TYPE	: PVC	FIELD OFFICE	: SURTRON				
CASING THICKNESS:		RECORDED BY	: CJ				
BIT SIZE	: 12.5	BOREHOLE FLUID	:		FILE	: ORIGINAL	
MAGNETIC DECL.	: 1.438	RM	:		TYPE	: 9012C	
MATRIX DENSITY	: 2.65	RM TEMPERATURE	:		LGDATE	: 02/22/16	
NEUTRON MATRIX	: SANDSTONE	MATRIX DELTA T	: 177				
					THRESH	: 90000	

ALL SERVICES PROVIDED SUBJECT TO STANDARD TERMS AND CONDITIONS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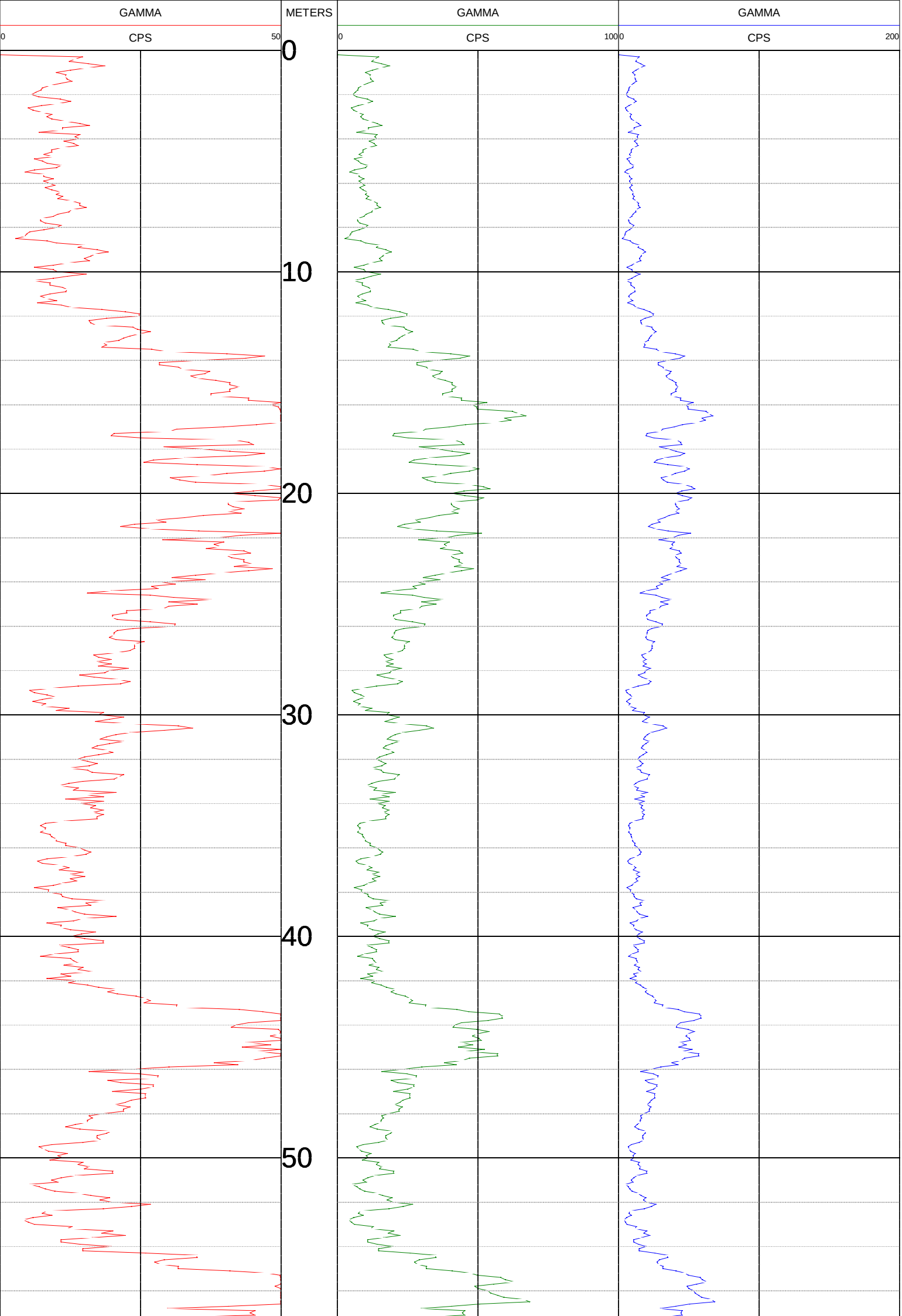
CPS
50
0
CPS
100
0
CPS
200
GAMMA
METERS
GAMMA
GAMMA

MB16MEH0013

COMPANY	:	RTIO			OTHER SERVICES:		
WELL	:	MB16MEH001			PEG#		
LOCATION/FIELD	:	MEH			16MEH		
COUNTY	:	MEGDC0202			_M04		
LOCATION	:	MEH					
SECTION	:		TOWNSHIP	:		RANGE	:
DATE	:	03/03/16	PERMANENT DATUM	:	GL		
DEPTH DRILLER	:	76				KB	:
LOG BOTTOM	:	74.90	LOG MEASURED FROM	:	GL	DF	:
LOG TOP	:	0.20	DRL MEASURED FROM	:	GL	GL	:
CASING DIAMETER	:	10.	LOGGING UNIT	:	SV10		
CASING TYPE	:	PVC	FIELD OFFICE	:	SURTRON		
CASING THICKNESS:			RECORDED BY	:	CJ		
BIT SIZE	:	31	BOREHOLE FLUID	:		FILE	: ORIGINAL
MAGNETIC DECL.	:	1.438	RM	:		TYPE	: 9012C
MATRIX DENSITY	:	2.65	RM TEMPERATURE	:		LGDATE	: 03/03/16
NEUTRON MATRIX	:	SANDSTONE	MATRIX DELTA T	:	177		
						THRESH	: 90000

ALL SERVICES PROVIDED SUBJECT TO STANDARD TERMS AND CONDITIONS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CPS
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CPS
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20
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40
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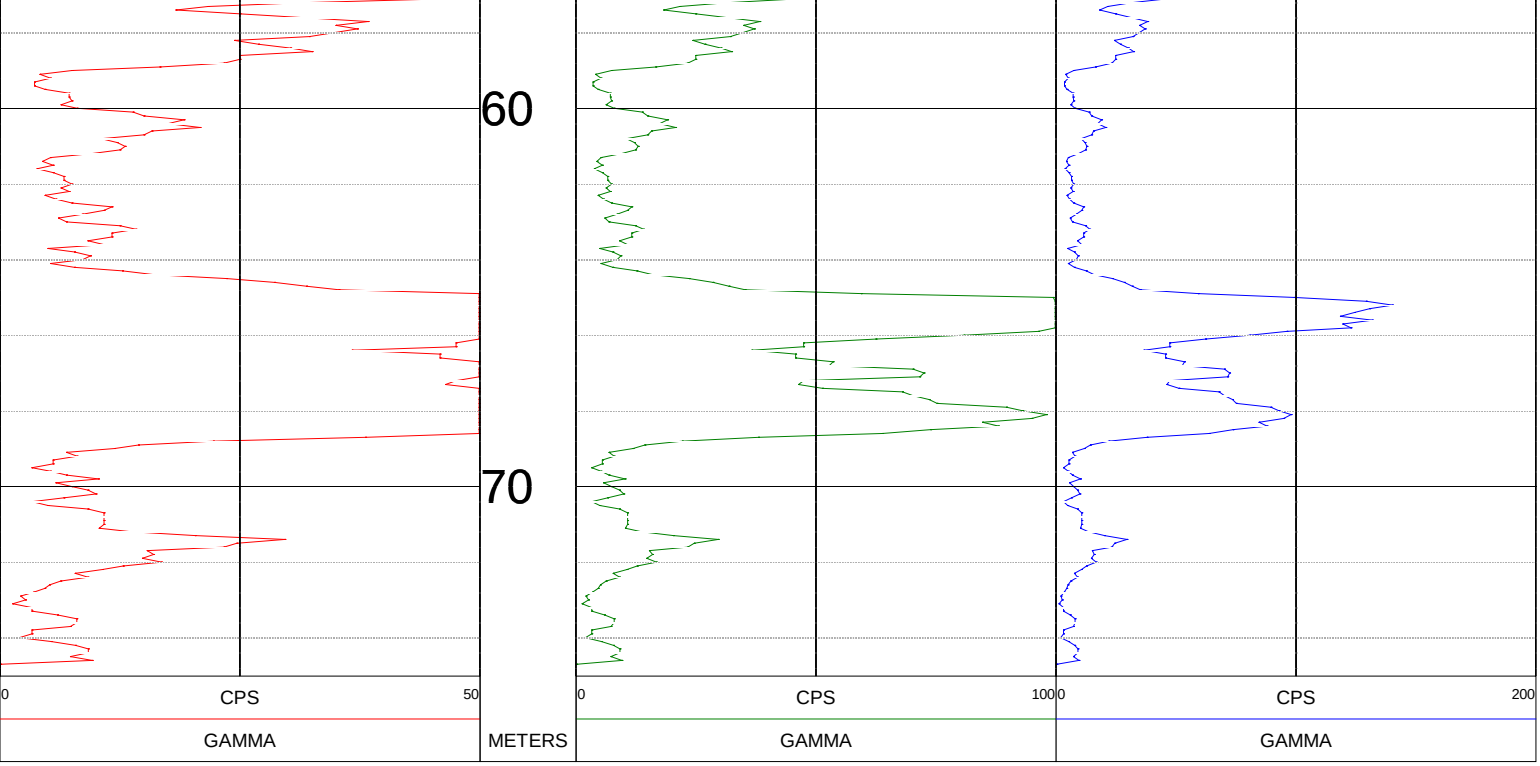
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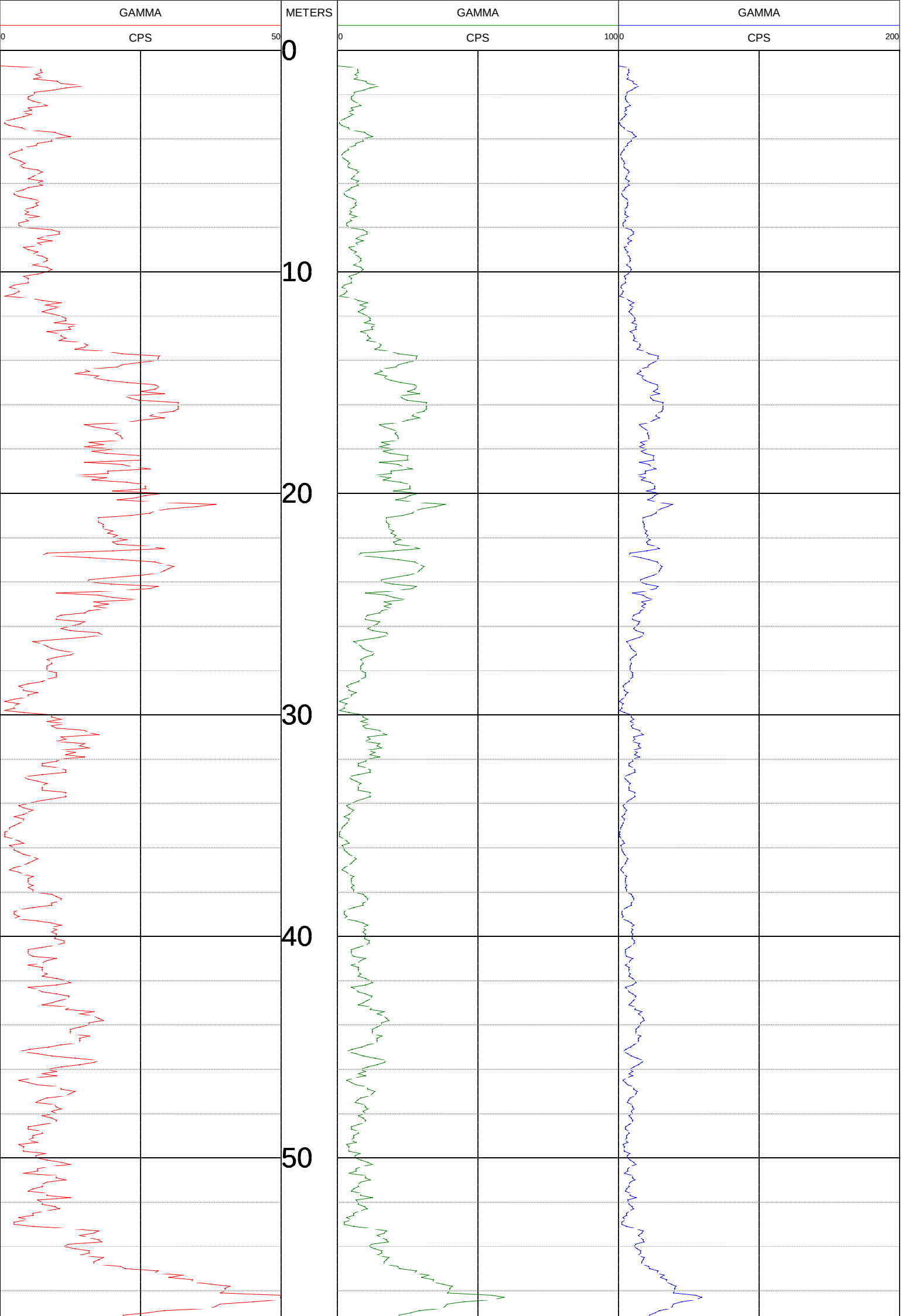
CPS
50
GAMMA
METERS
0
CPS
100
GAMMA
0
CPS
200
GAMMA

MB16MEH0013

COMPANY	: RTIO			OTHER SERVICES:			
WELL	: MB16MEH001			16MEH			
LOCATION/FIELD	:			_M04			
COUNTY	: MEGDC0202						
LOCATION	: MEH						
SECTION	: MEH	TOWNSHIP	:		RANGE	:	
DATE	: 02/22/16	PERMANENT DATUM	: GL				
DEPTH DRILLER	: 76				KB	:	
LOG BOTTOM	: 74.00	LOG MEASURED FROM:	GL		DF	:	
LOG TOP	: 0.70	DRL MEASURED FROM:	GL		GL	:	
CASING DIAMETER	: 10.	LOGGING UNIT	: SV25				
CASING TYPE	: RODS	FIELD OFFICE	: SURTRON				
CASING THICKNESS:		RECORDED BY	: CJ				
BIT SIZE	: 12.5	BOREHOLE FLUID	:		FILE	: ORIGINAL	
MAGNETIC DECL.	: 1.438	RM	:		TYPE	: 9012C	
MATRIX DENSITY	: 2.65	RM TEMPERATURE	:		LGDATE	: 02/22/16	
NEUTRON MATRIX	: SANDSTONE	MATRIX DELTA T	: 177				
					THRESH	: 90000	

ALL SERVICES PROVIDED SUBJECT TO STANDARD TERMS AND CONDITIONS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CPS
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METERS
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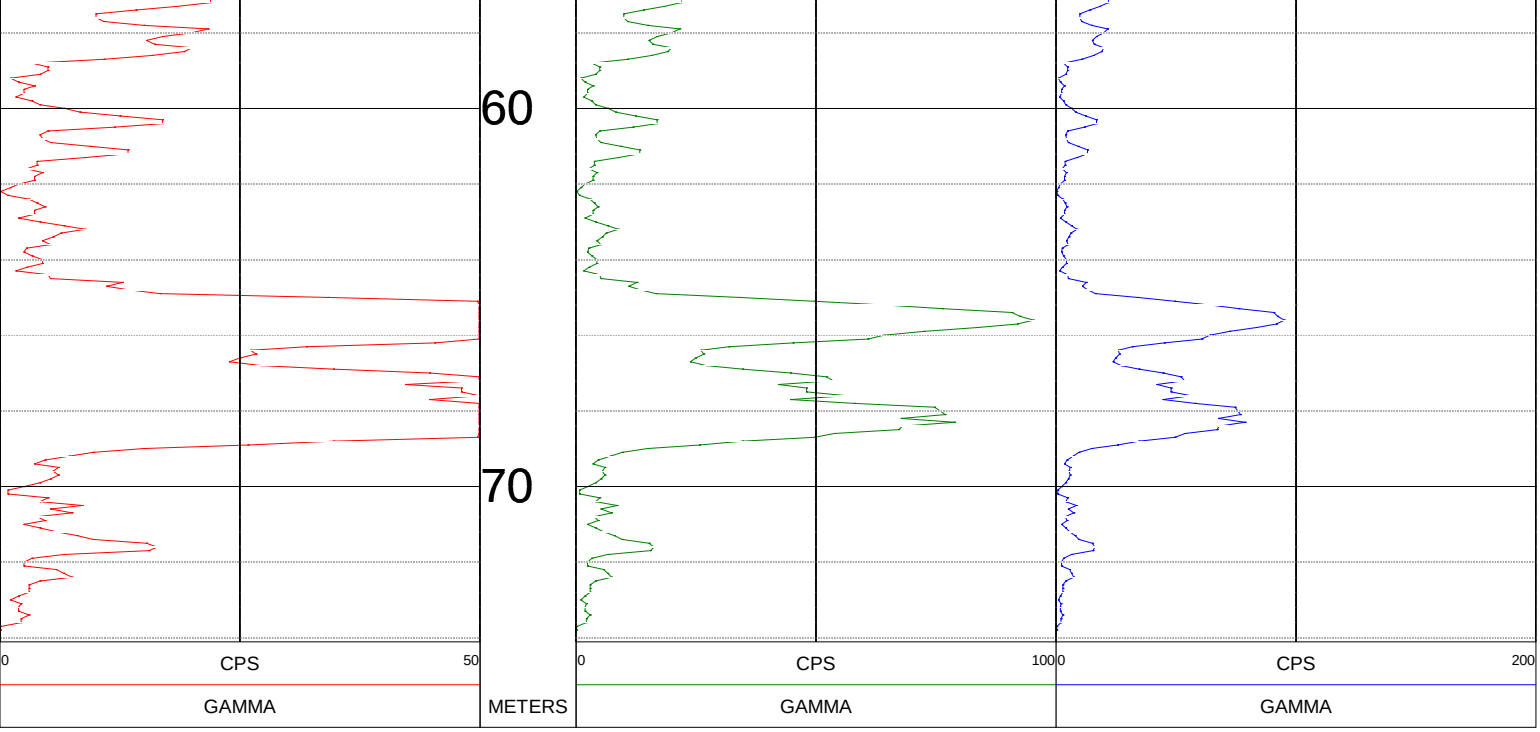
40
50
GAMMA
CPS
0
100
GAMMA
CPS
0
200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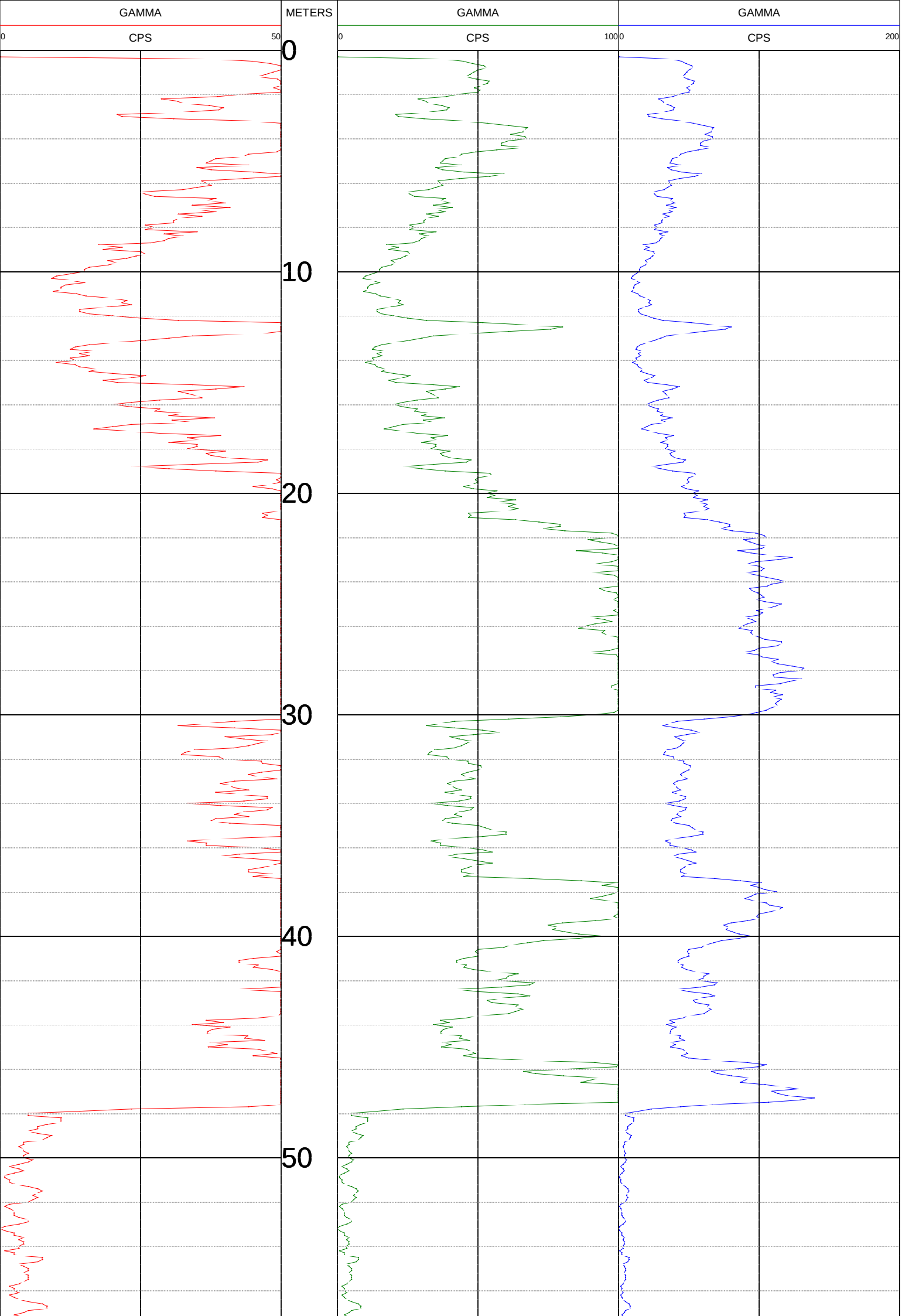
CPS
50
GAMMA
METERS
0
CPS
100
GAMMA
0
CPS
200
GAMMA

MB16MEH0014

COMPANY	: RTIO			OTHER SERVICES:			
WELL	: MB16MEH001			16MEH			
LOCATION/FIELD	:			_M11			
COUNTY	: MEGDC0202						
LOCATION	: MEH						
SECTION	: MEH	TOWNSHIP	:		RANGE	:	
DATE	: 02/20/16	PERMANENT DATUM	: GL				
DEPTH DRILLER	: 60				KB	:	
LOG BOTTOM	: 58.90	LOG MEASURED FROM:	GL		DF	:	
LOG TOP	: 0.30	DRL MEASURED FROM:	GL		GL	:	
CASING DIAMETER	: 10.	LOGGING UNIT	: SV25				
CASING TYPE	: PVC	FIELD OFFICE	: SURTRON				
CASING THICKNESS:		RECORDED BY	: CJ				
BIT SIZE	: 12.5	BOREHOLE FLUID	:		FILE	: ORIGINAL	
MAGNETIC DECL.	: 1.438	RM	:		TYPE	: 9012C	
MATRIX DENSITY	: 2.65	RM TEMPERATURE	:		LGDATE	: 02/20/16	
NEUTRON MATRIX	: SANDSTONE	MATRIX DELTA T	: 177				
					THRESH	: 90000	

ALL SERVICES PROVIDED SUBJECT TO STANDARD TERMS AND CONDITIONS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CPS
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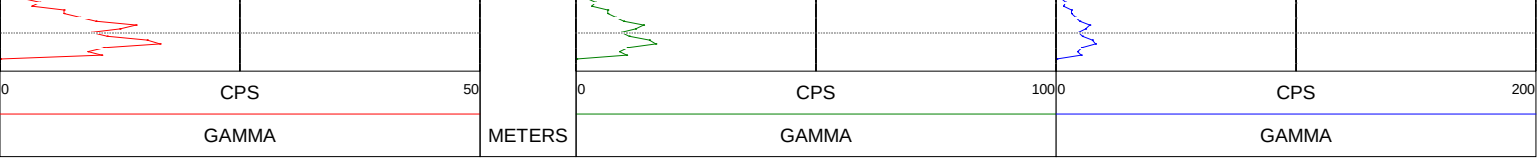
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METERS
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CPS
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GAMMA

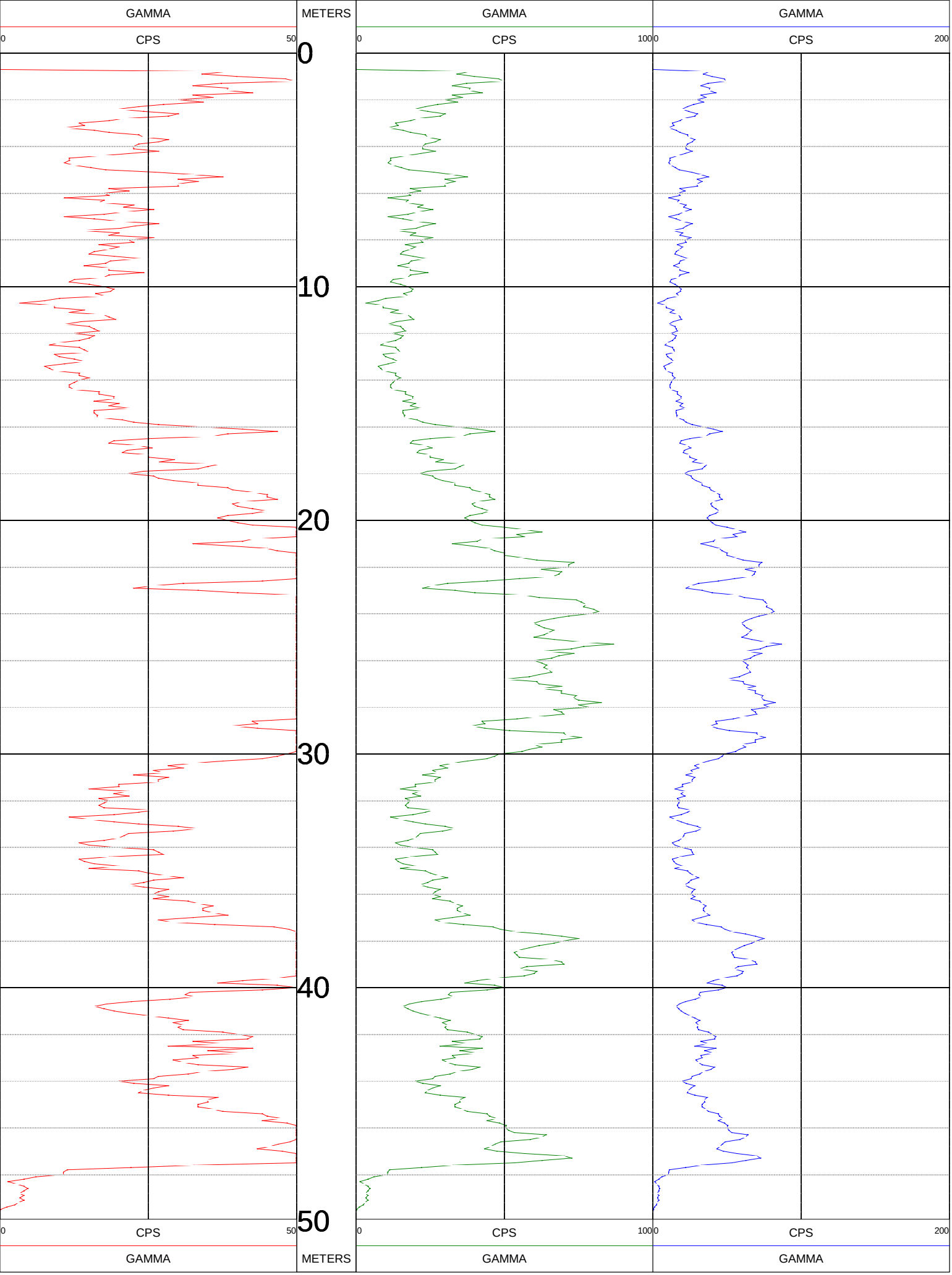
SURTRON

WIRELINE SERVICES

MB16MEH0014

COMPANY	: RTIO			OTHER SERVICES:	
WELL	: MB16MEH001			16MEH	
LOCATION/FIELD	:			_M11	
COUNTY	: MEGDC0202				
LOCATION	: MEH				
SECTION	: MEH	TOWNSHIP	:	RANGE	:
DATE	: 02/18/16	PERMANENT DATUM	: GL		
DEPTH DRILLER	: 52			KB	:
LOG BOTTOM	: 49.80	LOG MEASURED FROM:	GL	DF	:
LOG TOP	: 0.70	DRL MEASURED FROM:	GL	GL	:
CASING DIAMETER	: 10.	LOGGING UNIT	: SV25		
CASING TYPE	: RODS	FIELD OFFICE	: SURTRON		
CASING THICKNESS:		RECORDED BY	: CJ		
BIT SIZE	: 12.5	BOREHOLE FLUID	:	FILE	: PROCESSED
MAGNETIC DECL.	: 1.438	RM	:	TYPE	: 9012C
MATRIX DENSITY	: 2.65	RM TEMPERATURE	:	LGDATE	: 02/18/16
NEUTRON MATRIX	: SANDSTONE	MATRIX DELTA T	: 177		
				THRESH	: 90000

ALL SERVICES PROVIDED SUBJECT TO STANDARD TERMS AND CONDITIONS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CPS
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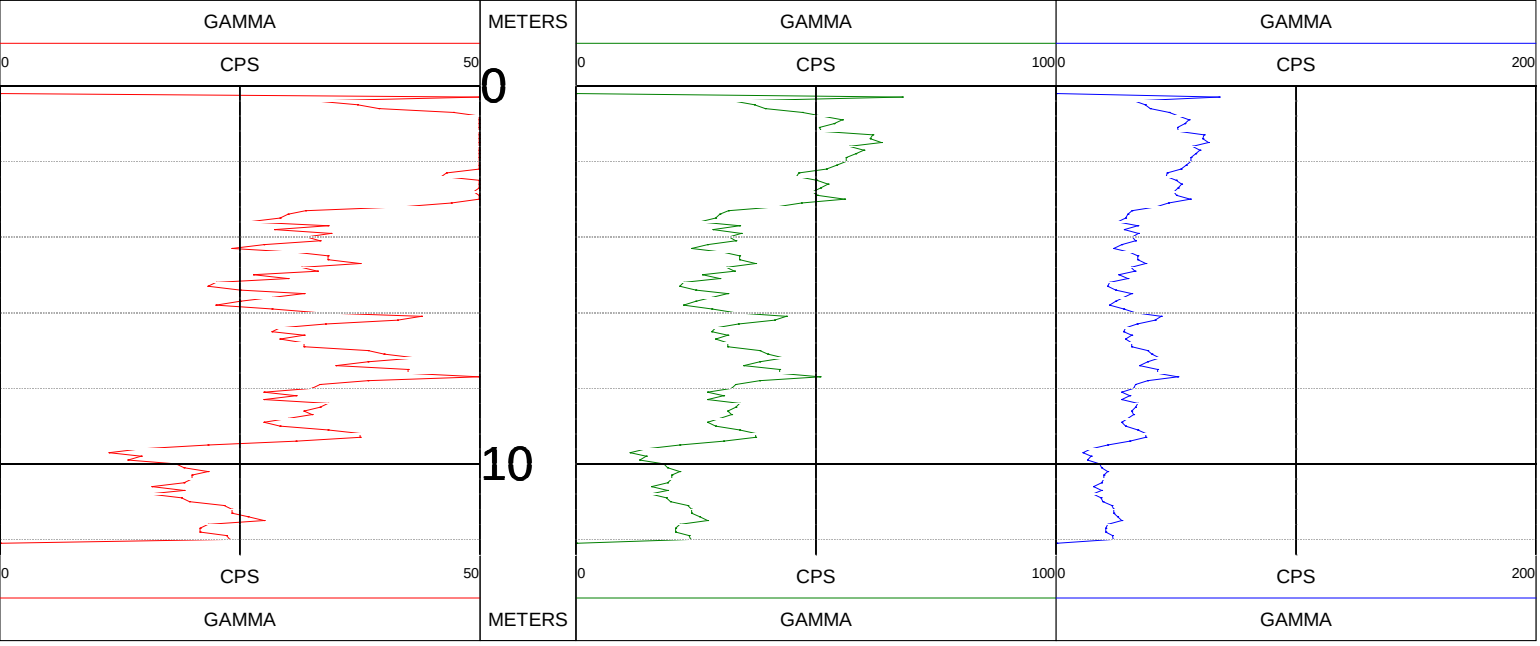
CPS
200
GAMMA
METERS
GAMMA
GAMMA

MB16MEH0016

COMPANY	: RTIO			OTHER SERVICES:			
WELL	: MB16MEH001			16MEH			
LOCATION/FIELD	:			_M21			
COUNTY	: MEGDC0202						
LOCATION	: MEH						
SECTION	: MEH	TOWNSHIP	:		RANGE	:	
DATE	: 02/21/16	PERMANENT DATUM	: GL				
DEPTH DRILLER	: 30				KB	:	
LOG BOTTOM	: 12.30	LOG MEASURED FROM:	GL		DF	:	
LOG TOP	: 0.20	DRL MEASURED FROM:	GL		GL	:	
CASING DIAMETER	: 10.	LOGGING UNIT	: SV25				
CASING TYPE	: PVC	FIELD OFFICE	: SURTRON				
CASING THICKNESS:		RECORDED BY	: CJ				
BIT SIZE	: 12.5	BOREHOLE FLUID	:		FILE	: ORIGINAL	
MAGNETIC DECL.	: 1.438	RM	:		TYPE	: 9012C	
MATRIX DENSITY	: 2.65	RM TEMPERATURE	:		LGDATE	: 02/21/16	
NEUTRON MATRIX	: SANDSTONE	MATRIX DELTA T	: 177				
					THRESH	: 90000	

ALL SERVICES PROVIDED SUBJECT TO STANDARD TERMS AND CONDITIONS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50
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CPS
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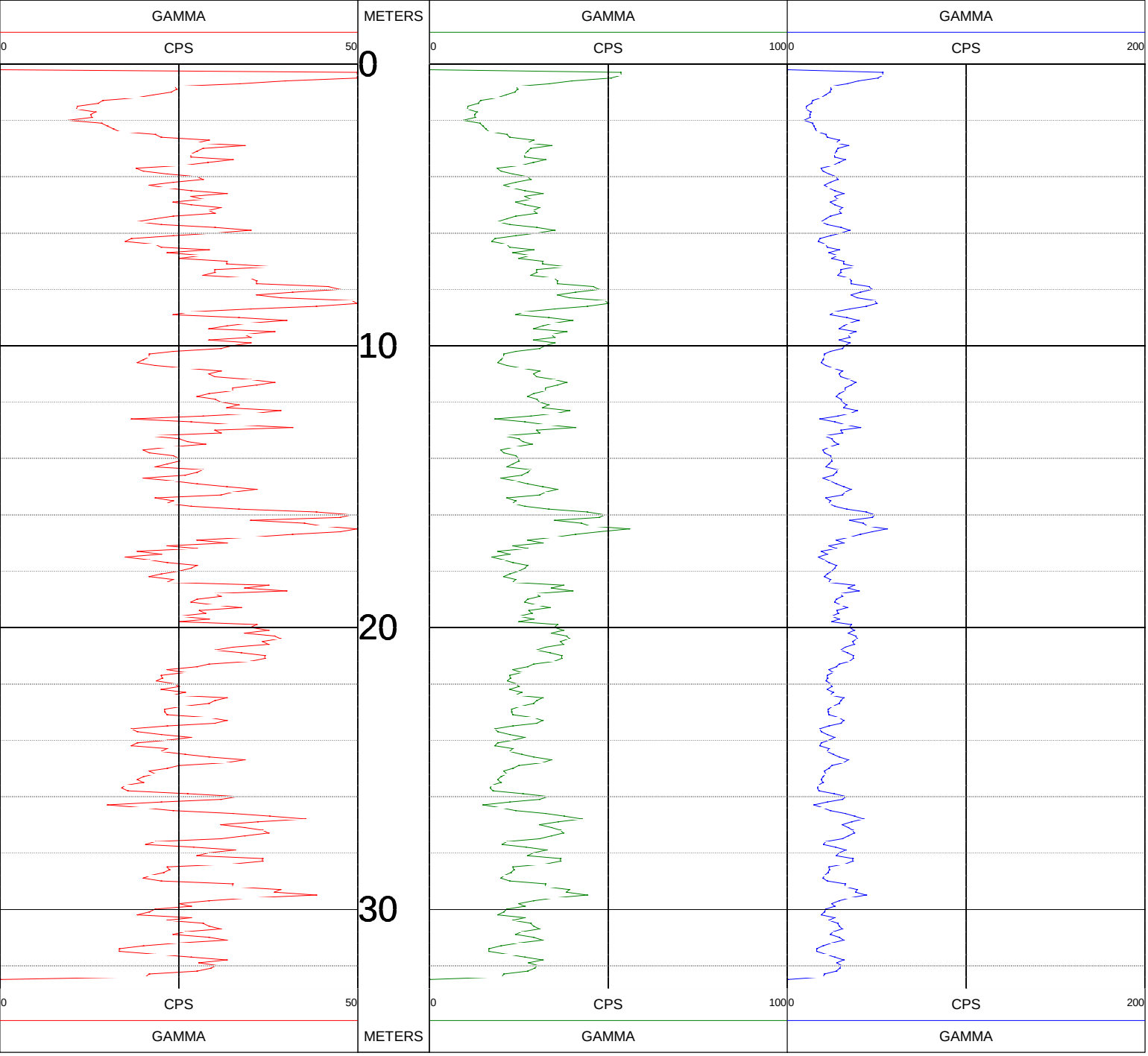
CPS
200
GAMMA
METERS
GAMMA
GAMMA

MB16MEH0017

COMPANY	:	RTIO			OTHER SERVICES:		
WELL	:	MB16MEH001			PEG#		
LOCATION/FIELD	:	MEH			16MEH		
COUNTY	:	MEGDC0202			_M13		
LOCATION	:	MEH					
SECTION	:		TOWNSHIP	:		RANGE	:
DATE	:	03/03/16	PERMANENT DATUM	:	GL		
DEPTH DRILLER	:	50				KB	:
LOG BOTTOM	:	32.70	LOG MEASURED FROM	:	GL	DF	:
LOG TOP	:	0.20	DRL MEASURED FROM	:	GL	GL	:
CASING DIAMETER	:	10.	LOGGING UNIT	:	SV10		
CASING TYPE	:	PVC	FIELD OFFICE	:	SURTRON		
CASING THICKNESS	:		RECORDED BY	:	CJ		
BIT SIZE	:	31	BOREHOLE FLUID	:		FILE	: ORIGINAL
MAGNETIC DECL.	:	1.438	RM	:		TYPE	: 9012C
MATRIX DENSITY	:	2.65	RM TEMPERATURE	:		LGDATE	: 03/03/16
NEUTRON MATRIX	:	SANDSTONE	MATRIX DELTA T	:	177		
						THRESH	: 90000

ALL SERVICES PROVIDED SUBJECT TO STANDARD TERMS AND CONDITIONS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CPS
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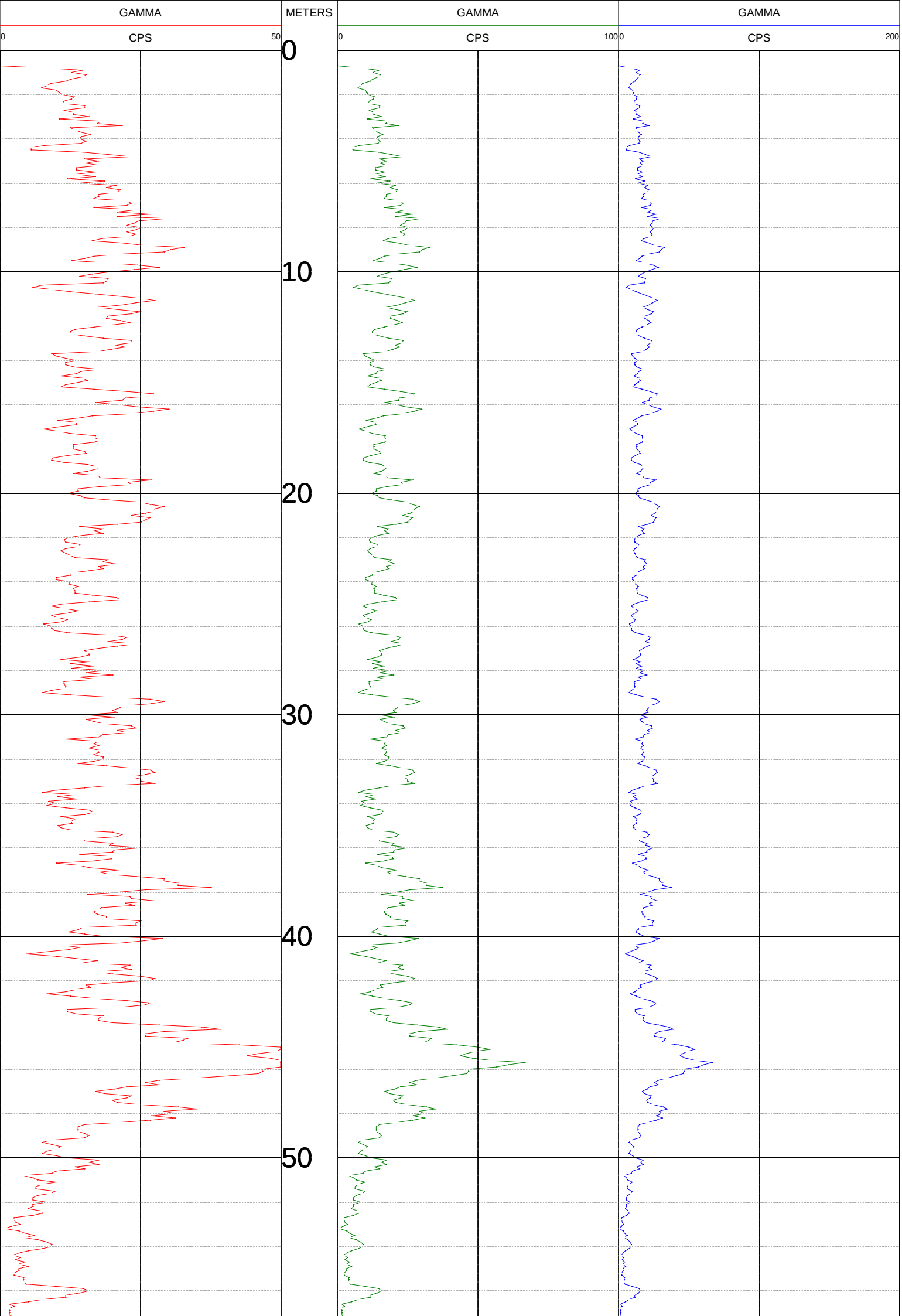
CPS
200
GAMMA
METERS
GAMMA
GAMMA

MB16MEH0017

COMPANY	:	RTIO			OTHER SERVICES:		
WELL	:	MB16MEH001			16MEH		
LOCATION/FIELD	:				_M13		
COUNTY	:	MEGDC0202					
LOCATION	:	MEH					
SECTION	:	MEH	TOWNSHIP	:		RANGE	:
DATE	:	02/21/16	PERMANENT DATUM	:	GL		
DEPTH DRILLER	:	76				KB	:
LOG BOTTOM	:	73.30	LOG MEASURED FROM	:	GL	DF	:
LOG TOP	:	0.70	DRL MEASURED FROM	:	GL	GL	:
CASING DIAMETER	:	10.	LOGGING UNIT	:	SV25		
CASING TYPE	:	NONE	FIELD OFFICE	:	SURTRON		
CASING THICKNESS:			RECORDED BY	:	CJ		
BIT SIZE	:	12.5	BOREHOLE FLUID	:		FILE	: ORIGINAL
MAGNETIC DECL.	:	1.438	RM	:		TYPE	: 9012C
MATRIX DENSITY	:	2.65	RM TEMPERATURE	:		LGDATE	: 02/21/16
NEUTRON MATRIX	:	SANDSTONE	MATRIX DELTA T	:	177		
						THRESH	: 90000

ALL SERVICES PROVIDED SUBJECT TO STANDARD TERMS AND CONDITIONS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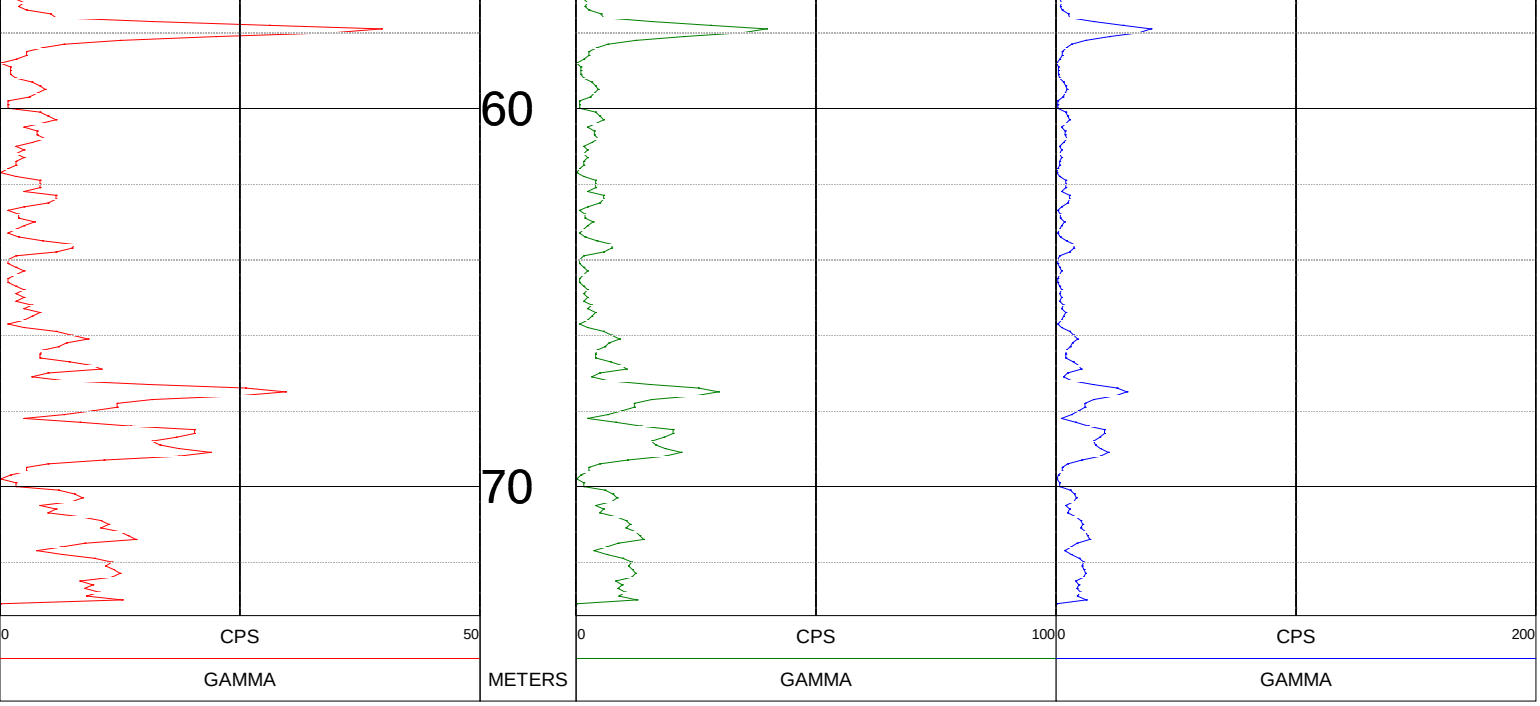
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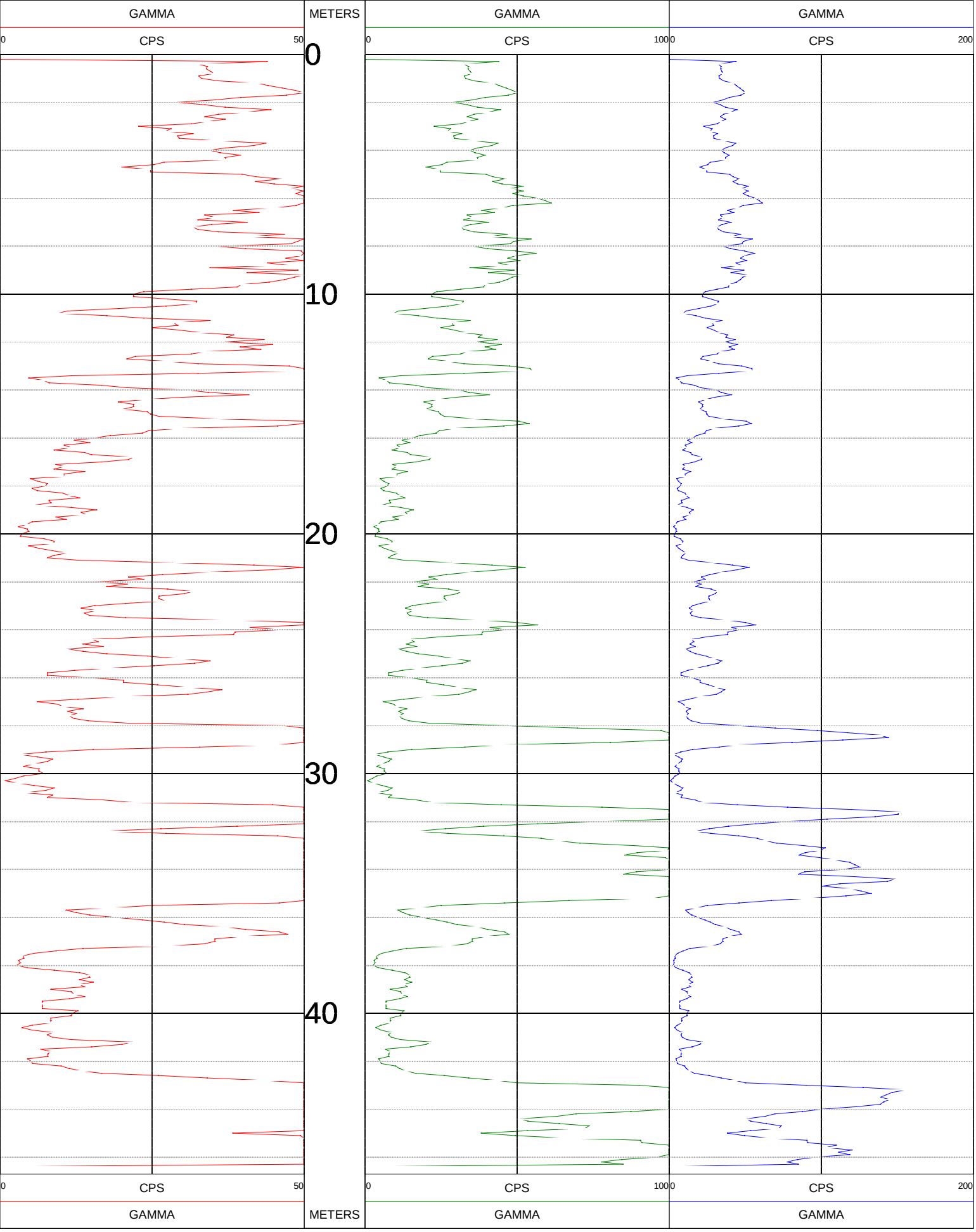
GAMMA

MB16MEH0018

COMPANY	:	RTIO			OTHER SERVICES:		
WELL	:	MB16MEH001			PEG#		
LOCATION/FIELD	:	MEH			16MEH		
COUNTY	:	MEGDC0202			_M05		
LOCATION	:	MEH					
SECTION	:		TOWNSHIP	:		RANGE	:
DATE	:	03/03/16	PERMANENT DATUM	:	GL		
DEPTH DRILLER	:	48				KB	:
LOG BOTTOM	:	46.60	LOG MEASURED FROM	:	GL	DF	:
LOG TOP	:	0.20	DRL MEASURED FROM	:	GL	GL	:
CASING DIAMETER	:	10.	LOGGING UNIT	:	SV10		
CASING TYPE	:	PVC	FIELD OFFICE	:	SURTRON		
CASING THICKNESS:			RECORDED BY	:	CJ		
BIT SIZE	:	31	BOREHOLE FLUID	:		FILE	: ORIGINAL
MAGNETIC DECL.	:	1.438	RM	:		TYPE	: 9012C
MATRIX DENSITY	:	2.65	RM TEMPERATURE	:		LGDATE	: 03/03/16
NEUTRON MATRIX	:	SANDSTONE	MATRIX DELTA T	:	177		
						THRESH	: 90000

ALL SERVICES PROVIDED SUBJECT TO STANDARD TERMS AND CONDITIONS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MB16MEH0018

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LOCATION	: MEH						
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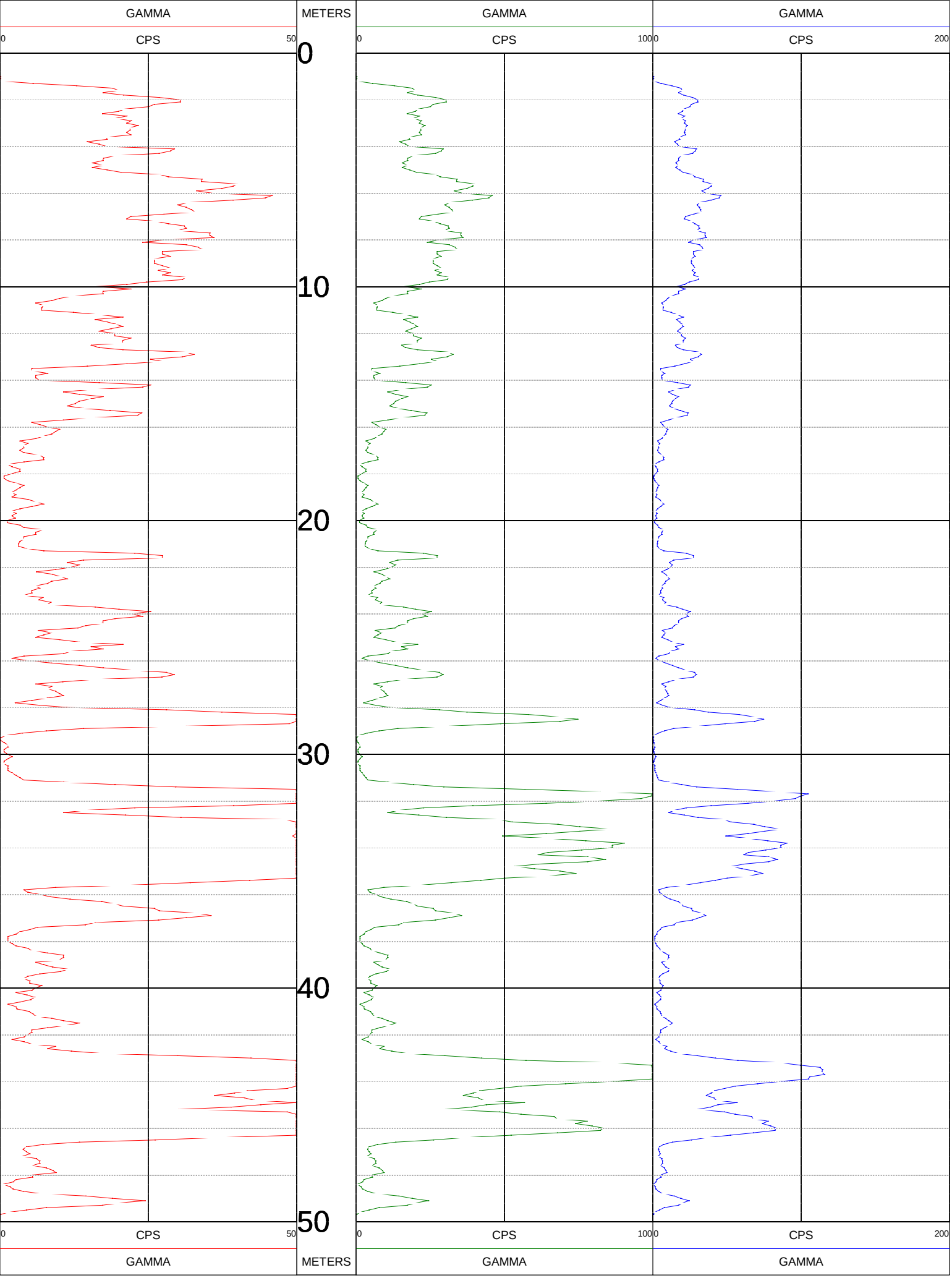
ALL SERVICES PROVIDED SUBJECT TO STANDARD TERMS AND CONDITIONS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MB16MEH0019

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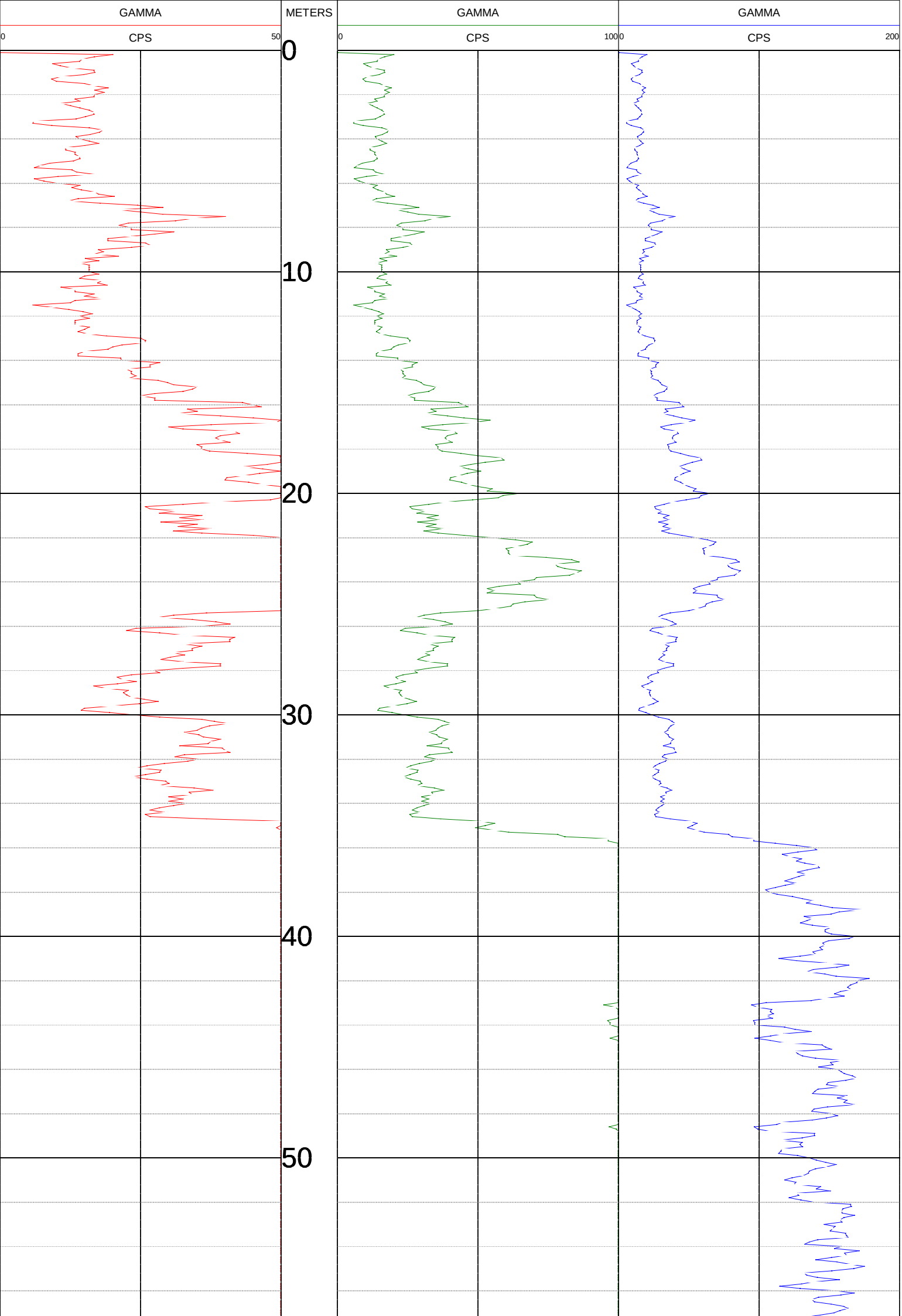
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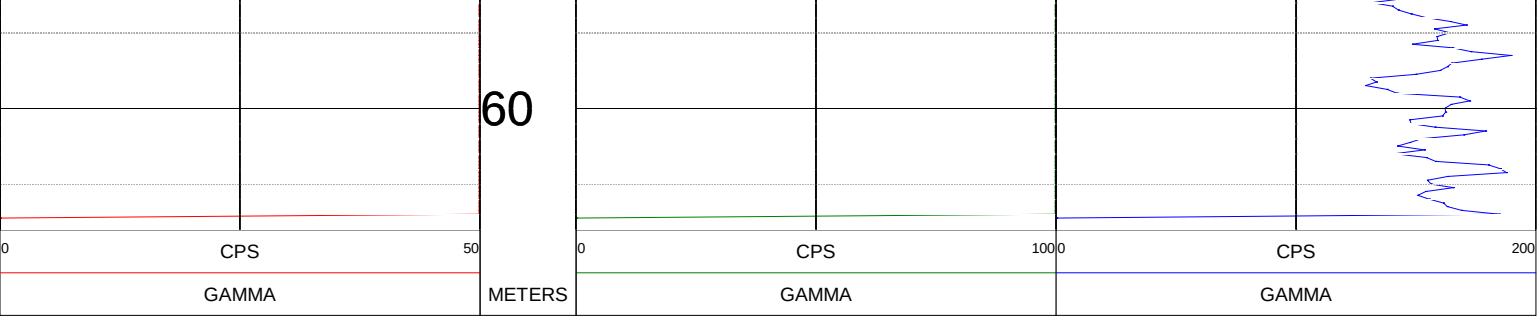
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LOCATION	: MEH						
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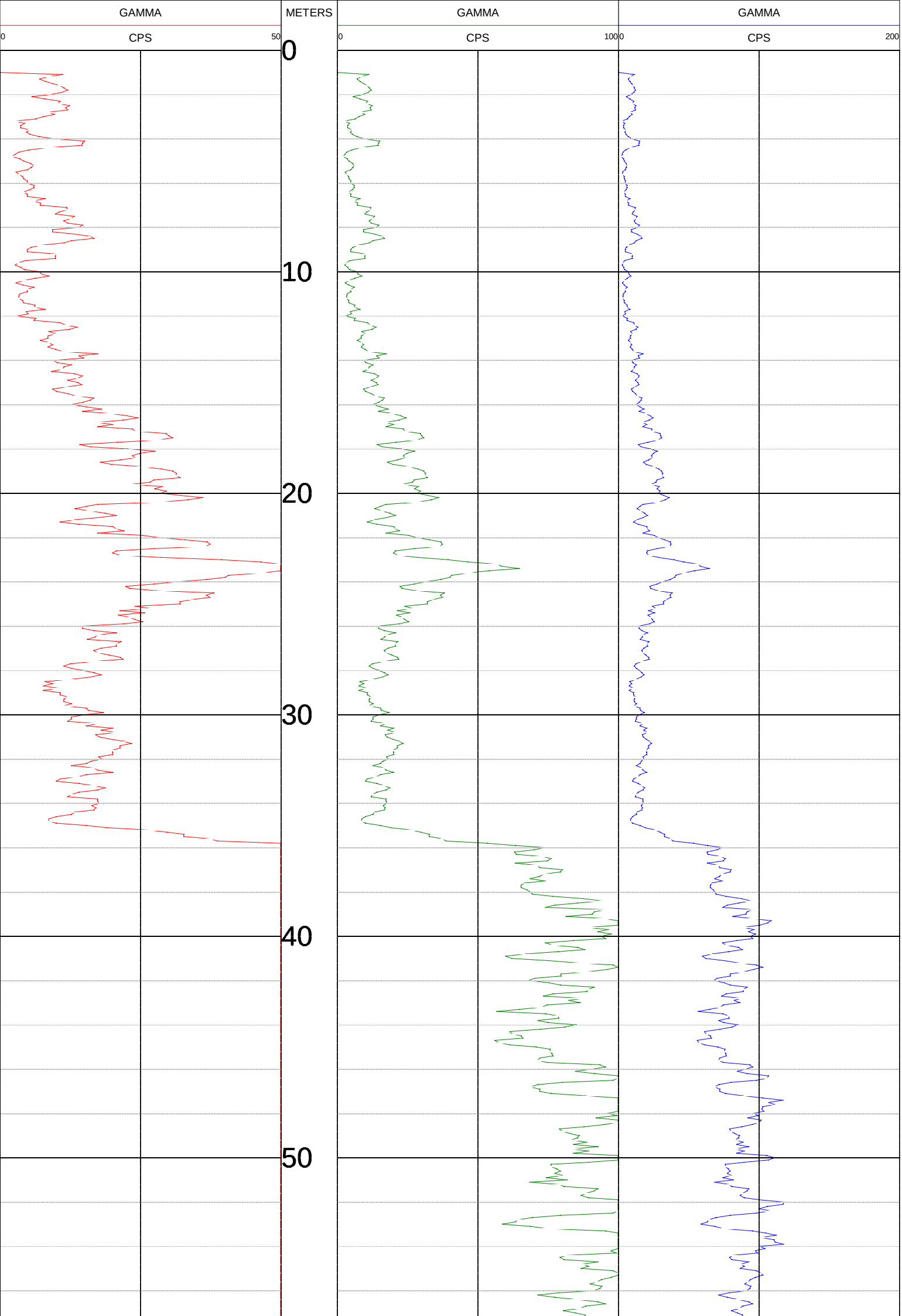
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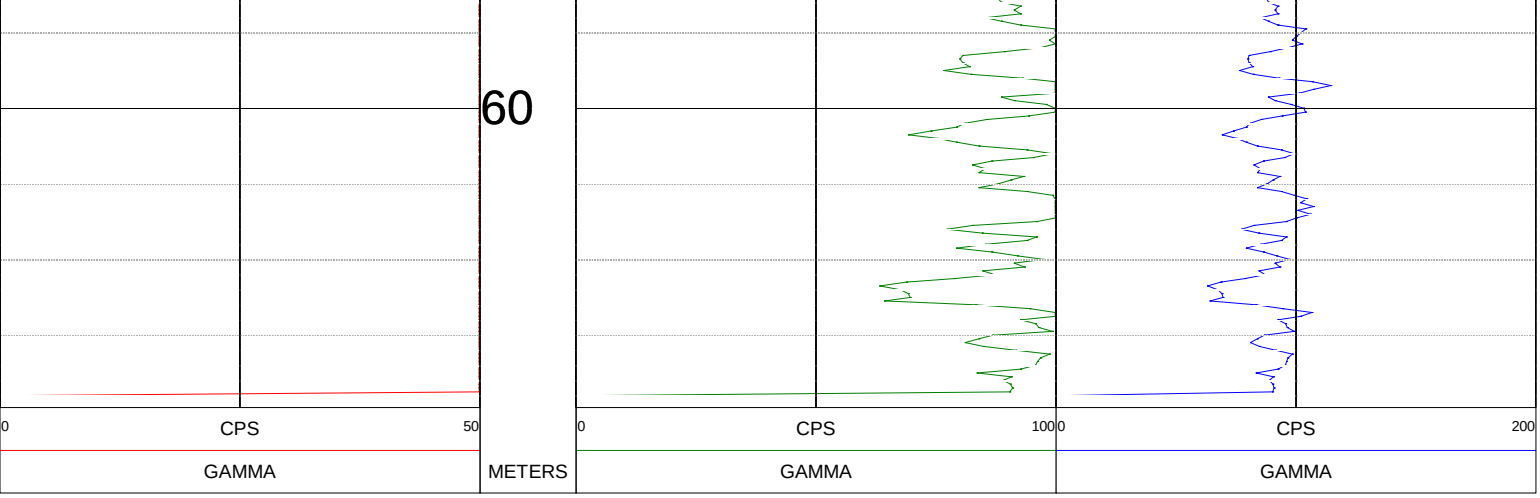
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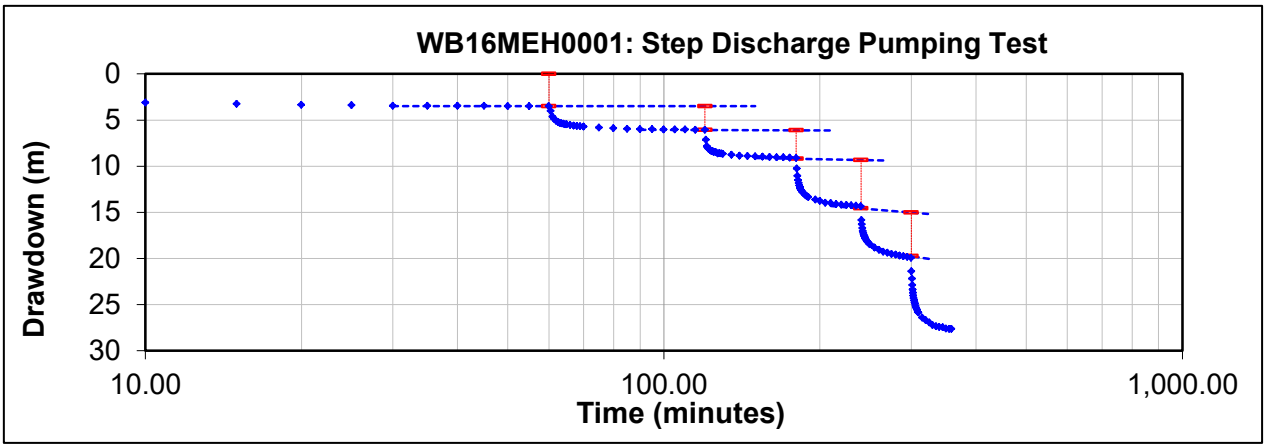
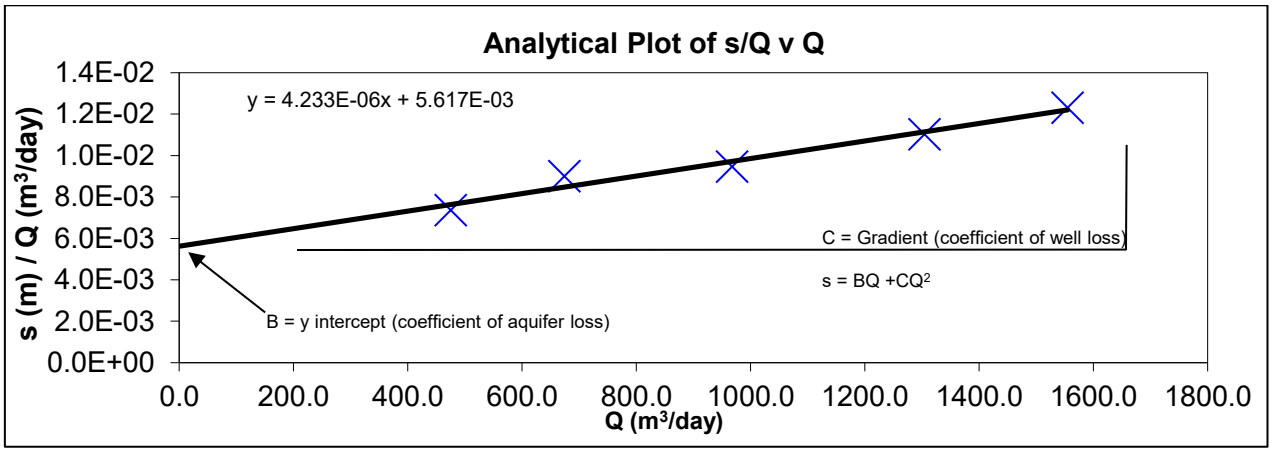
APPENDIX D TEST PUMPING RESULTS

Step Rate Tests

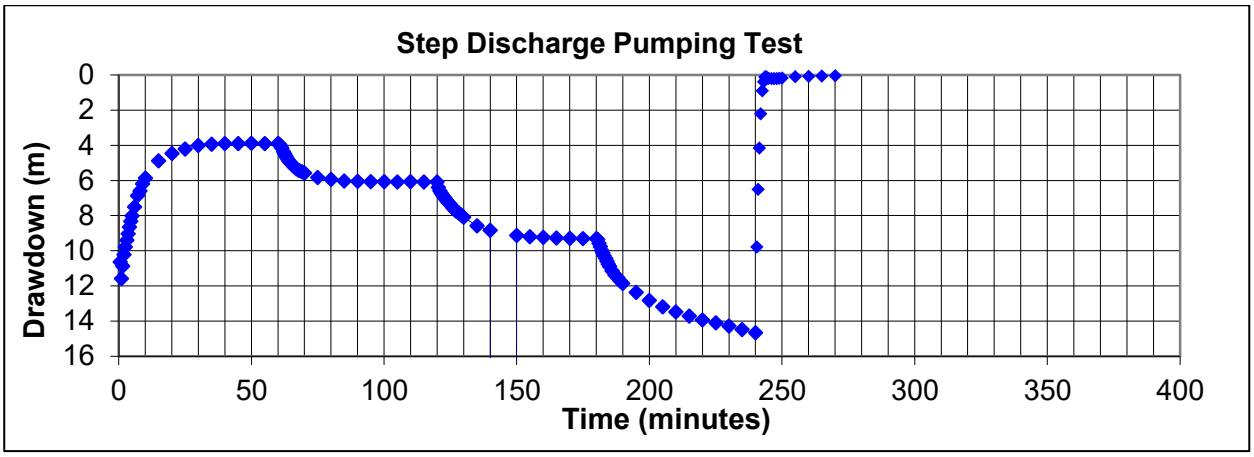
WB16MEH0001

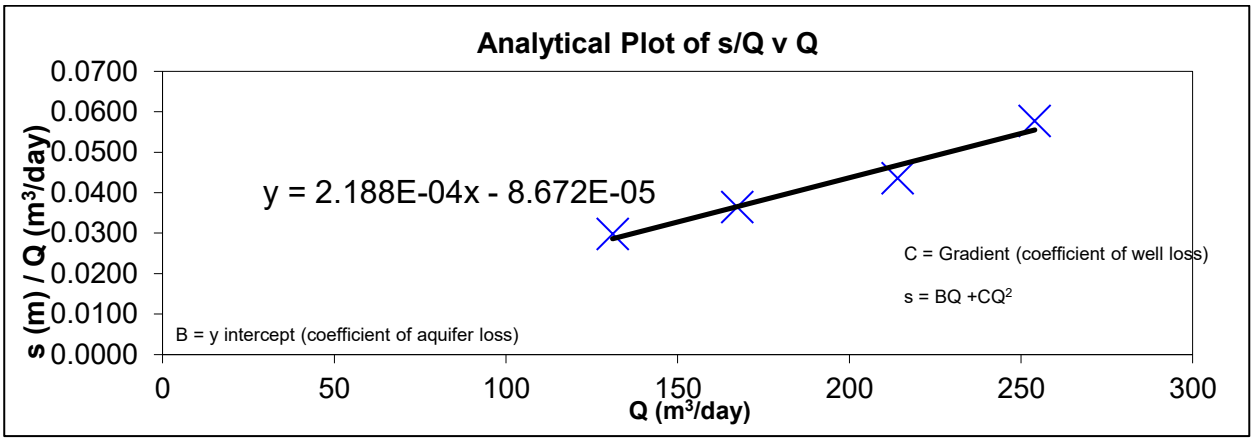




Intercept (B) 5.617E-03
Intercept (C) 4.233E-06

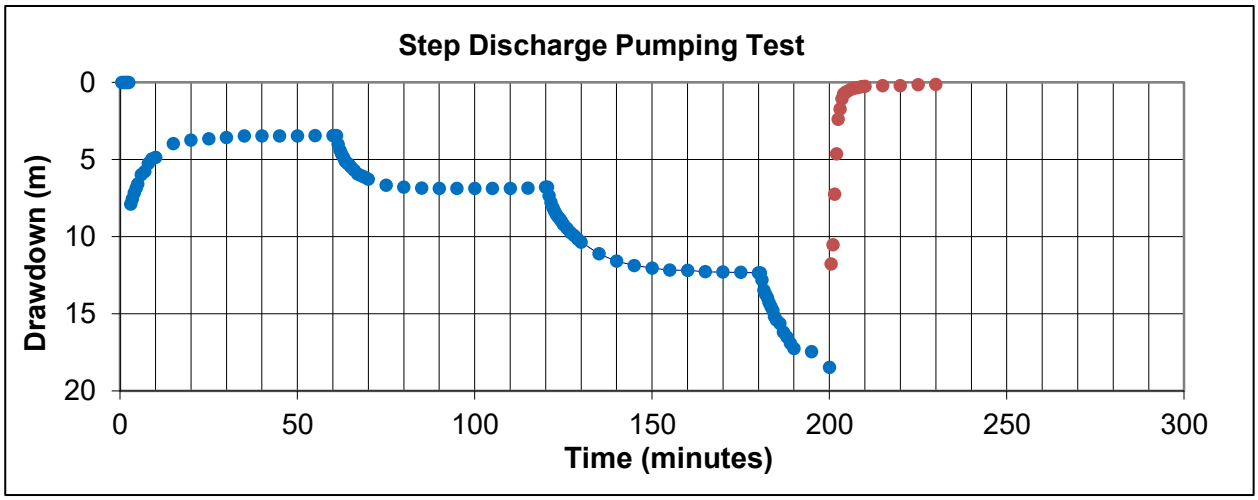
Calculation of well efficiency and comparison of observed and predicted drawdowns							
Step (100 minute duration)	Discharge (l/s)	Discharge (Q) (m^3/d)	Measured Incremental Drawdown (metres)	Corrected Drawdown (metres)	Predicted Drawdown (metres)	s/Q	Apparent Efficiency (Ew) %
1	5.5	475.2	3.49	3.49	3.63	7.35E-03	73.6
2	7.8	673.9	2.58	6.07	5.71	9.01E-03	66.3
3	11.2	967.7	3.09	9.16	9.40	9.46E-03	57.8
4	15.1	1304.6	5.23	14.39	14.53	1.10E-02	50.4
5	18.0	1555.2	4.74	19.13	18.98	1.23E-02	46.0

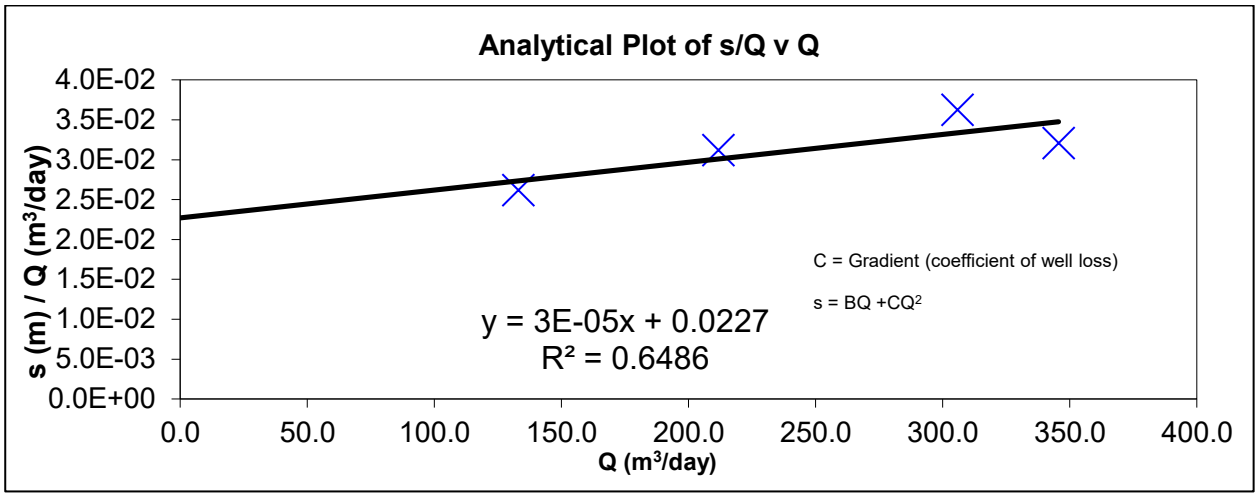




Intercept (B) 8.290E-03
Intercept (C) 1.646E-04

Calculation of well efficiency and comparison of observed and predicted drawdowns							
Step (30 minute duration)	Discharge (l/s)	Discharge (Q) (m^3/d)	Measured Incremental Drawdown (metres)	Corrected Drawdown (metres)	Predicted Drawdown (metres)	s/Q	Apparent Efficiency (Ew) %
1	1.5	131	3.9	3.90	3.92	0.0298	27.8
2	1.9	167	2.19	6.09	6.00	0.0364	23.1
3	2.5	214	3.23	9.32	9.32	0.0435	19.0
4	2.9	254	5.34	14.66	12.73	0.0577	16.5





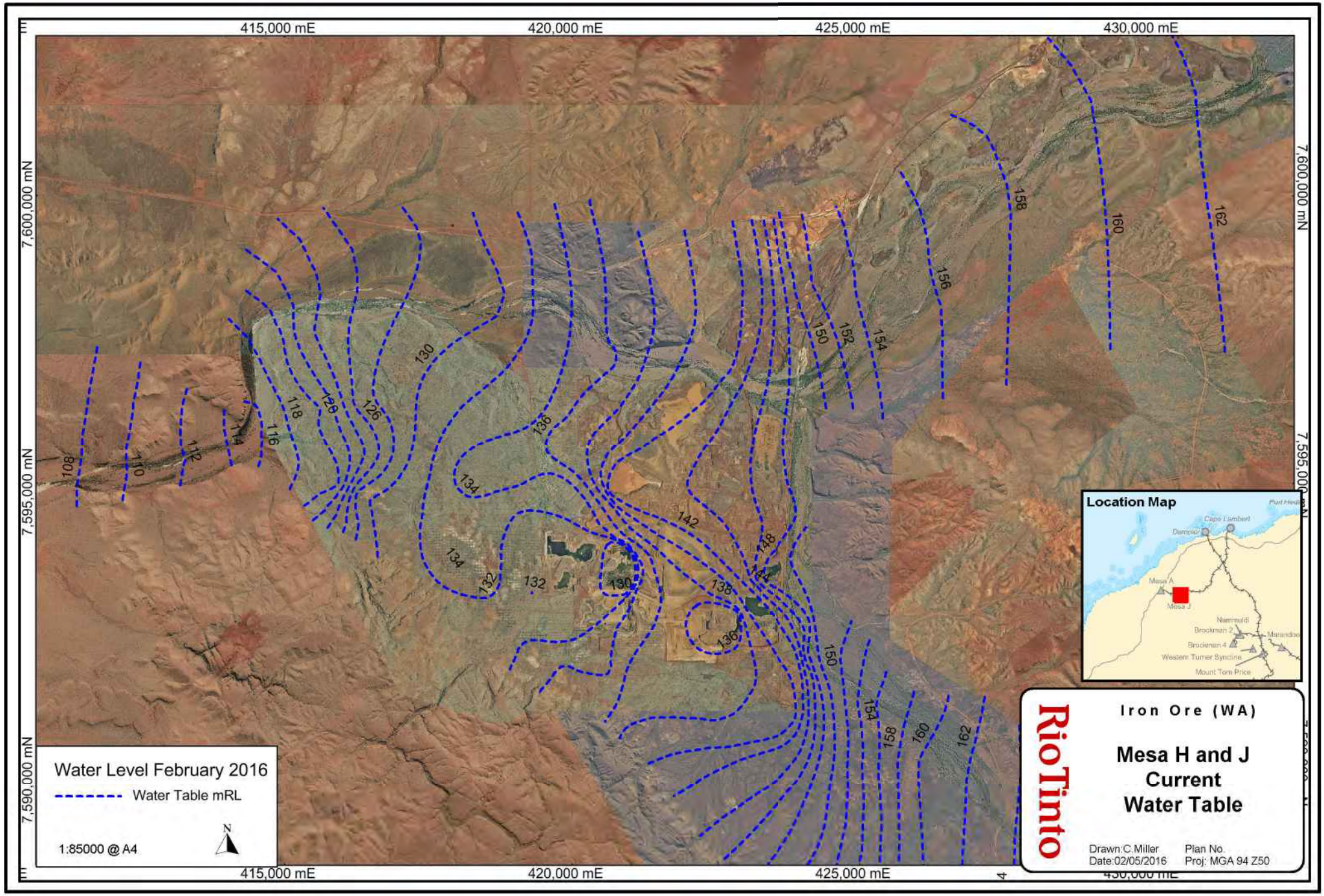
Intercept (B) 2.025^{E}-02
Intercept (C) 3.486E-05

Calculation of well efficiency and comparison of observed and predicted drawdowns							
Step (30 minute duration)	Discharge (l/s)	Discharge (Q) (m^3/d)	Measured Incremental Drawdown (metres)	Corrected Drawdown (metres)	Predicted Drawdown (metres)	s/Q	Apparent Efficiency (Ew) %
1	1.5	133.1	3.48	3.48	3.31	2.62E-02	81.4
2	2.5	211.7	3.12	6.60	5.85	3.12E-02	73.3
3	3.5	305.9	4.48	11.08	9.45	3.62E-02	65.5
4 (incomplete)	4.0	345.6	0.00	11.08	11.16	3.21E-02	62.7

APPENDIX E GEOCHEMICAL ANALYSIS RESULTS

Sample ID			WB16MEH0001	WB16MEH0002	WB16MEH0003	WB16MEH0004-A	WB16MEH0004-B
Analyte grouping/Analyte	**Units**	**LOR**					
pH Value	pH Unit	0.01	**7.68**	**7.75**	**7.63**	**7.10**	**7.33**
Electrical Conductivity @ 25°C	µS/cm	1	**606**	**497**	**798**	**576**	**663**
Total Dissolved Solids @180°C	mg/L	10	**370**	**378**	**570**	**388**	**380**
Suspended Solids (SS)	mg/L	5	<5	<5	**280**	<5	<5
Total Hardness as CaCO3	mg/L	1			**163**		
Bicarbonate Alkalinity as CaCO3	mg/L	1	**192**	**194**	**204**	**160**	**177**
Total Alkalinity as CaCO3	mg/L	1	**192**	**194**	**204**	**160**	**177**
Sulfur as S	mg/L	1			**15**		
Silicon	mg/L	0.05	**23.1**	**22.3**	**51.8**	**21.9**	**23.0**
Sulfate as SO4 - Turbidimetric	mg/L	1	**30**	**24**	**55**	**38**	**35**
Chloride	mg/L	1	**76**	**60**	**127**	**69**	**70**
Calcium	mg/L	1	**34**	**38**	**29**	**33**	**35**
Magnesium	mg/L	1	**25**	**25**	**22**	**24**	**24**
Sodium	mg/L	1	**49**	**41**	**115**	**48**	**47**
Potassium	mg/L	1	**8**	**7**	**8**	**8**	**8**
Aluminium	mg/L	0.01	<0.01	<0.01	**0.02**	<0.01	<0.01
Arsenic	mg/L	0.001	<0.001	<0.001	**0.005**	<0.001	<0.001
Barium	mg/L	0.001	**0.002**	**0.004**	**0.006**	**0.012**	**0.010**
Cobalt	mg/L	0.001	<0.001	<0.001	<0.001	**0.003**	**0.002**
Manganese	mg/L	0.001	**0.008**	**0.019**	**0.256**	**0.033**	**0.018**
Molybdenum	mg/L	0.001	<0.001	<0.001	**0.004**	<0.001	<0.001
Zinc	mg/L	0.005	<0.005	<0.005	<0.005	**0.022**	**0.009**
Boron	mg/L	0.05	**0.20**	**0.18**	**0.22**	**0.22**	**0.20**
Iron	mg/L	0.05	<0.05	**0.11**	**0.74**	**0.05**	<0.05
Fluoride	mg/L	0.1	**0.4**	**0.4**	**0.5**	**0.4**	**0.4**
EK055G-NH4: Ammonium as N	mg/L	0.01	**0.02**	**0.01**	**0.03**	**0.02**	
EK055G: Ammonia as N	mg/L	0.01	**0.02**	**0.02**	**0.04**	**0.03**	**0.03**
EK057G: Nitrite as N	mg/L	0.01	<0.01	**0.01**	**0.08**	**0.02**	<0.01
EK058G: Nitrate as N	mg/L	0.01	**0.54**	**0.67**	**0.25**	**0.76**	**0.86**
EK059G: Nitrite + Nitrate as N	mg/L	0.01	**0.54**	**0.68**	**0.33**	**0.78**	**0.86**
EK061G: Total Kjeldahl Nitrogen as N	mg/L	0.1	<0.1	**0.1**	<0.5	<0.1	<0.1
EK062G: Total Nitrogen as N	mg/L	0.1	**0.5**	**0.8**	<0.5	**0.8**	**0.9**
EK067G: Total Phosphorus as P	mg/L	0.01	<0.01	<0.01	**9.48**	<0.01	<0.01
			37				

APPENDIX F CONTOUR MAP


415,000 mE
420,000 mE
425,000 mE
430,000 mE
7,600,000 mN
7,595,000 mN
7,590,000 mN
Water Level February 2016
Water Table mRL
1:85000 @ A4
N
Location Map
Port Hedland
Cape Lambert
Dampier
Mesa A
Mesa J
Nammuldi
Brockman 2
Marandoo
Brockman 4
Western Turner Syncline
Mount Tom Price
RioTinto
Iron Ore (WA)
Mesa H and J
Current
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Drawn:C.Miller
Date:02/05/2016
Plan No.
Proj: MGA 94 Z50

APPENDIX B: GROUNDWATER NUMERICAL MODEL REPORT

Water Resource Evaluation & Services

Mesa H Groundwater Modelling

RTIO-PDE-0161859

6th July 2018

Distant view of Caves Creek (July, 2015)

Prepared By:

Checked By:			
Approved By:			
	Name	**Signature**	**Date**

EXECUTIVE SUMMARY

Background

The Mesa H Project is an iron ore mining operation located immediately west and adjacent to the existing Mesa J mine, approximately 17 km south-east of the Pannawonica township.

The Mesa H deposit is proposed to be mined over approximately 18 years, beginning in early 2020 and finishing in 2037.

The objective of this groundwater modelling study is to assess the dewatering rates necessary to facilitate dry mining conditions at Mesa H and Mesa J, as well as impacts of dewatering and water supply abstraction (including cumulative impact of the Coastal Water Supply project at Bungaroo Valley) on regional groundwater levels and surface water pools along the Robe River and Jimmawurrada Creek.

Groundwater Modelling

The original Aquaterra 2006 groundwater model (RTIO-PDE-0153689) has been updated to include the current hydrogeological conceptualisation for the Mesa J and Mesa H orebodies. This is based on the results of the recently completed drilling and testing investigations (RTIO-PDE-0156803) and monitoring data. The model has been calibrated to available historical data from January 1990 to December 2016.

The overall model confidence level classification (as per the National Water Commission 2012 guide, Table 2-1) is Class 2. The model meets most criteria for Class 3, other than the absence of sufficient monitoring data in areas along the Robe River and Jimmawurrada Creek and associated surface water pools.

The model was used to predict dewatering rates, water supply pumping requirements and groundwater drawdown impacts for the Life of Mine (LoM) schedule 221211 option 112 for the Robe Valley deposits. Two dewatering scenarios have been simulated. Case 1 assumed no water return from Tailings Storage Facilities (TSFs) due to the commissioning of a thickener plant and Case 2 assumed water return from TSFs ranging between 30% and 50% of discharged tailings. A maximum drawdown of 40 m (Case 2) at the end of mining at Mesa H (end of 2037), is predicted to occur in the immediate borefield area.

Potential groundwater drawdown impacts of dewatering and water supply pumping on the surface water pools along the Robe River are predicted to be temporary in duration and relatively small compared to drawdown predicted in the Mesa H and J mine areas and the water supply borefield. Drawdowns of more than 1 m are not predicted to extend into the Robe River alluvium.

Maximum predicted drawdown along the Jimmawurrada Creek is predicted close to the water supply borefield. Maximum drawdowns are predicted to occur in 2030, 2032 and 2034. Case 1 results predict 9 m of drawdown at tracking point TP7 in 2030. Case 2 results predicts maximum drawdowns of 18 m (2030 and

2032) and 16 m (2034) at TP7 as a larger water demand in included in Case 2 and requires more pumping from the water supply borefield.

Uncertainty Runs, which included the reduction of Robe River and Jimmawurrada Creek flows (including reduced base flow to the river alluvium) resulted in the greatest increase in predicted groundwater drawdown along the Robe River and Jimmawurrada Creek.

To increase confidence in model predictions it is recommended that the model should be periodically reviewed and updated based on the results of ongoing investigations along the Robe River and in the Mesa H and Mesa J mining areas and calibrated against the latest monitoring data sets.

Model Reliability

Long term monitoring data that includes periods of significant aquifer stress (i.e. pumping resulting in groundwater level drawdown) is limited to Mesa H and does not extend along the Robe River and Jimmawurrada Creek. Therefore, there is a significant degree of uncertainty in the model calibration due to the non-uniqueness of the numerical solution (particularly adopted hydraulic connection between the aquifers) that potentially impacts confidence in predictive reliability of outputs.

To help improve model prediction reliability the following are recommended:

- Additional monitoring is required along the Robe River near the surface water pools to collect groundwater data associated with the Robe River alluvial aquifer.

- Once additional drilling and monitoring data becomes available, the model should be revised to include the revised conceptual understanding and if required recalibrated. At this time, it is also recommended that groundwater predictions, that include the latest mine plan are completed.

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Figure 6: Modelled Hydraulic Conductivity Distribution in Layer 2

Figure 7: Modelled Hydraulic Conductivity Distribution in Layer 3

Figure 8: Modelled Hydraulic Conductivity Distribution in Layer 4

Figure 9: Modelled Hydraulic Conductivity Distribution in Layer 5

Figure 10: Modelled Hydraulic Conductivity Distribution in Layer 6/7

Figure 11: Modflow Stream Package (Schematic Section)

Figure 12: Modelled Rainfall Recharge Zones

Figure 13: Schematic EVT Setup

Figure 14: Modelled Evapotranspiration Zones

Figure 15: Predicted Steady State Groundwater Level Contours

Figure 16: Monitoring Bore Location

Figure 17: Discharge Locations

Figure 18: Mine Plan, Bores and Tracking Points

Figure 19: Predicted Drawdown – year 2029 (Case 1)

Figure 20: Predicted Drawdown – year 2037 (Case 1)

Figure 21: Predicted Drawdown - year 2029 (Case 2)

Figure 22: Predicted Drawdown - year 2037 (Case 2)

Figure 23: Predicted Drawdown – Tracking Points (Base Case)

Figure 24: Predicted Drawdown – Tracking Points (Base Case)

Figure 25: Predicted Drawdown – Tracking Points (Base Case)

APPENDICES

Appendix A – Calibration Hydrographs

Appendix B – Predicted Dewatering

Appendix C – Closure Results

Appendix D – Uncertainty Results

1. INTRODUCTION

1.1 Background

Mesa H is a channel iron deposit (CID) that forms part of a sinuous chain of mesas (from Mesa A to Mesa N) which define the palaeochannel of the Robe River and its associated tributaries. Mesa H is located immediately west and adjacent to the existing Mesa J mine, downstream from the confluence of the Robe River and the Jimmawurrada Creek, approximately 17 km south-east of the Pannawonica township (Figure 1).

The majority of the orebody occurred below the pre-mining water table, however due to the lowering of the water table in response to dewatering at Mesa J, parts of the Mesa H mine is above the present-day water table (i.e. Pit 9) or partially dewatered.

The local catchment is defined by three major aquifers:

- The basement aquifer comprising the weathered Paraburdoo and Bee Gorge Members of the Wittenoom Formation and weathered Marra Mamba BIF, hereafter referred to as the Wittenoom Aquifer.
- The Channel Iron Deposit aquifer, hereafter referred to as the CID Aquifer, which overlies the Wittenoom Aquifer.
- The Robe River alluvium aquifer, which occurs with the shallow alluvium adjacent to the Robe River and associated tributaries.

The Robe River regional catchment covers an area of approximately 7,500 km^2. Major watercourses occurring within the catchment include the Robe River and the Jimmawurrada, Bungaroo and Mungarathoona Creeks.

The Robe River is an ephemeral river, which carries significant underflow in its alluvial bed. This subsurface flow maintains permanent pools in the river channel, and these pools play an important role in the river ecosystem, supporting a diverse range of aquatic fauna and acts as refuges during periods of drought. Several pools in the Robe River to the north and north-west of the Mesa H deposit have significant environmental and heritage values and dewatering of the deposit could potentially impact some of these pools.

The numerical groundwater model for the catchment (the model) has been developed utilising existing information on the mine area and regional hydrogeology and the outcomes of existing pit area specific dewatering models.

1.2 Scope

The scope of the current modelling work was to:

- Update the regional groundwater model to include the current hydrogeological understanding of the orebody aquifers (Mesa J and Mesa

H) and the regional aquifer system.

- Calibrate the model to available groundwater levels in the Mesa J and Mesa H mining areas and along the Robe River and its tributaries.
- Use the groundwater model to predict:
  - The range of dewatering requirements for Mesa J and Mesa H over the life of mine.
  - The range of potential drawdown associated with groundwater abstraction (i.e. dewatering and water supply) on surface water pools along the Robe River and Jimmawurrada Creek.
  - Groundwater level recovery along the Robe River and Jimmawurrada Creek and in mining area(s) once mining is completed.

2. CONCEPTUAL HYDROGEOLOGICAL MODEL

The regional setting and regional hydrology have been well documented in the Mesa H H3 hydrogeological level assessment (RTIO-PDE-0155970), and the 2017 Mesa H FS Hydrogeological Drilling Bore Completion Report (RTIO-PDE-0156803) and are not detailed as part of this report. Figures 2 and 3 summarise the geological and hydrogeological setting, with the cross-sections (Figure 3) showing the influence of the conceptual hydrogeology on dewatering requirements.

2.1 Pre-mining Water Balance

Groundwater throughflow is estimated to be 1,600 ML/yr based on a 3.5 km cross section of the valley south of Mesa H / J, a saturated profile of 60 m, a hydraulic conductivity of 7 m/d and a hydraulic gradient of 0.004 (RTIO-PDE-0155970). The throughflow derived in previous studies in the Bungaroo Valley up gradient from Mesa H / J, was between 1,800 and 3,800 ML/yr.

To meet water demand for the wet process plant at Mesa J, RTIO has, in the past, harvested surface run-off from the Mesa H central catchment and pumped this into the Pit 11 at Mesa J.

A summary of the estimated water balance inflows and outflows is presented in Table 2.1.

Table 2.1: Conceptual Water Balance Summary

Inflow	ML/yr	Outflow	ML/yr
Throughflow	1,600	Throughflow	1,600
Rainfall recharge	20	Evaporation	1,600
Seepage	500	Abstraction (Environmental Discharge)	7,000 (3,000)
Loss of storage (drawdown)*	8,080		
Total	**10,200**	**Total**	**10,200**

3. GROUNDWATER MODEL SETUP

A groundwater model was developed in 2002 to predict inflows to the open pit workings for the proposed Mesa J mine (Aquaterra 2002a). This model was sequentially updated and upgraded by Aquaterra in 2003, 2004 and 2006.

The core of the current numerical groundwater model is the latest conceptual hydrogeological model developed by RTIO. The current model also includes the results and setups of the previous groundwater models (namely the Aquaterra 2006 model: RTIO-PDE-0153689).

The numerical groundwater flow modelling package Modflow-Surfact (Version 4.0, Hydrogeologic Inc. 1996) was used to develop the model operating under the Groundwater Vistas graphical user interface (Version 7.17 Build 15, Rumbaugh and Rumbaugh 1996–2017). The Modflow-Surfact numerical code was chosen to allow simulation of shallow water tables, reduction of water levels in the mining area and subsequent groundwater recovery.

3.1 Model Grid and Extent

The rectangular dimensions of the modelled area are ~20 km (SE–NW) by ~10 km (SW–NE). The extent, boundary conditions and general features of the model are shown in Figure 4. The model grid comprises seven layers, 391 rows and 193 columns, resulting in 266,026 active model cells. The model grid was rotated 45 degrees counter clockwise from the MGA Zone 50 grid, which aligns it with the groundwater inflow and outflow boundaries, including bounding rivers and the project mining area.

Coordinates of the four corners of the model domain are detailed in Table 3.1. The model grid has uniform spatial resolution of 50 m by 50 m throughout the model domain.

Table 3.1: Model Domain

	Easting (m)*	**Northing (m)***
Top Right	418,033	7,603,938
Top Left	411,208	7,597,117
Bottom Left	425,033	7,583,294
Bottom Right	431,855	7,590,116

*MGA94 Zone50

The hydrogeology of the Mesa H and J areas are represented by seven model layers as illustrated in Figures 5 to 10.

The model utilises flat layers of variable thickness. The thicknesses of the remaining layers are summarised in Table 3.2.

Table 3.2: Layer Setup

Layer	Layer Top (mAHD)	Layer Bottom (mAHD)	Layer Thickness (m)
Layer 1	160 - 180	140	20
Layer 2	140	130	10
Layer 3	130	120	10
Layer 4	120	110	10
Layer 5	110	100	10
Layer 6	100	80	20
Layer 7	80	60	20

3.2 Groundwater Inflow and Outflow

3.2.1 Model Boundaries

Model boundary conditions are shown in Figure 4. The model is bounded in the north, east and west by basement outcrops, represented by no flow boundaries. The Stream Package (STR1 package) of Modflow-Surfact was used to represent the Robe River and its tributaries (Jimmawurrada Creek and West Creek) within the model domain. The STR1 package allows water to flow into (or out of) the model and from (or to) the underlying aquifer at designated stream cells. Flows into or out of a stream cell are controlled by the difference between the groundwater elevation beneath the stream cell and either:

- the difference between the elevation of the bottom of the streambed and the calculated stream stage (option 1), or
- the calculated stream stage (option 2)

and a conductance or calibration term that accounts for stream bed properties (permeability, thickness and width). This is illustrated schematically in Figure 11.

The STR1 package also allows stream flow (river or creek flow) to be included as a designated stream input within the stream package, maintaining a balance between inflows and outflows at each stream cell, with any excess flow routed to the next downstream cell. This feature also assumes that any excess water at the last modelled stream cell is effectively lost from the groundwater system as outflow. The streambed elevations were assigned consistent with RTIO topographic data. The option to compute a stream stage was used and stream stages (Hs) were calculated by the model as shown in Figure 11. Stream width (50 m), streambed conductance (100 m^2/d), roughness (0.045) and slope (0.00245) were set consistent with the RTIO 2016 model.

The stream package approximates field conditions, which may involve complex patterns of saturated and unsaturated material beneath a modelled stream and the underlying aquifer. One of the limitations of the STR1 package becomes important when water levels in the aquifer fall well below the base of the modelled stream. When this occurs, seepage from the stream ceases to depend on head in the aquifer and is driven by the difference between the calculated

head in the stream and the stream bed elevation (option 1 above). This process does not take into account unsaturated flow processes between the base of the stream and the underlying aquifer water levels. However, if the water level in the aquifer is above the bottom of the streambed, flow from the stream is proportional to the head difference between the stream and the underlying aquifer (option 2 above).

The Robe River also carries a significant underflow in its alluvial bed. This subsurface inflow and outflow are simulated using the General Head Boundary (GHB) package in Modflow-Surfact. Underflow boundaries are assigned to the Robe River Valley at the north west model boundary and the eastern model boundary (refer Figure 4). These boundaries were assigned elevations of 114 mAHD and 149 mAHD (respectively) and a conductance of 100 m^2/d.

In the south, the groundwater inflow from the Bungaroo Valley is also represented by a General Head Boundary (assigned an elevation of 172 mAHD and a conductance of 100 m^2/d).

Inflow to the Robe River was based on recorded flows at Ngalooin Pool Station (station #707004), located approximately 18 km upstream from the Mesa J mine site. Due to a lack of gauging stations along the Jimmawurrada Creek, it was assumed that each time the Robe River was flowing, there was also surface water flow in Jimmawurrada Creek. The Jimmawurrada Creek catchment was estimated to be five times smaller than the Robe River catchment and therefore 20% of the recorded Robe River flow was applied to the Jimmawurrada Creek stream input. No natural flow was assigned to the West Creek as its main function in the model was to accommodate surface water discharge from mining at Mesa J.

3.2.2 Rainfall Recharge and Evapotranspiration

Recharge to the groundwater system is assumed to occur via rainfall recharge over the model domain (Figure 12). It was specified as a percentage of the recorded annual rainfall, distributed as follows:

- 0% to BIF outcrop
- 15% to Robe River alluvium
- 2% to Jimmawurrada Creek alluvium
- 1% to CID outcrops.

A mixture of Hardcapped / Hydrated Pisolite (HTP), Tertiary Pisolite TPM (mixed clay and pisolite) and hard Pisolite TPH overlies the CID Aquifer. Hydraulic properties have not yet been defined for these units, however, due to the impermeable nature of these units they are expected to function as a partial barrier to vertical flow, preventing rainfall recharge to the underlying aquifers (CID and TPB). These units were not included in the current model as they are above the pre-development water table and, due to their physical characteristics recharge to the CID aquifer is very low.

Evapotranspiration occurs from the shallow water table within the Robe River and the Jimmawurrada Creek where surface pools and vegetation occur. Elsewhere,

the water table is generally more than 10 m below the surface and losses from the water table to the atmosphere are negligible.

Evaporation from phreatophytic vegetation and from the shallow or near surface water table is modelled using the Evapotranspiration Package (EVT) in Modflow-Surfact. Modflow-Surfact uses a depth dependent relationship to calculate evapotranspiration (EVT) such that if aquifer water levels rise to, or above, a specified evapotranspiration surface, EVT occurs at the maximum specified rate. If the aquifer water level falls to below the specified ET surface, the EVT rate decreases linearly to zero until the water level falls to below an elevation equal to the ET surface minus a set extinction depth. The ET surface was set consistent with topographic data with an extinction depth of 5 m, consistent with type of vegetation along the Robe River and recorded groundwater levels. The EVT relationship is illustrated schematically in Figure 13.

The distribution of evapotranspiration included in the model is shown in Figure 14. Evaporation, measured as pan evaporation is 3,400 mm/yr (BOM, 2008). The EVT rate (70% of recorded pan evaporation) was set consistent with the RTIO conceptual model.

4. GROUNDWATER MODEL CALIBRATION

4.1 Steady State Calibration

The steady state calibration provides:

- A distribution of groundwater levels that reflects the groundwater system prior to any development.
- Initial conditions for the transient calibration.
- Quantification of the groundwater flow through the model domain, under average recharge conditions prior to any development.

The focus of the steady state calibration was to calibrate the model to interpreted pre-development groundwater levels and flows across the catchment. However, the time variant monitoring data covering the period 1990 to 2016 indicates a seasonal trend in water levels, in the order of several meters resulting from the wet and dry season recharge and stream flow patterns. Thus, the groundwater conditions within the catchment are not readily described by an average or steady state set of water level conditions. To accommodate this, a set of initial conditions was generated using average values for groundwater recharge and assigned stream flows for the Robe River and Jimmawurrada Creek which were then used as initial conditions for the transient calibration model. This process involved running the steady state and transient models, and fine-tuning model parameters until a set of conditions were generated that closely matched the start of the calibration period and the pre-development water balance.

Modelling has been completed using a conservative approach with respect to the data limitations and with conservative assumptions made in many instances where actual data is unavailable.

The modelled steady state groundwater level contours are presented in Figure 15. The steady state water balance is presented in Table 4.1.

Table 4.1: Steady State Modelled Water Balance

Flow Component	Inflow (ML/yr)	Outflow (ML/yr)
Groundwater Inflow / Outflow	1,250	295
Evapotranspiration	-	3,265
Recharge	735	-
Stream Leakage	4,600	3,025
Total	**6,585**	**6,585**

A comparison between the modelled steady state water balance and estimated pre-mining water balance is presented in Table 4.2.

Table 4.2: Numerical vs Analytical Water Balance

Flow Component	RTIO Water Balance (ML/yr)	Numerical Model (ML/yr)
Inflow from the Bungaroo Valley	~1,500	Inflow from the GHB = 800 Inflow from the Jimmawurrada Creek = 700 TOTAL = 1,500
Robe River underflow (inflow from the upstream)	>900	Inflow from the GHB = 430 Inflow from the stream leakage = 420 TOTAL = 850
Robe River underflow (outflow to the downstream)	>900	Outflow through the GHB = 290 Inflow from the stream leakage = 330 TOTAL = 630
Robe River flow (inflow from the upstream)	-	43,860
Jimmawurrada Creek flow (inflow from the upstream)	-	8,770
Robe River flow (outflow to the downstream)	-	51,100

As presented in Table 4.2 above, inflow to the model from the Bungaroo Valley and outflow from the model through the Wittenoom aquifer are well matched by the model.

4.2 Transient Model Calibration

The model calibration includes annual time increments from 1990 to 2016 and includes:

- Mesa J mine dewatering to date.
- Historical mine water supply pumping in the area.
- Discharge to Dan's Dam (Mesa J's water reservoir), Jimmawurrada Creek and West Creek.

Transient model performance was tested by comparing predicted and observed groundwater levels over the period 1990 to 2016. It is noted that data are not available for all monitoring locations for the entire calibration period. There are 37 monitoring bores with long term monitoring records and 33 bores with short term monitoring records (both regional bores and Mesa J mine monitoring bores). All of these bores were used in the calibration dataset. The locations of these bores are shown in Figure 16.

Rainfall recharge was applied annually based on the rainfall data records, recorded at Yarraloola Station (station #005032) and the rainfall rates outlined in Section 3.2.2. While the Yarraloola Station provides long term monitoring records, the record is incomplete from 1999 to 2016. To provide a complete and representative rainfall record for the Mesa H site, gridded rainfall data (BOM 2009) was used for the period 1999 to 2016.

Evapotranspiration was assigned a constant value of 0.0065 m/d or 70% of measured average pan evaporation of 3,400 mm/yr.

Discharge to Dan's Dam was simulated using the Recharge (RCH) package of Modflow-Surfact and assigned at 60% of the recorded dam discharge to account for evaporative losses.

During mining at Mesa J, surplus dewatering was historically discharged at two locations (Jimmawurrada Creek and West Creek). These locations are included in the model as shown in Figure 17. Discharge to the creeks is applied as stream inflows at designated locations based on the recorded discharge.

Inflow assigned to the Robe River and Jimmawurrada Creek and excess water discharge to Jimmawurrada and West Creek is presented in Table 4.3. Robe River inflows were assigned as stream inflow based on the recorded Robe River flow at Ngalooin Pool Station. Flow records were available from 1977 until 1999. From 1999 onwards, historical flow data from 1977 to 1993 was used to provide flow estimates for the period 2000 to 2016. As the model was run in annual increments, short term peak flows that occurred in 2006 and 2010 are not included.

Table 4.3: Average Annual Surface Water Flow (ML/yr)

Year	Robe River	Jimmawurrada Creek	Discharge to Jimmawurrada Creek	Discharge to West Creek
1990	4,326	865	0	0
1991	0	0	0	0
1992	50	10	0	0
1993	194,900	38,980	0	0
1994	21,610	4,322	0	0
1995	254,600	50,920	0	0
1996	10,140	2,028	0	0
1997	126,300	25,260	0	0
1998	266	53	0	0
1999	76,880	15,376	0	0

Year	Robe River	Jimmawurrada Creek	Discharge to Jimmawurrada Creek	Discharge to West Creek
2000	1,394	279	0	0
2001	16,410	3,282	0	0
2002	18,990	3,798	0	0
2003	52,020	10,404	0	0
2004	36,470	7,294	0	0
2005	9,099	1,820	0	0
2006	1,195	239	0	0
2007	49,250	9,850	0	602
2008	41,430	8,286	0	1,862
2009	2,850	570	594	1,997
2010	44,790	8,958	3,582	1,354
2011	18,240	3,648	2,513	10,184
2012	27,530	5,506	4	1,022
2013	4,326	865	0	1
2014	0	0	84	1
2015	50	10	2,006	2,248
2016	194,900	38,980	1,511	176

Abstraction from the Mesa J borefield was simulated using the Fracture Well (FWL4) package in Modflow-Surfact. Individual bore pumping rates were assigned based on historical abstraction records.

Dewatering at Mesa J was simulated using the Drain (DRN) package in Modflow-Surfact. It is noted that historical pit progressions for Mesa J were not available at the time of this study. Drain elevations were set based on the interpolated historical data. Drain conductance was set sufficiently high (1,000 m^2/d) such that the only resistance to groundwater inflow was provided by the surrounding aquifer rather than the assigned drain cell properties (i.e. drain bed conductance).

4.2.1 Calibration Performance

Calibration hydrographs are presented in Figures A1 to A21. The locations of monitoring bores used for model calibration are shown in Figure 16. Measured groundwater levels and trends are generally well matched by the model. In the immediate vicinity of the Mesa J mine, the decreasing water level trend associated with dewatering is well replicated by the model. The impact of ongoing dewatering and water supply pumping is well matched at MB12MEJ001, MB13MEJ005 and MB13MEJ007 (Figure A1), MB15MEH001 and JWO06 (Figure A2), JWO08, JWO09 and JW011 (Figure A3), JWO16 and JWO18 (Figure A4) and JW020 (Figure A5).

Groundwater levels are over predicted by 5 m at MB15MEH009 (Figure A2), and JW019 (Figure A4) and JW020 (Figure A5), however the decreasing water level trend is replicated by the model at these locations.

Measured groundwater levels are very well matched by the model in the immediate borefield area at DWB01 and DWB02 (Figure A5), DWB03, DWB04 and DWB06 (Figure A6) and DWB07, DWB08 and DWB09 (Figure A7). There is still some uncertainty as to the geology and structural features in this area (the deep, fractured and weathered aquifers which existing and proposed water supply bores draw from). It is suspected that there may also be another groundwater flow path associated with one of the fault splays or even another inflow feature to the east or west that could influence groundwater behaviour in the borefield area.

Further to the south (south of Mesa J) towards the Bungaroo Valley, measured groundwater levels at JWO21 and JWO23 (Figure A8) are well matched by the model. Some of the measured seasonal water level trends are not replicated by the model, however, this is because the current model set up does not include measured surface water flows in Jimmawurrada Creek that originate further upstream.

Further to the north (north of Mesa J) towards the Robe River, measured groundwater levels at JWO17 (Figure A8) and JWO13 (Figure A11) along the Jimmawurrada Creek are well matched by the model.

Long term monitoring records in the Mesa H area and along the Robe River are not available. The model performance in these areas was compared to the monitoring records from 33 recently installed monitoring bores (Figures A12 to A21, bore locations shown in Figure 16). There is a generally good match to the measured groundwater levels at these bores especially at locations closest to the Robe River (RR1 and VW16MEH013, Figure A19, MB15MEH014, Figure A20, MB15MEH013 and MB16MEH009, Figure A21), and to the north of the Robe River (MB16MEH014, Figure A20).

4.2.2 Aquifer Parameters

Figures 5 to 10 show the distribution of hydrogeological units for the calibrated model. The aquifer parameters adopted for the calibrated model are summarised in Table 4.4. Assigned aquifer parameters are consistent with the conceptual model, available hydraulic testing data, previous groundwater models, published data and similar hydrogeological environments.

Table 4.4: Calibrated Aquifer Parameters

Formation	Kh (m/d)	Kv (m/d)	Specific Yield (%)	Confined Storage
Robe River Alluvium	100	50	30	0.0001
Jimmawurrada Creek Alluvium	5	0.5	20	0.0001
CID	4	2	10	0.0001
Tertiary Pisolite TPB	1	0.1	6	0.0001
Weathered Boolgeeda Formation	8	8	5	0.0001
Boolgeeda Formation	0.0001	0.0001	0.1	0.0001
Weathered Weeli Wooli Formation	8	8	1	0.0001
Weeli Wooli Formation	0.0001	0.0001	0.1	0.0001
Brockman Formation	0.0001	0.0001	0.1	0.0001

Formation	Kh (m/d)	Kv (m/d)	Specific Yield (%)	Confined Storage
Weathered Wittenoom Formation	8	8	10	0.0001
Wittenoom Formation	0.0001	0.0001	0.1	0.0001
Weathered Marra Mamba Formation	8	8	10	0.0001
Marra Mamba Formation	0.0001	0.0001	0.1	0.0001

The predicted groundwater balance is presented in Table 4.5. The water balance shows that inflows from upstream (Robe River and Jimmawurrada Creek flows) dominate the inputs to the modelled catchment. Besides replenishing the surface water pools along its path, the Robe River and Jimmawurrada Creek flow that recharges the underlying aquifer also feeds partially dewatered aquifers. Inflow from the Robe River and Jimmawurrada Creek into the model (modelled aquifers) is almost 50% of the overall water balance. Dewatering and borefield pumping combined provide the greatest outputs (almost 50% of the overall water balance).

Table 4.5: Modelled Water Balance (January 1990 to December 2016 Average)

Flow Component	Inflow (ML/y)	Outflow (ML/y)
Storage	3,515	900
Borefield Pumping		1,170
Dewatering		4,640
Rainfall Recharge	695	
Discharge to Dan's Dam	510	
Evapotranspiration		2,880
Groundwater Inflow / Outflow	1,430	290
Stream Leakage	5,900	2,170
Total	**12,050**	**12,050**

5. MODEL PREDICTIONS

Approach

The calibrated model was used to predict:

- The dewatering requirements for the Mesa J and Mesa H mines.
- The volume of abstraction required from the water supply borefield in addition to dewatering from Mesa J and Mesa H to meet the project water demand.
- The mine dewatering, water supply borefield abstraction and closure impacts on surface water pools along the Robe River and Jimmawurrada Creek.

Model predictions were based on the current mine plan provided by RTIO (Case 221211 option 112 – RO5_J0.5_A0.5_RV_Report Template_PFS_ 20170111.xlsx) and included:

- Mesa J – Pits 3, 5, 6, 7, 8, 9, 11, 12, 14 and 15.
- Mesa H – Pits 1 to 8 (Pit 9 is above the water table and does not require dewatering).

5.1 Dewatering Model Configuration

The mine schedules adopted for Mesa J and Mesa H dewatering predictions are summarised in Tables 5.1 and 5.2:

Table 5.1: Mesa J Mine Plan

End of Year	Pit 3	Pit 5	Pit 6	Pit 7	Pit 8	Pit 9	Pit 11	Pit 12	Pit 14	Pit 15
2019	146		182	**138**	**126**	158				**142**
2020	146		174	**134**		158				**134**
2021			174	**134**		158		138		**130**
2022			**134**	**134**		158		138		**130**
2023			**134**	**134**		158		**130**		**130**
2024			**130**	**134**		154		**130**	162	**130**
2025				**134**		154		**130**	146	**130**
2026				**134**		142	146	**130**	134	**130**
2027		170		**130**			138	**130**	**120**	**130**
2028		170		**130**			**130**	**110**		**130**
2029		154					**114**			

* Underlined numbers represent bench elevations below the water table

Table 5.2: Mesa H Mine Plan

End of Year	Pit 1	Pit 2	Pit 3	Pit 4	Pit 5	Pit 6	Pit 7	Pit 8
2019								
2020						162		
2021						158		
2022						154		
2023						134		
2024						**114**	162	166
2025							162	166
2026							162	162
2027							150	162
2028	150						150	158
2029	134						150	150
2030	134						**122**	**122**
2031	**122**	166					**122**	
2032		**126**	166				**118**	
2033		**114**	**126**	150			**118**	
2034			**114**	**130**	166		**118**	
2035				**118**	150		**114**	
2036					**130**		**110**	
2037					**122**			

* Underlined numbers represent bench elevations below the water table

The predictions were completed as outlined below:

- Initial groundwater level/flow conditions were derived from the end of the transient calibration (December 2016).
- The prediction period starts in January 2019.
- The model was run for a period of 19 years (January 2019 to December 2037).
- The model predictions were run using annual time increments (stress periods).
- Steady state evapotranspiration rates were used in the prediction model.
- As outlined in the model setup section, Robe River flow records exist until 1999. For the 19 year prediction period, the last 19 years of recorded Robe River flows were used (from 1981 to 1999). Similarly, the rainfall recharge data from the period 1981 to 1999 was used in the prediction models.
- Dewatering at Mesa J and Mesa H was simulated using the Drain Package (DRN) in Modflow-Surfact. Drain elevations and extents were set consistent with the proposed mine plan. Drain bed conductance was set consistent with the calibrated model (i.e. 1,000 m^2/d). When mining and dewatering of individual pits was complete, as shown in Tables 5.1 and 5.2, drain cells were switched off and in pit water levels could recover. Details of infilled

pits included in dewatering and closure predictions are discussed in Section 6.1.

- Discharge to Dan's Dam was applied using the Recharge Package (RCH) in Modflow-Surfact at the average recorded discharge rate from the calibration period.

- Surface water excess discharge to Jimmawurrada Creek and West Creek was not included.

- The water level impact of the Coastal Water Supply borefield was included in model predictions based on the results of a separate groundwater modelling study undertaken by RTIO. Drawdown impacts from the CWS were included in the prediction model by reducing the head assigned to the southern inflow boundary (General Head Boundary, refer Figure 4) consistent with the predicted drawdown impact. The RTIO model for the CWS predicts that 6 m of drawdown will extend north toward the southern model boundary after five years, with 8 m of drawdown at this boundary after 10 years, 9 m of drawdown at this boundary after 15 years and 11 m of drawdown at this boundary after 30 years of water supply pumping. The GHB elevation was lowered linearly over the prediction period consistent with these estimates of drawdown (i.e. reduced from the value assigned in model calibration of 172 mAHD).

- Two projected water supply demands were included as follow:

    - **Case 1**: No water return from TSFs due to the commissioning of a thickener plant.

    - **Case 2**: Water return from TSFs ranging between 30% and 50% of discharged tailings;

The projected water demand for Cases 1 and 2 are presented in Table 5.3 below:

Table 5.3: Projected Water Supply Demand (ML/yr)

Year	Case 1	Case 2
2020	5,000	7,000
2021	5,000	7,000
2022	5,000	7,000
2023	5,000	7,000
2024	5,000	9,000
2025	5,000	9,000
2026	5,000	9,000
2027	5,000	9,000
2028	5,000	9,000
2029	5,000	9,000
2030	5,000	9,000
2031	5,000	9,000

Year	Case 1	Case 2
2032	5,000	9,000
2033	5,000	9,000
2034	4,000	7,000
2035	4,000	7,000
2036	4,000	7,000
2037	4,000	7,000

- Water supply pumping was simulated using the Fracture Well Package (FWL4) in Modflow-Surfact. The volume of abstraction required was calculated as the difference between the projected water demand and the predicted total dewatering. The pumping rates required were calculated using an iterative process and the prediction model was re-run until the assigned borefield pumping and predicted dewatering satisfied the water demands outlined in Table 5.3.

- Seven existing and nine nominal bores were used to simulate water supply pumping when required. Bore locations are shown in Figure 18 and Table 5.4 below:

Table 5.4: Water Supply Bore Location

Bore ID	Easting (m)*	Northing (m)*	Status
DWB18	423,608	7,591,732	Existing bore
DWB15	423,601	7,592,032	Existing bore
DWB20	423,370	7,591,593	Existing bore
WB13MEJ001	423,542	7,589,975	Existing bore
WB13MEJ002	423,443	7,590,213	Existing bore
WB12MEJ003	422,651	7,591,175	Existing bore
WB13MEJ004	423,551	7,590,716	Existing bore
Nominal_1	424,538	7,589,862	Nominal future bore
Nominal_2	425,287	7,589,421	Nominal future bore
Nominal_3	425,325	7,590,128	Nominal future bore
Nominal_4	424,413	7,590,694	Nominal future bore
Nominal_5	424,268	7,591,335	Nominal future bore

* MGA94 Zone 50

Prediction runs have been completed using a conservative approach (i.e. reduced inflow from the southern model boundary, no surface water discharge to creeks when dewatering exceeds water supply requirements, and no seepage from the TSFs) to allow prediction of maximum potential groundwater drawdown throughout the modelled catchment.

5.2 Results

5.2.1 Mesa J Water Levels and Dewatering

Predicted water levels across the Mesa J and Mesa H mine areas are shown in Figures B1 to B9. Modelled observation locations are shown in Figure 18. Predicted water levels closely follow the mining schedule as drains are used to simulate dewatering (i.e. no advanced dewatering using bores is included in model predictions).

Predicted dewatering at Mesa J is presented in Figure B10. For Case 1, dewatering at Mesa J is predicted to peak at 8,100 ML/yr in 2023 (from dewatering at Pits 6, 12 and 15), with another peak of up to 7,170 ML/yr predicted in 2027 (from dewatering at Pits 7, 12, 14 and 15). For Case 2, dewatering at Mesa J is predicted to peak at 8,085 ML/yr in 2023 (similar to Case 1), with another peak of up to 6,140 ML/yr in 2027. The lower water supply requirement for Case 1 is predicted to result in higher dewatering requirements for Case 1 compared to Case 2. Water supply requirements are discussed in the sections below.

Mining at Mesa J ends in December 2029. Drain cells used to simulate dewatering at Mesa J were not included from January 2030 onwards and water levels could recover, assuming mined out voids were infilled to above the pre-mining water table. Predicted water levels in Mesa J are predicted to increase from 2030 to 2037 (Figures B5 to B9).

5.2.2 Mesa H Water Levels and Dewatering

Predicted water levels for Mesa H are shown in Figures B1 to B4. Dewatering at Mesa H is shown in Figure B10 and, is predicted to be similar for both Case 1 and 2, with dewatering for Case 1 predicted to be marginally higher than Case 2 after 2031, due to the greater water supply requirement and borefield pumping included in Case 2.

For Cases 1 and 2, dewatering rates are predicted to reach a maximum of 2,900 ML/yr in 2033, from dewatering at Pit 2. Dewatering is predicted to decrease to 2,500 ML/yr by 2035. After 2035 dewatering is predicted to decrease to 940 ML/y in 2036 and increase to 1,300 ML/yr in 2037.

5.2.3 Borefield Pumping

The model predicts that pumping from the proposed borefield will be required to supplement the predicted dewatering to meet the water demand for both cases (Figure B10). Maximum predicted pumping from the water supply borefield is predicted in 2030 for Case 1 (3,850 ML/yr) reducing to 1,500 ML/yr in 2035, with a further increase to 3,000 ML/yr by 2037. For Case 2, maximum water supply pumping is predicted in 2030 (7,800 ML/yr) reducing to 4,700 ML/yr in 2035 with a further increase to 6,000 ML/yr in 2036 and 2037.

Total pumping (dewatering and water supply pumping) and the required water demand for Cases 1 and 2 are shown in Figure B10, with dewatering and borefield pumping equalling or exceeding the water demand over the life of the mine.

5.3 Drawdown

Contours of predicted drawdown at the end of mining at Mesa J (December 2029) and at end of mining at Mesa H (December 2037) are presented in Figures 19 and 20 for Case 1 and in Figures 21 and 22 for Case 2. These drawdown contours were derived by subtracting the predicted water levels from the dewatering models (Case 1 and Case 2 models), at the end of 2029 and 2037, from predicted water levels at the corresponding times for the No-Development Case. The No-Development Case is simulated for the same duration as the Case 1 and 2 predictions and includes the undisturbed groundwater regime (i.e. with the same stream flows and groundwater recharge as Cases 1 and 2 and without dewatering, water supply pumping, impacts of the CWS or excess water discharge).

5.3.1 Case 1

For Case 1 (Figure 19), maximum drawdown at the end of mining at Mesa J (the end of 2029) is predicted to occur at Pits 11 and 12 which are the deepest two pits at Mesa J (up to 39 m of drawdown), and in the immediate borefield area (10 to 20 m of drawdown). Predicted drawdown to the north-west and north results from ongoing dewatering at Mesa J and dewatering at Mesa H Pits 6, 7 and 8. To the north-west, towards Mesa H, 1 m of drawdown is predicted to extend 6 km north-west of Mesa J Pit 11 and north of Mesa H Pit 9 by the end of 2029. Drawdown of 1 m is not predicted to reach the Robe River by the end of 2029.

By 2037, (Figure 20) a maximum predicted drawdown of 29 m is predicted at Pits 4 and 5 of Mesa H. As dewatering at Mesa J finishes at the end of 2029, borefield pumping is required to meet the projected water demand and drawdown of 15 m is predicted in the borefield area at the end of mining (December 2037).

5.2.2 Case 2

Similar to Case 1, maximum drawdown at the end of mining at Mesa J (end of 2029) is predicted to occur at Pits 11 and 12 which are the deepest two pits at Mesa J (up to 39 m of drawdown, Figure 21). Similar drawdown to Case 1 is also predicted to extend north of Mesa J Pit 9 (drawdown of 1 m) and to the north west of Mesa J. The requirement for pumping from the water supply borefield is predicted to result in drawdown of up to 27 m in the borefield area. Drawdown of up to 5 m is predicted to the south-east of Mesa J towards the Bungaroo Valley, as a result of water supply pumping from the water supply borefield and the CWS, as well as dewatering at Mesa J. Drawdown of 1 m is not predicted to reach the Robe River by the end of 2029.

At the end of mining, in 2037, to the north and north west, the drawdown predicted for Case 2 is similar to the drawdown predicted for Case 1 (i.e. 1 m of drawdown does not reach the Robe River). The increased water demand for Case 2 requires additional pumping from the borefield, resulting in increased drawdown in the borefield area by 2037 (when compared to Case 1). Maximum drawdown of 40 m is predicted in the immediate borefield area. By 2037, drawdown of 10 m is predicted to extend south of the proposed borefield, with

drawdown of up to 5 m predicted towards the Bungaroo Valley (i.e. more than that predicted for Case 1).

5.2.3 Drawdown at Tracking Points

Long term monitoring data in the immediate area of the surface water pools or in the Robe River alluvium are not available. However, monitoring records from nearby bores, located close to the Robe River show a seasonal variation in groundwater levels of around 2 m. Predicted drawdown of 1 m is considered a reasonable drawdown trigger to assess environmental impact in the Robe River because:

- The estimated seasonal groundwater fluctuation is greater than 2 m.
- Groundwater recharge near the Robe River is primarily due to surface water infiltration after storm events, and
- Monitoring indicates that groundwater levels are generally below the bed elevations along the Robe River. A groundwater level drawdown of 1 m is considered to be small compared to the rooting depth of potentially groundwater dependent vegetation.

The location of tracking points, at five locations across the modelled catchment are shown in Figures 19 to 22. At these locations the proposed mining may be adjacent to the surface water pools and potentially groundwater dependent vegetation. These tracking points are used to assess the potential impacts of dewatering and water supply pumping at Mesa J and Mesa H on the surface water pools along the Robe River.

Predicted drawdown at tracking points along the Robe River over the life of the mine are presented in Figures 23 to 25. This drawdown is calculated by subtracting predicted water levels at each tracking point for the No Development Case (described in Section 5.3 above) from predicted water levels for Cases 1 and 2. Predicted drawdown hydrographs show maximum predicted drawdown at all tracking points to be temporary and less than 1 m.

The maximum predicted drawdown at tracking points at the five key areas across the model domain are discussed below:

- Tracking point TP2 is located at the confluence of the Robe River and the Jimmawurrada Creek. At this location dewatering from Mesa J and the water supply borefield pumping may result in drawdown in the Jimmawurrada Creek alluvium extending to the north towards the Robe River. Maximum predicted drawdown at TP2 is 0.26 m for Cases 1 and 2 (Figure 23).
- Tracking points TP11, 12, 13 and 14 are located in the section of the Robe River between the Jimmawurrada and West Creeks, adjacent to the Mesa J mining areas. The maximum predicted drawdown in this area is 0.45 m at TP14 for Case 2 (Figure 24).
- Tracking points TP25 and 26 are located along the Robe River, west of the

West Creek confluence. This area is not only in direct hydraulic connection with the orebody aquifers via the TPB but is also underlain by high permeability associated with the (weathered) Wittenoom aquifer. Maximum predicted drawdown in this area is up to 0.68 m at TP25 for Cases 1 and 2 (Figure 25).

- Tracking points TP22, 23 and 24 are located in the Robe River alluvium, downstream or west of TP25 and TP26. Maximum predicted drawdown in this area is 0.28 m at TP23 (Figure 24).

- Tracking point TP7 is located along the Jimmawurrada Creek near the proposed water supply borefield. Maximum predicted drawdown at TP7 is 8.81 m in Case 1 and 17.42 m in Case 2 (Figure 25). The greater drawdown predicted in Case 2 results from the higher water demand and increased pumping requirement from the water supply borefield.

5.3 Water Balance

The model predicted water balance (average inflows and outflows over the life of mine) is presented in Table 5.5. Consistent with the calibrated model, the sources of inflow are depletion of aquifer storage (by dewatering and borefield pumping), and aquifer recharge from stream leakage (from the Robe River and Jimmawurrada Creek). The major outflow components are pumping from the water supply borefield and mine dewatering.

In the model calibration (steady state and transient) and the No Development prediction models, the southern model boundary associated with the Bungaroo Valley is an inflow boundary. The reduction in elevation at this model boundary included in model predictions to account for impact of the CWS reverses the groundwater flow direction across the model boundary from 2021 onwards. This boundary functions as a groundwater outflow boundary, with groundwater flow and some of the stream leakage from the Jimmawurrada Creek predicted to flow to the south, toward the CWS rather than downstream towards the Robe River. This assumption provides further conservatism to predictions of groundwater drawdown at tracking points along the Robe River.

Table 5.5: Average Predicted Inflows and Outflows over Life of Mine: Base Case Predictions

Flow Component	**Inflow (ML/yr) – Case 1** **Inflow (ML/yr) – Case 2**	**Outflow (ML/yr) – Case 1** **Outflow (ML/yr) – Case 2**
Storage	3,930 **5,020**	3,770 **2,890**
Borefield Pumping	-	1,905 **4,485**
Dewatering	-	3,920 **3,730**
Rainfall Recharge	590 **590**	-
Discharge to Dan's Dam	1,300	-

Flow Component	Inflow (ML/yr) – Case 1 Inflow (ML/yr) – Case 2	Outflow (ML/yr) – Case 1 Outflow (ML/yr) – Case 2
	1,300	
Evapotranspiration	- 	2,130 1,990
Groundwater Inflow / Outflow	830 945	850 780
Stream Leakage	7,545 7,645	1,620 1,625
Total	**14,195** 15,500	**14,195** 15,500

6. CLOSURE MODELLING

6.1 Setup

Once mining is complete and dewatering and water supply pumping ceases, groundwater levels at Mesa J and Mesa H and the water supply borefield area will recover until a balance is reached between groundwater inflows and groundwater outflows. As all pit voids are planned to be infilled with waste / tailings to above the pre-mining water table, groundwater levels will eventually recover to pre-development levels. The Case 1 and Case 2 dewatering models were used to predict the groundwater response, once mining is complete.

To assess the potential impact of key parameters adopted for the closure runs (namely rainfall recharge and stream flows) two closure scenarios were simulated, as outlined below:

Closure Scenario 1 – Variable Recharge Case

- Initial conditions from the end of Case 1 and 2 dewatering and water supply predictions (December 2037).
- Case 1 and 2 models were run for a period of 190 years (January 2038 to December 2137).
- The model predictions were run using annual time increments (stress periods).
- Infilling of all mine voids was completed prior to any groundwater recovery. Some of this infilling is assumed to have occurred as mining was completed at pits at Mesa J (in 2029) and at some pits at Mesa H before 2037.
- The hydraulic conductivity of the infill material will be the same as the material of the original formations excavated during mining.
- The mined out voids will be infilled to a level above the pre-development groundwater table and the final land form will be designed such that there will be no increase or decrease in recharge to the infilled mine voids.
- The ET setup is identical to that used for the predictions. No ET was included for the infilled pits.
- Recharge rates, as a percentage of annual rainfall, and stream flows are identical to those used for the model predictions. Annual rainfall and stream flow data from the prediction period is repeated to simulate variable annual recharge and flows for the closure predictions.
- The predictions do not include any further pumping, dewatering or discharge from any other area in the modelled catchment or impacts associated with the CWS.

- All other model parameters were set consistent with the steady state model.

Closure Scenario 2 – Steady State Recharge Case

The same conditions as Closure Scenario 1, except for the following:

- Average annual rainfall and stream flow conditions were included in the closure model.

6.2 Results

The predicted recovery of groundwater levels at tracking points along the Robe River and for the mined out and infilled areas of Mesa J and Mesa H are shown in Figures C1 to C8 (Case 1) and Figures C9 to C16 (Case 2) (in pit observation locations and tracking point locations are shown in Figure 18). The approach for calculating drawdown at tracking points is the same as that adopted for the Case 1 and 2 dewatering and water supply predictions (outlined in Section 5.3). No Development models were also run for the closure period (January 2038 to December 2137), assuming undisturbed aquifer conditions from 2038 onwards, and the same recharge and stream flow conditions as Closure Scenarios 1 and 2.

Predicted groundwater recovery at tracking points along the Robe River for Cases 1 and 2 are shown in Figures C1 to C3 and C9 to C11 for both variable and steady state recharge and stream flow. For all predictions, groundwater levels are predicted to have recovered within 50 to 60 years after the end of mining and water supply pumping. As would be expected, for the steady state recharge cases, the predicted groundwater recovery does not show annual variations in predicted water levels. Annual variations in recharge and streamflow are predicted to result in a similar overall groundwater recovery trend, with some increases in drawdown before complete recovery is achieved. Despite these early increases in predicted drawdown, the same equilibrium and recovered water levels are predicted at all locations for both recharge cases.

Predicted groundwater recovery at TP7 located along the Jimmawurrada Creek, near the proposed water supply borefield, is presented in Figures C3 and C11. Water levels at TP7 are predicted to have recovered after 20 years or 30 to 40 years earlier than water levels at other tracking points in the catchment. The location of TP7, closer to the Bungaroo Valley (southern inflow boundary) and the water supply borefield area is associated with a much more rapid predicted recovery of water levels compared to the rest of the modelled catchment. Groundwater recovery for Case 1 is also predicted ten years earlier than Case 2 due to the reduced water supply pumping requirement of Case 1.

Predicted groundwater recovery at Mesa J and Mesa H is shown in Figures C4 to C8 and C12 to C16 (locations across Mesa J and Mesa H are shown in Figure 18). The rate of groundwater recovery across the mining areas is related to re-establishment of natural, pre-mining, throughflow across the model domain which

is largely controlled by inflow from the Bungaroo Valley and inflows from the Robe River and the Jimmawurrada Creek. During closure predictions, water supply pumping associated with the CWS in the Bungaroo Valley was assumed to be complete resulting in pre-development groundwater conditions and inflows at the southern model boundary associated with the Bungaroo Valley. During closure predictions, the model predicts resumption of groundwater inflow from the south-east (Bungaroo Valley) to the north/north-west with subsequent recovery of water levels in the borefield area. Areas of maximum drawdown are then predicted further to the north as shown in Mesa J - Pit 15 (Figure C8). Further drawdown propagation to the north (north of the Mesa J mine towards the Robe River) is limited by the low permeability basement outcrops north of the Mesa J mine.

Across the Mesa J and Mesa H mine areas, groundwater levels are predicted to recover to predevelopment levels. The results suggest that groundwater recovery to predevelopment levels is predicted to occur within 50 to 60 years after closure.

7. UNCERTAINTY ANALYSES

7.1 Prediction Uncertainty Approach

While a reasonable calibration to steady state and time-varying conditions has been achieved for the groundwater flow model, there remains inherent uncertainty in the parameters and model setup adopted to describe the hydrogeological system with consequent risks in the prediction of dewatering impacts, owing to the absence of historical monitoring data for calibration.

To assess the potential impact of these uncertainties, Uncertainty Predictions have been conducted on both of the Base Case prediction models (Case 1 and Case 2 models). Details of the Uncertainty Runs, are outlined in Table 7.1.

Table 7.1: Summary of Uncertainty Runs

Run	Description	Type of Uncertainty
1	Natural inflows to the Robe River and Jimmawurrada Creek not simulated (set to zero)	Stress
2	Natural inflows to the Robe River and Jimmawurrada Creek reduced by 50%	Climate
3	Natural inflows to the Robe River reduced by 50%. Inflows to the Jimmawurrada Creek not simulated (set to zero)	Climate
4	Natural inflows to the Robe River not simulated. Inflows to the Jimmawurrada Creek reduced by 50%	Climate
5	Steady state rainfall recharge and stream flows. Impact associated with CWS not included.	Stress
6	Rainfall recharge reduced by 50% everywhere	Climate
7	Rainfall recharge reduced by 50% everywhere and discharge to Dan's Dam not simulated (set to zero)	Stress
8	General head inflow boundary associated with Robe River not simulated (removed from the model)	Conceptual
9	Rainfall recharge increased by 50% everywhere. Robe River and Jimmawurrada flows increased by 50%.	Climate
10	Unconfined storage (Sy) of the Robe River alluvium increased by 10% (from 30 to 40%)	Conceptual
11	Hydraulic conductivity of the outcropping Brockman Formation increased to 5 m/d	Conceptual
12	Outflow from the Wittenoom Formation included (General Head Boundary included across the northern model boundary at 115 mAHD)	Conceptual
13	No dewatering from Mesa H and J. All water demand supplied from proposed borefield	Stress

Normally, uncertainty analysis is limited to varying input parameters within reasonable limits which are not necessarily supported by the model calibration. However, as part of this investigation the uncertainty analysis also included combinations of parameters to assess what conditions might be required to produce dewatering impacts that would trigger mitigation measures to maintain surface water pools along the Robe River.

The uncertainty runs are grouped into three categories:

- **Conceptual Model Uncertainties**: These runs were designed to investigate the impact that hydrogeological changes, that are not supported

by the current conceptualisation or the model calibration, may have on predicted drawdown impacts on surface water pools along the Robe River. These include Runs 8, 10, 11 and 12.

- **Climatic Uncertainties**: These runs were designed to assess what hydrological conditions might be required to produce worst case drawdown impacts on surface water pools along the Robe River. These include Runs 2, 3, 4, 6 and 9.

- **Extreme /Stress Uncertainties**: These runs included extreme changes in the model set or operating conditions to assess the drawdown impact on surface water pools along the Robe River. These included Runs 1, 5, 7 and 13.

For some of the Uncertainty Runs, the steady state and transient model calibrations and the No Development Cases were also re-run with the corresponding changes. None of the steady state or transient models were recalibrated, nor were Uncertainty Run dewatering and water supply predictions re-optimised as part of the current study.

7.2 Results

Predicted drawdown at tracking points for the Base Case Runs (Cases 1 and 2) and Uncertainty Runs 1 to 13 are grouped by Conceptual, Climatic and Extreme / Stress Uncertainty as outlined in Table 7.1 (Case 1, Figures D1 to D9 and Case 2, Figures D10 to D18). Drawdown is calculated by subtracting predicted water levels at each tracking point for the No Development Case (as outlined in Section 5.3) from the corresponding Uncertainty Run. The maximum predicted drawdowns at each tracking point for all Uncertainty Runs are summarised in Table 7.2 (Case 1) and 7.3 (Case 2).

The ranking of the impact of uncertainty on predicted drawdown impacts has been assessed by comparing the sum of the maximum predicted drawdowns at all tracking points for each Uncertainty Run, excluding TP7. The maximum drawdown at TP7, located near the water supply borefield is much larger than the other tracking point maximum predicted drawdowns throughout the catchment. As a result, its inclusion skews the ranking system. Total predicted drawdowns for all Uncertainty Runs (and Base Cases), excluding TP7, are summarised in Table 7.4 and ranked in order from greatest to least impact on total predicted drawdown. Predicted drawdown at TP7 is discussed separately in the sections below.

Table 7.2: Uncertainty Runs - Summary of Maximum Predicted Drawdown (m) – Case 1

Run	TP2	TP11	TP12	TP13	TP14	TP22	TP23	TP24	TP25	TP26	TP7
BC*	0.26	0.14	0.15	0.36	0.44	0.07	0.28	0.06	0.68	0.32	8.81
1	1.01	1.68	1.95	2.08	1.59	0.98	1.58	0.65	2.18	1.82	18.46
2	0.31	0.28	0.39	0.40	0.50	0.12	0.35	0.17	0.75	0.37	11.02
3	0.37	0.28	0.39	0.41	0.50	0.13	0.36	0.19	0.76	0.38	18.46
4	0.83	1.27	1.56	1.77	1.32	0.48	0.96	0.35	1.32	1.13	11.02
5	0.02	0.08	0.03	0.01	0.01	0.01	0.01	0.06	0.43	0.28	5.16
6	0.27	0.23	0.26	0.46	0.54	0.20	0.53	0.08	0.80	0.39	8.88
7	0.27	0.23	0.27	0.46	0.54	0.20	0.53	0.08	0.81	0.39	9.41
8	3.17	0.24	0.31	1.14	1.84	0.08	0.29	0.06	0.70	0.33	8.81
9	0.24	0.16	0.18	0.42	0.40	0.01	0.05	0.06	0.55	0.29	8.35
10	0.26	0.12	0.12	0.31	0.37	0.05	0.21	0.06	0.60	0.30	8.81
11	0.26	0.14	0.14	0.35	0.44	0.05	0.18	0.14	0.60	0.29	8.80
12	0.26	0.23	0.19	0.36	0.45	0.15	0.21	0.47	1.18	0.55	8.81
13	0.24	0.11	0.12	0.30	0.36	0.01	0.01	0.02	0.31	0.20	12.57

*BC – Base Case,

Table 7.3: Uncertainty Runs - Summary of Maximum Predicted Drawdown (m) – Case 2

Run	TP2	TP11	TP12	TP13	TP14	TP22	TP23	TP24	TP25	TP26	TP7
BC*	0.26	0.14	0.15	0.36	0.45	0.07	0.28	0.06	0.68	0.32	17.42
1	1.02	1.69	1.95	2.09	1.60	0.98	1.58	0.65	2.18	1.82	34.70
2	0.31	0.28	0.39	0.40	0.50	0.12	0.35	0.17	0.75	0.37	20.65
3	0.38	0.28	0.39	0.43	0.50	0.13	0.36	0.19	0.76	0.38	34.69
4	0.83	1.27	1.56	1.77	1.32	0.48	0.96	0.35	1.33	1.13	20.65
5	0.24	0.08	0.03	0.03	0.07	0.01	0.01	0.06	0.43	0.28	5.40
6	0.27	0.23	0.27	0.46	0.54	0.20	0.53	0.08	0.81	0.39	17.58
7	0.27	0.23	0.27	0.46	0.55	0.20	0.53	0.08	0.81	0.39	19.04
8	3.18	0.23	0.30	1.14	1.84	0.08	0.29	0.06	0.70	0.33	17.42
9	0.25	0.16	0.18	0.43	0.42	0.01	0.05	0.06	0.55	0.29	15.43
10	0.26	0.12	0.12	0.31	0.37	0.05	0.21	0.06	0.60	0.30	17.42
11	0.26	0.14	0.14	0.35	0.44	0.05	0.18	0.14	0.60	0.29	17.42
12	0.26	0.23	0.19	0.36	0.45	0.15	0.21	0.47	1.18	0.55	17.42
13	0.24	0.11	0.12	0.29	0.36	0.01	0.01	0.02	0.31	0.20	29.34

*BC – Base Case,

Uncertainty Runs 1 (no stream flows), 4 (inflows to the Robe River not simulated and inflows to the Jimmawurrada Creek reduced by 50%) and 8 (Robe River inflow boundary not simulated) are predicted to result in the greatest increase in predicted drawdown across the modelled catchment (ranked 1st, 2nd and 3rd for both Case 1 and 2 Base Cases). The total drawdown at tracking points for these three Uncertainty Runs is at least double the total drawdown predicted for the

other Uncertainty Runs (and the Base Cases). The next greatest impact on drawdown is predicted by Uncertainty Run 12 (outflow to the Wittenoom Formation included), however it is less than half of the total drawdown predicted for Uncertainty Runs ranked 1st to 3rd.

Overall however, Uncertainty Runs 1, 2, 3, 4, 6, 7, 8 and 12 predict more drawdown at tracking points compared to the Case 1 and 2 Base Cases. Very small differences in total maximum predicted drawdown are predicted for Uncertainty Runs ranked from 5th to 8th with the same maximum total drawdown predicted for the 8th ranked Uncertainty Run for Case 1 and 2 (Run 2, natural inflows to the Robe River and Jimmawurrada Creek reduced by 50%). There are some minor differences in the rankings for Cases 1 and 2 (Uncertainty Runs 3 and 7 are ranked differently for Cases 1 and 2).

Uncertainty Runs 5, 9, 10, 11 and 13 all predict less combined drawdown at tracking points than the Case 1 and 2 Bases Cases. For these runs, the ranking of impact on drawdown is the same for Case 1 and 2 Base Cases apart from slightly different rankings for Uncertainty Runs 9 and 10. As would be expected, Uncertainty Runs 5 and 13 predict less drawdown at tracking points along the Robe River due to the inclusion of constant recharge and stream flow and moving all pumping to the water supply borefield.

Considering the predicted drawdown at TP7, Uncertainty Runs 1 and 3 (Run 1, natural inflows to the Robe River and Jimmawurrada Creek set to zero and Run 3, natural inflows to the Robe River reduced by 50% and inflows to the Jimmawurrada Creek set to zero), are predicted to result in the greatest increase in predicted drawdown at TP7 as it is located along the Jimmawurrada Creek. At other tracking points, Uncertainty Run 3 is not predicted to have a significant impact on predicted drawdown as the simulated inflow from the Robe River boundary is still sufficient to mitigate predicted drawdown along the Robe River. As would be expected, simulating all water demand drawn from the borefield (Uncertainty Run 13) predicted the next greatest impact on predicted drawdown at TP7 (Figures D9 and D16) as TP7 is closest to the water supply borefield. As would be expected, this Uncertainty Run reduced the predicted drawdown at all other tracking points.

Table 7.4 Ranking of Uncertainty Runs

Ranking	Case 1 Uncertainty Runs	Total Maximum Drawdown (m) (without TP7)	Case 2 Uncertainty Runs	Total Maximum Drawdown (m) (without TP7)
1	1 Natural inflows to the Robe River and Jimmawurrada Creek set to zero	**15.52**	1 Natural inflows to the Robe River and Jimmawurrada Creek not set to zero	**15.56**
2	4 Natural inflows to the Robe River not simulated. Inflows to the Jimmawurrada Creek reduced by 50%	**10.99**	4 Natural inflows to the Robe River not simulated. Inflows to the Jimmawurrada Creek reduced by 50%	**11.00**
3	8 General head inflow boundary associated with Robe River not simulated (removed from the model)	**8.16**	8 General head inflow boundary associated with Robe River not simulated (removed from the model)	**8.15**
4	12 Outflow from the Wittenoom Formation included (General Head Boundary included across the northern model boundary at 115 mAHD)	**4.05**	12 Outflow from the Wittenoom Formation included (General Head Boundary included across the northern model boundary at 115 mAHD)	**4.05**
5	7 Rainfall recharge reduced by 50% everywhere and discharge to Dan's Dam not simulated (set to zero)	**3.78**	3 Natural inflows to the Robe River reduced by 50%. Inflows to the Jimmawurrada Creek not simulated (set to zero)	**3.80**
6	3 Natural inflows to the Robe River reduced by 50%. Inflows to the Jimmawurrada Creek not simulated (set to zero)	**3.77**	7 Rainfall recharge reduced by 50% everywhere and discharge to Dan's Dam not simulated (set to zero)	**3.79**
7	6 Rainfall recharge reduced by 50% everywhere	**3.76**	6 Rainfall recharge reduced by 50% everywhere	**3.78**
8	2 Natural inflows to the Robe River and Jimmawurrada Creek reduced by 50%	**3.64**	2 Natural inflows to the Robe River and Jimmawurrada Creek reduced by 50%	**3.64**
-	Base Case	**2.76**	Base Case	**2.77**
9	11 Hydraulic conductivity of the outcropping Brockman Formation increased to 5 m/d	**2.59**	11 Hydraulic conductivity of the outcropping Brockman Formation increased to 5 m/d	**2.59**

10	10 Unconfined storage (Sy) of the Robe River alluvium increased by 10% (from 30 to 40%)	**2.40**	9 Rainfall recharge increased by 50%. Robe River and Jimmawurrada flows increased by 50%.	**2.40**
11	9 Rainfall recharge increased by 50%. Robe River and Jimmawurrada flows increased by 50%.	**2.36**	10 Unconfined storage (Sy) of the Robe River alluvium increased by 10% (from 30 to 40%)	**2.40**
12	13 No dewatering from Mesa H and J. All water demand supplied from proposed borefield	**1.68**	13 No dewatering from Mesa H and J. All water demand supplied from proposed borefield	**1.66**
13	5 Steady state rainfall recharge and stream flows. Impact associated with CWS not included.	**0.94**	5 Steady state rainfall recharge and stream flows. Impact associated with CWS not included.	**1.24**

8. MODEL CONFIDENCE LEVEL CLASSIFICATION

The classification of the current model is based on "Australian groundwater modelling guidelines – Waterlines Report Series No. 82 June 2012". It is derived from a semi-quantitative assessment of the available data on which the model is based (for both conceptualisation and calibration), the manner in which the model is calibrated and how the predictions are formulated.

The current model is considered to provide a Class 2 confidence level according to the proposed model classification due to lack of long-term monitoring data along the Robe River which was the key focus of this modelling study.

Factors that restrict the current model to Class 2 confidence level are:

- Data: Groundwater levels were available throughout the model domain, but they do not provide adequate coverage along the Robe River.
- Calibration: As a result of lack of data along the Robe River, long-term trends were not available in all parts of model domain.

The current model is considered to meet some of the requirements of a Class 3 confidence level in terms of model predictions and key indicators, as follows:

- Predictions
  - The length of dewatering, water supply and closure prediction models is not excessive compared to the length of the calibration period.
  - Temporal discretisation used in the predictive model is consistent with the transient calibration.
  - The level and type of stresses included in the predictive model are within the range of those used in the transient calibration.
- Key Indicators
  - The model dewatering prediction time frame is less than the duration of the transient calibration and the closure prediction time frame (up to 60 years taken for groundwater recovery) is less than three times the length of the calibration (27 years).
  - Stresses are no more than two times greater than those included in calibration.
  - Temporal discretisation in the prediction model is the same as that used in calibration.
  - The mass balance closure error is less than 0.5% of the total.
  - The model parameters are consistent with the conceptualisation.
  - Appropriate computational methods were used along with appropriate spatial discretisation.
  - The model has been reviewed and deemed fit for purpose by an experienced, independent hydrogeologist with modelling experience.

9. SUMMARY

The Mesa H regional groundwater flow model includes the current regional hydrogeological understanding of the Mesa J and Mesa H mining areas. The model has been calibrated to pre-development (steady state) and transient conditions using available data, including:

- Measured groundwater levels across the catchment.
- Ongoing dewatering at the Mesa J mine.
- Long term water supply pumping from the Mesa J bores.
- Long term surface water discharge to Jimmawurrada and West Creek.

There are no long term monitoring data covering periods of significant aquifer stress (i.e. pumping and resulting groundwater level drawdown) available for the Robe River, Jimmawurrada Creek or Mesa H deposits. As such, the calibration data are not sufficient to provide a robust transient calibration in those areas. Therefore, there still remains a degree of uncertainty in the model parameterisation (in particular regional hydraulic connection) and predictive reliability. To account for this, modelling has been completed using a conservative approach with respect to the data limitations and with conservative assumptions made in many instances (namely Robe River flows) where actual data is unavailable. Uncertainty analysis was undertaken to address areas of climatic, conceptual and operational /aquifer stress uncertainty.

The calibrated model was used to predict required dewatering rates, water supply requirements and drawdown impacts for a nominal mine plan for the Mesa H and Mesa J mines, over an 19 year period (January 2019 to December 2037) for two total water demands (up to 5,000 ML/yr for Case 1 and up to 9,000 ML/yr for Case 2).

Average predicted dewatering or sump pumping required to maintain groundwater levels below the projected base of mining over the period January 2020 to December 2037 is ~4,000 ML/yr. Abstraction from the water supply borefield is predicted to be required to supplement the shortfalls in predicted dewatering and maintain projected water demands (for both Case 1 and Case 2 water demands of up to 5,000 and 9,000 ML/yr).

The drawdown from dewatering across the mining areas (assuming the current mine plans) is not predicted to extend a significant distance and create a significant impact on surface water pools along the Robe River to the north, north-east or north-west of the Mesa H and Mesa J mine areas. By 2037 dewatering/drawdown impacts are estimated to be less than 1 m at tracking points along the Robe River.

Results of the Uncertainty Runs suggest that predicted groundwater levels at surface water pools along the Robe River are controlled by the leakage from surface water flows and underflow in its alluvial bed. Model predictions were most sensitive to changes in the amount of inflow or underflow associated with the

Robe River. Results suggest that if the Robe River inflows or underflows are significantly reduced, groundwater levels in surface water pools may be reduced.

The groundwater model was also used to predict the time taken for groundwater recovery (post closure) for Cases 1 and 2 for steady state and historical recharge and streamflow conditions. Prediction results suggest that groundwater levels, within all mine voids (infilled to above the pre-mining water table), would recover to final or equilibrium water levels, similar to pre-development levels, after some 50 to 60 years for both recharge cases.

The current model is considered to provide a Class 2 confidence level according to the Australian Groundwater Modelling Guidelines, due to lack of long-term monitoring data along the Robe River (the key focus of this modelling study). However, the model meets the criteria for Class 3 confidence level in all other aspects.

REFERENCES

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RTIO (2016). Mesa H Hydrogeology Conceptualisation.

RTIO (2016). Robe Valley Mesa H Pre-Feasibility Study – Dewatering, Water Supply and Impact Assessments (RTIO 2016 Numerical Groundwater Model).

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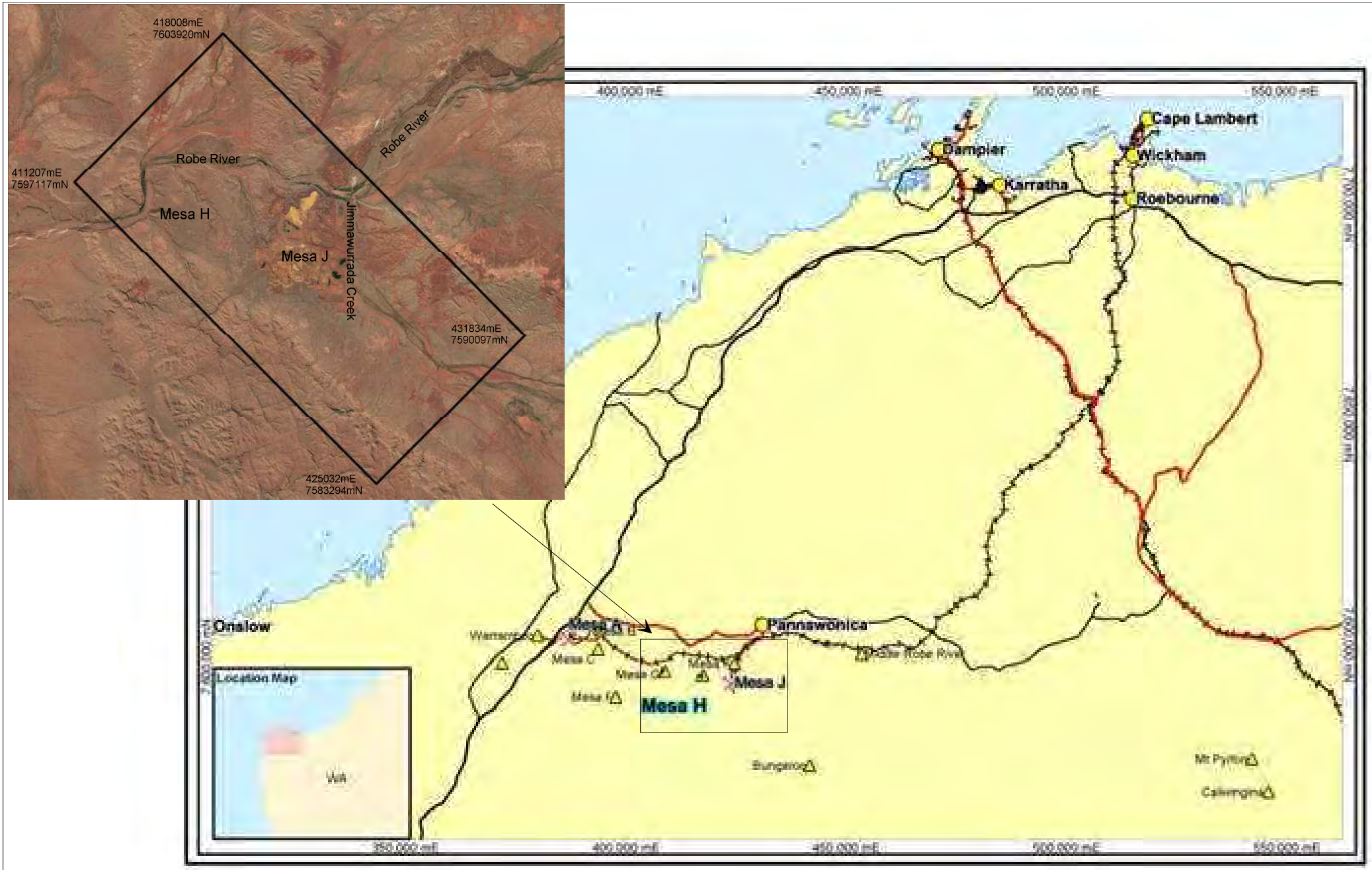
Figure 24: Predicted Drawdown – Tracking Points (Base Case)
Figure 25: Predicted Drawdown – Tracking Points (Base Case)



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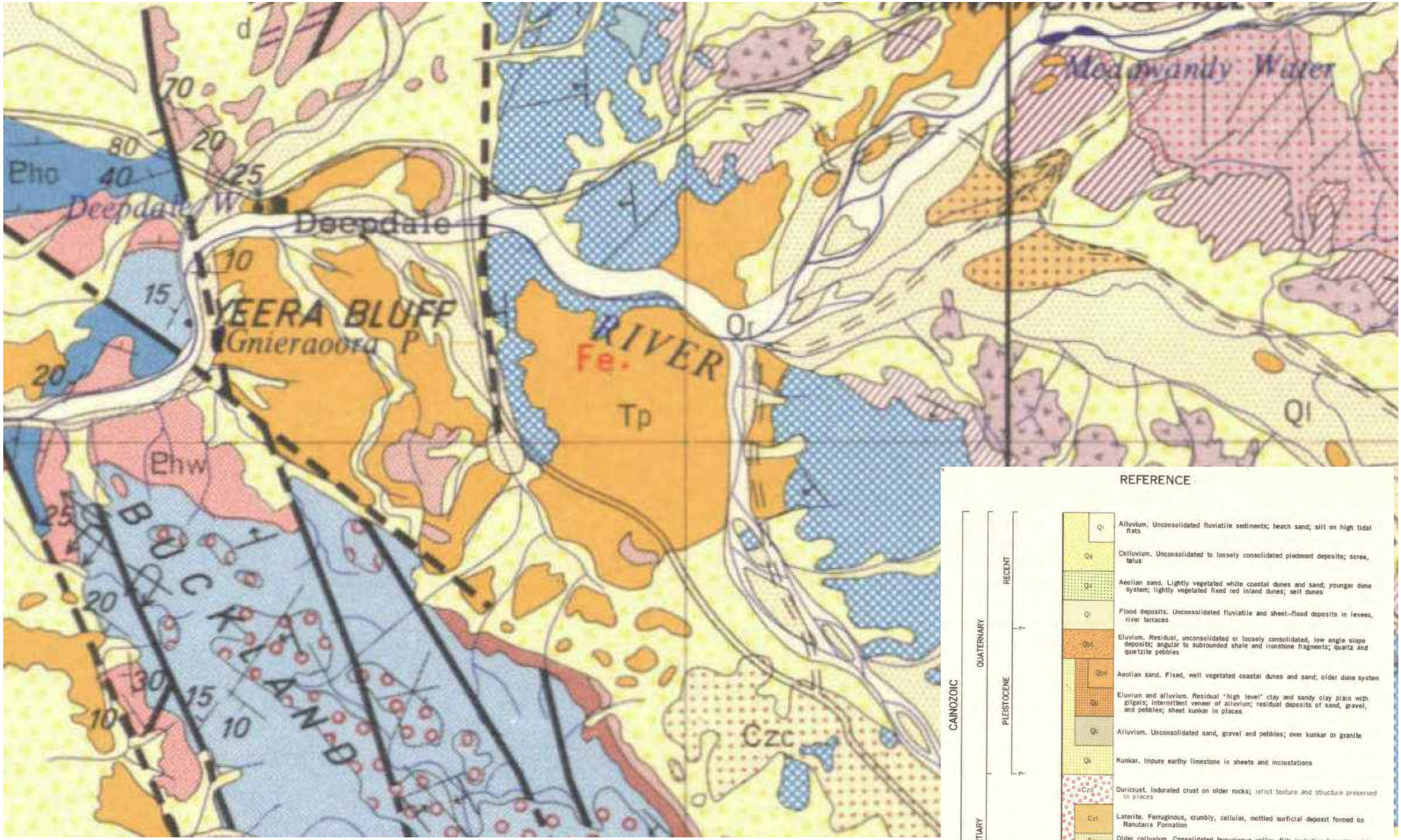
LOCATION MAP FIGURE 1

K:/08_WRE&S/09_Groundwater Modelling/02_Projects/Mesa_H/2018/Groundwater Model/Spatial Data/Surfer/Figure 01.srf



RioTinto

GEOLOGICAL SETTING FIGURE 2

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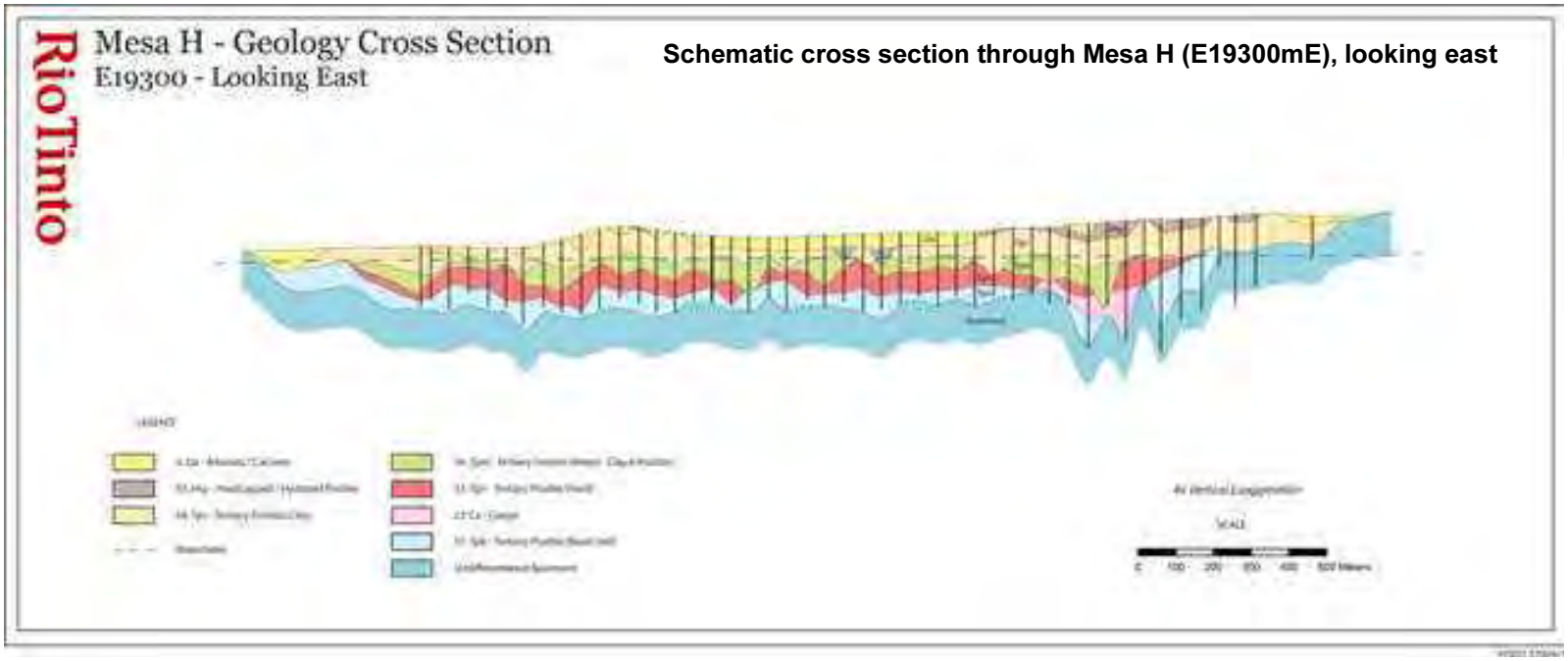

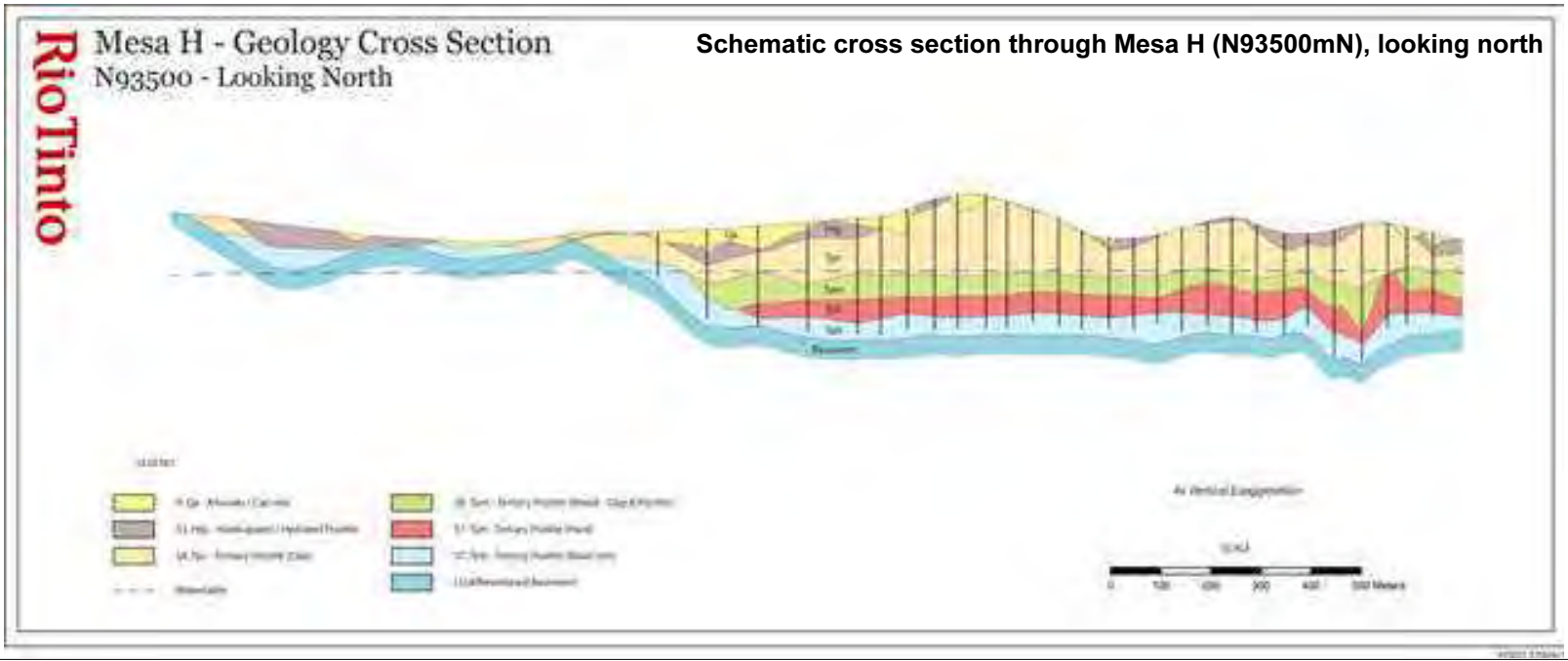

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SCHEMATIC GEOLOGCAL CROSS SECTIONS FIGURE 3

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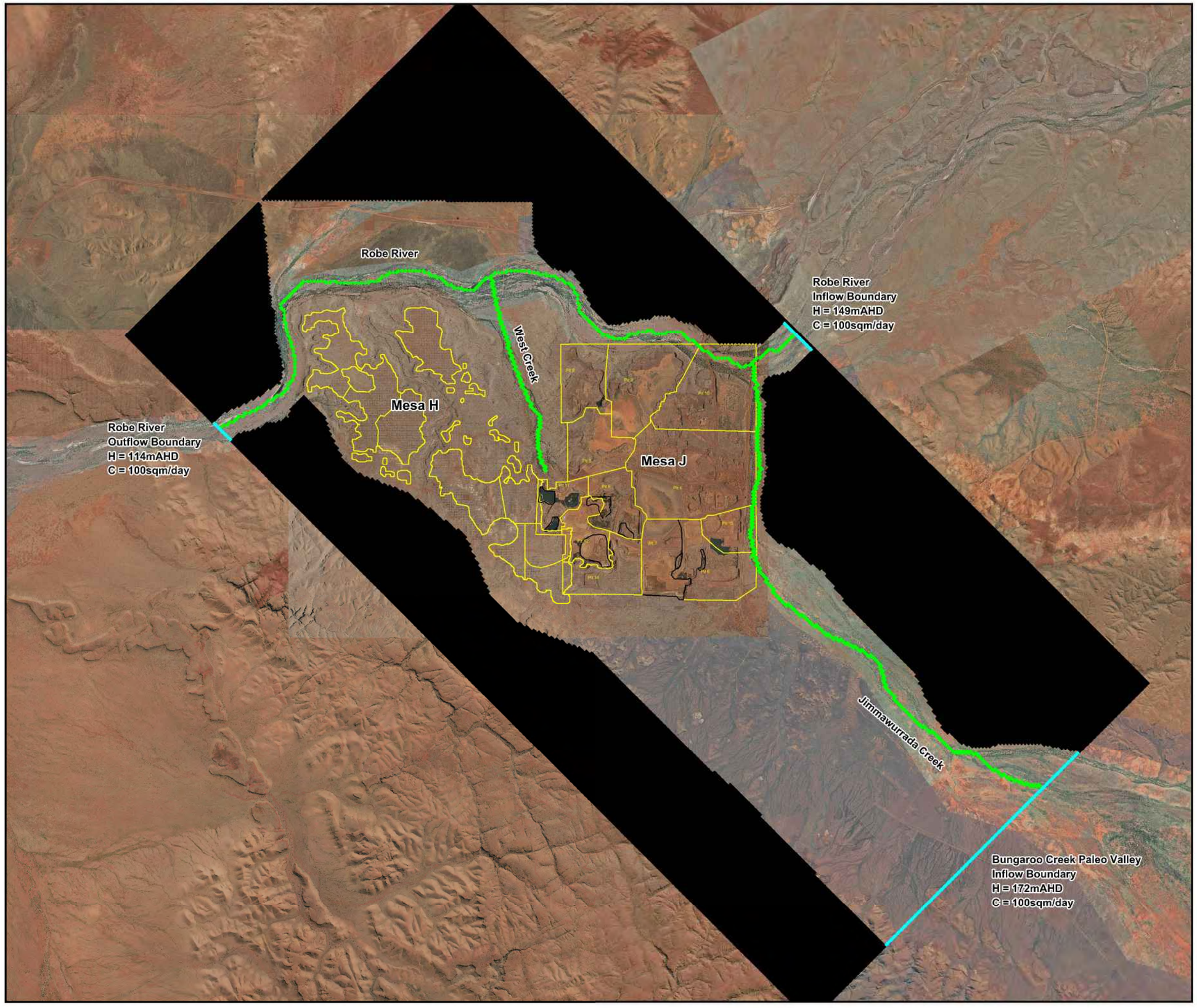


LEGEND

- Modelled General Head Boundary
- Modelled Streams
- Inactive Area (No-Flow Cells)
- Pit Outline

N

SCALE

1:Scale @ A3

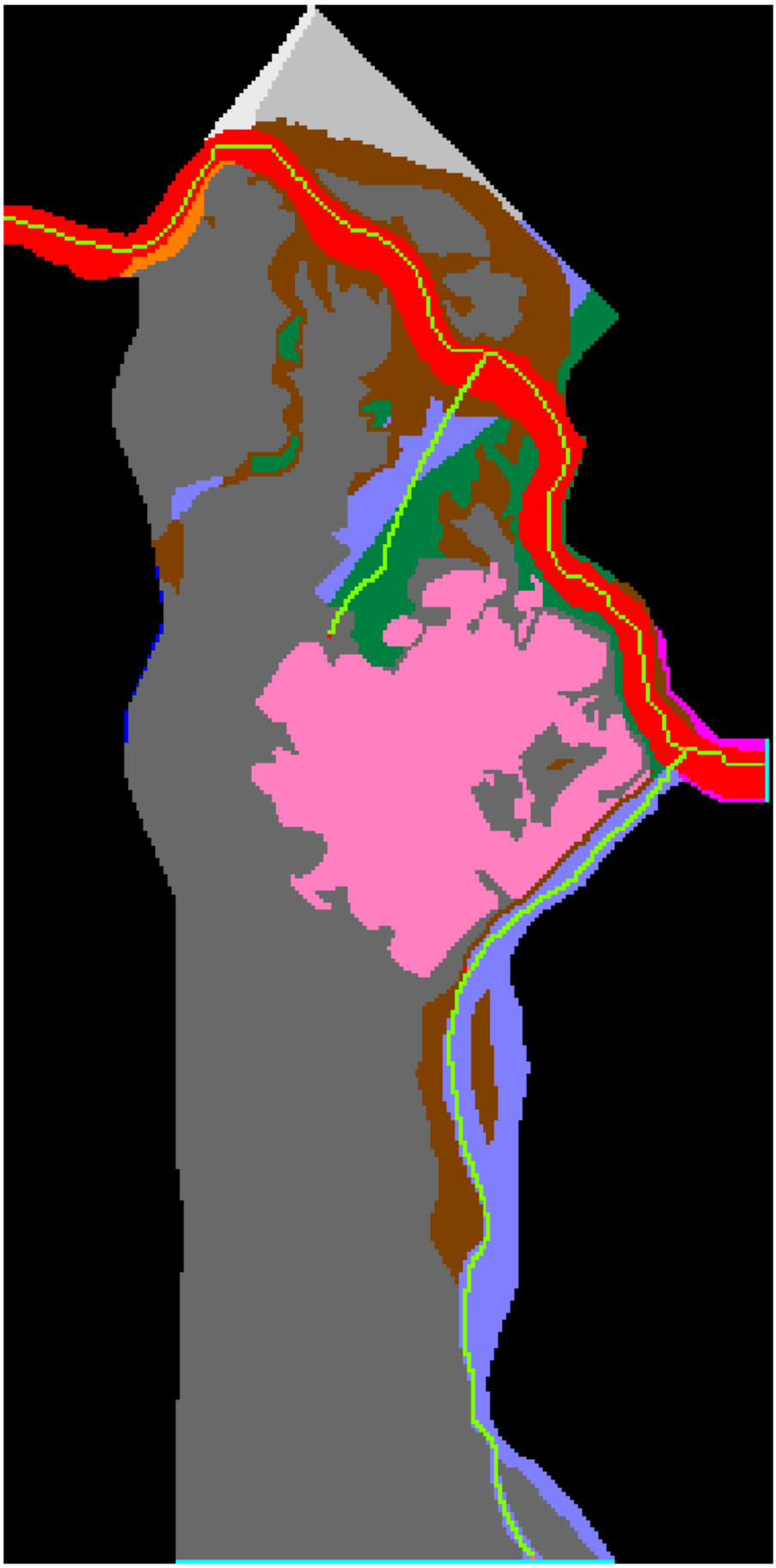
FIGURE 4

MODEL DOMAIN

Drawn: MILOS PAVLOVIC
Date: 9/03/2018

Plan No:
Proj: MESA H GROUNDWATER MODELLING

K:\08_WRE&S\09_Groundwater Modelling\02_Projects\Mesa_H\2018\Groundwater Model\Spatial Data\MapInfo\Workspaces\Figure 4 - Model Domain.WOR



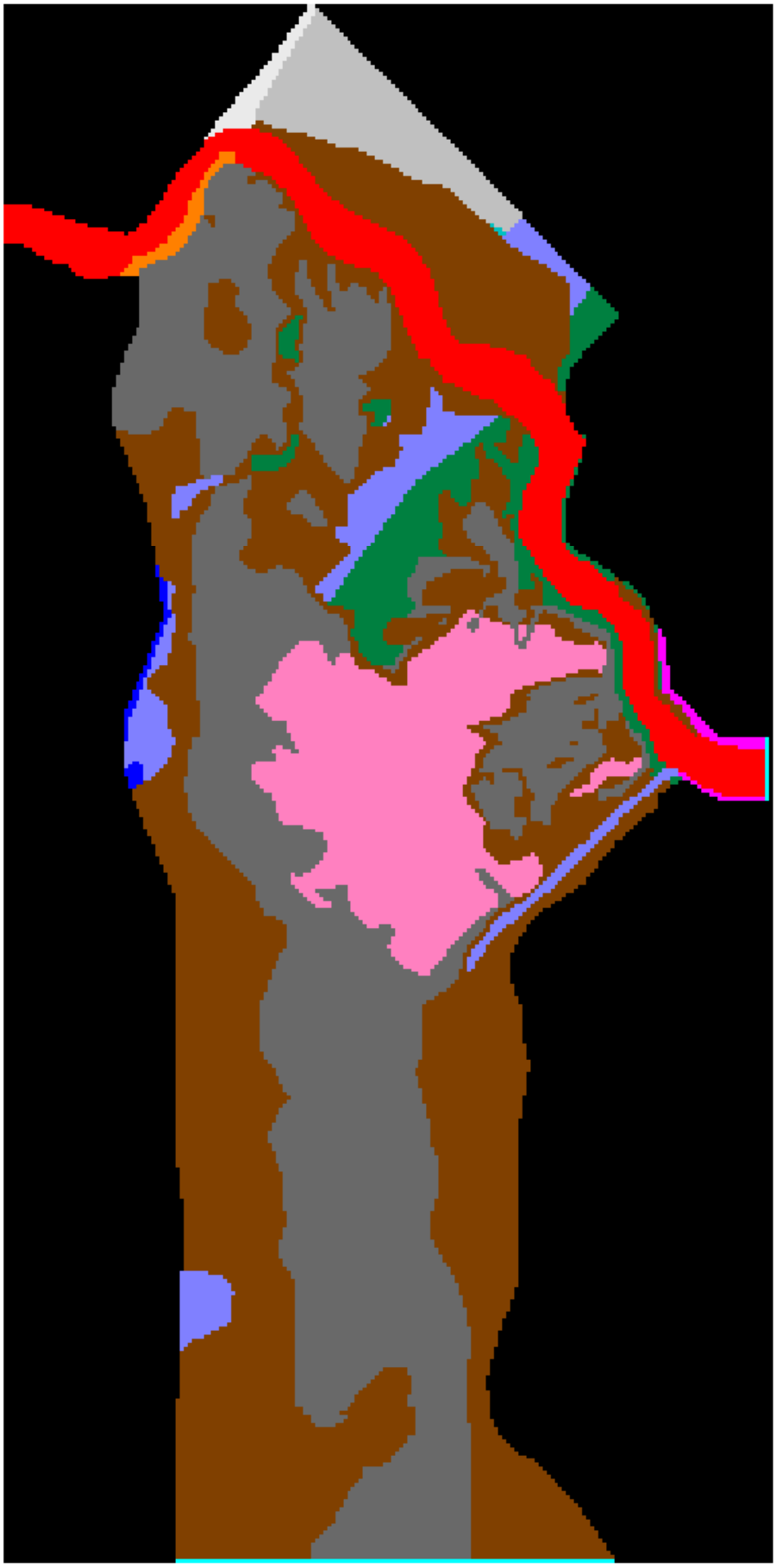
Legend:

- Robe River Alluvium
- Jimmawurrada Creek Alluvium
- Channel Iron Deposit CID
- Channel Iron Deposit CID
- Tertiary Pisolite TPB
- Weathered Boolgeeda Formation
- Weathered Weeli Wooli Formation
- Brockman Formation
- Wittenoom Formation
- Weathered Marra Mamba Formation

RioTinto

HYDRAULIC CONDUCTIVITY DISTRIBUTION (LAYER 1) FIGURE 5

K:/08_WRE&S/09_Groundwater Modelling/02_Projects/Mesa_H/2018/Groundwater Model/Spatial Data/Surfer/Figure 05.srf



Legend:

- Robe River Alluvium
- Jimmawurrada Creek Alluvium
- Channel Iron Deposit CID
- Channel Iron Deposit CID
- Tertiary Pisolite TPB
- Weathered Boolgeeda Formation
- Weathered Weeli Wooli Formation
- Brockman Formation
- Wittenoom Formation
- Weathered Marra Mamba Formation
- Marra Mamba Formation

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HYDRAULIC CONDUCTIVITY DISTRIBUTION (LAYER 2) FIGURE 6

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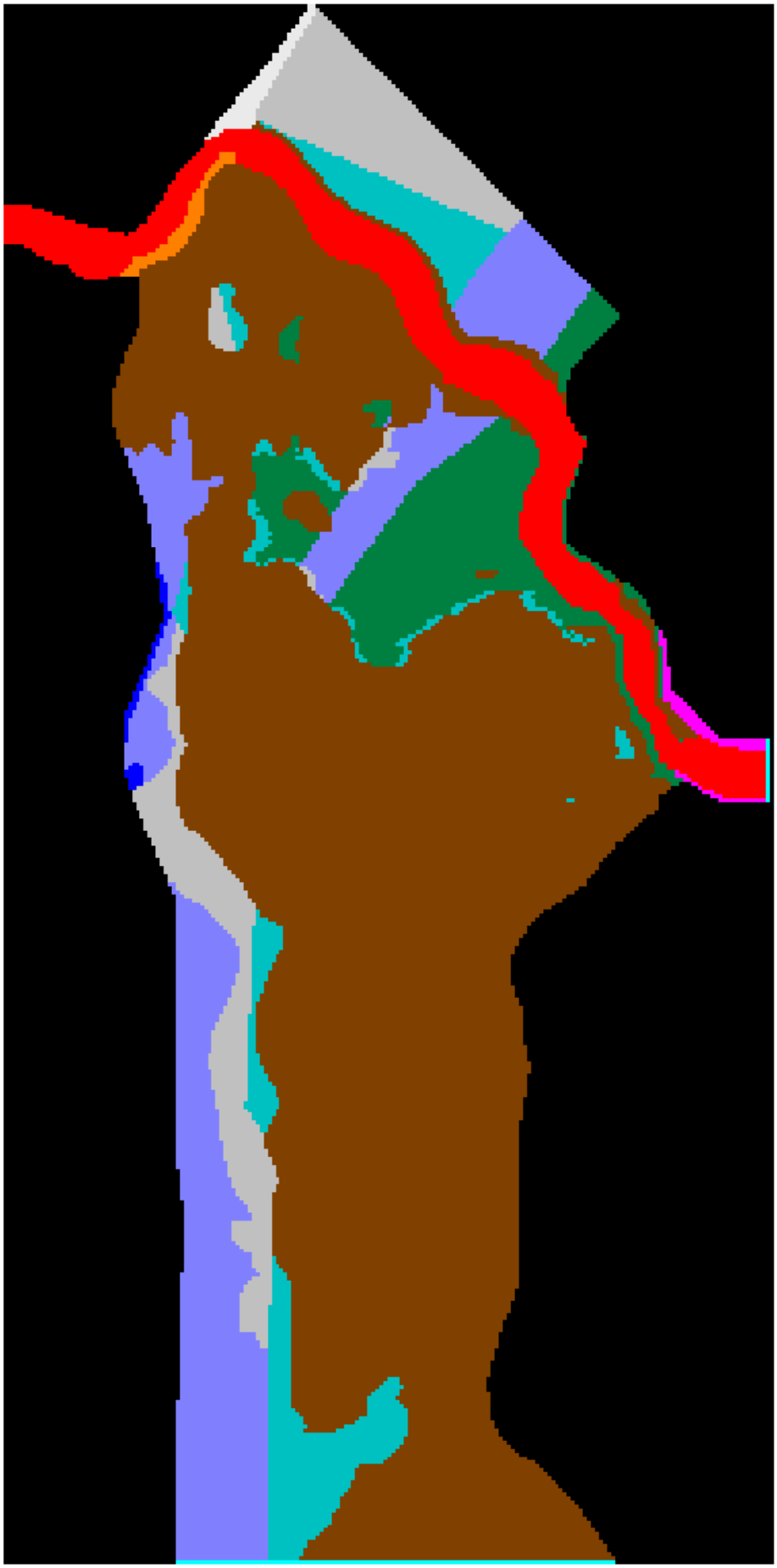

Legend:

- Robe River Alluvium
- Tertiary Pisolite TPB
- Weathered Boolgeeda Formation
- Weathered Weeli Wooli Formation
- Brockman Formation
- Weathered Wittenoom Formation
- Wittenoom Formation
- Weathered Marra Mamba Formation
- Marra Mamba Formation

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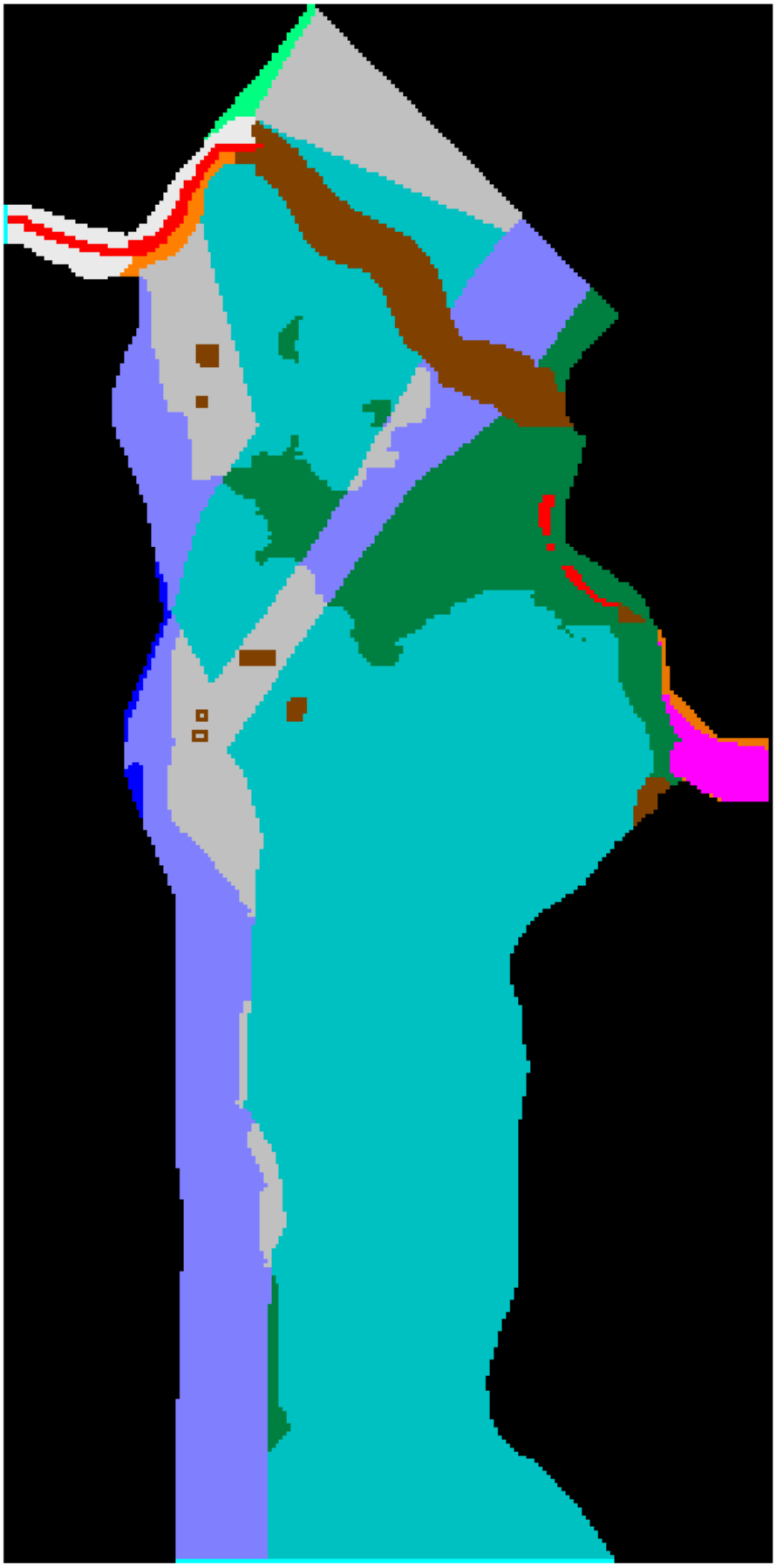
HYDRAULIC CONDUCTIVITY DISTRIBUTION (LAYER 3) FIGURE 7

K:/08_WRE&S/09_Groundwater Modelling/02_Projects/Mesa_H/2018/Groundwater Model/Spatial Data/Surfer/Figure 07.srf



Legend:

- Robe River Alluvium
- Tertiary Pisolite TPB
- Weathered Boolgeeda Formation
- Boolgeeda Formation
- Weathered Weeli Wooli Formation
- Weeli Wooli Formation
- Brockman Formation
- Weathered Wittenoom Formation
- Wittenoom Formation
- Weathered Marra Mamba Formation
- Marra Mamba Formation

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HYDRAULIC CONDUCTIVITY DISTRIBUTION (LAYER 4) FIGURE 8

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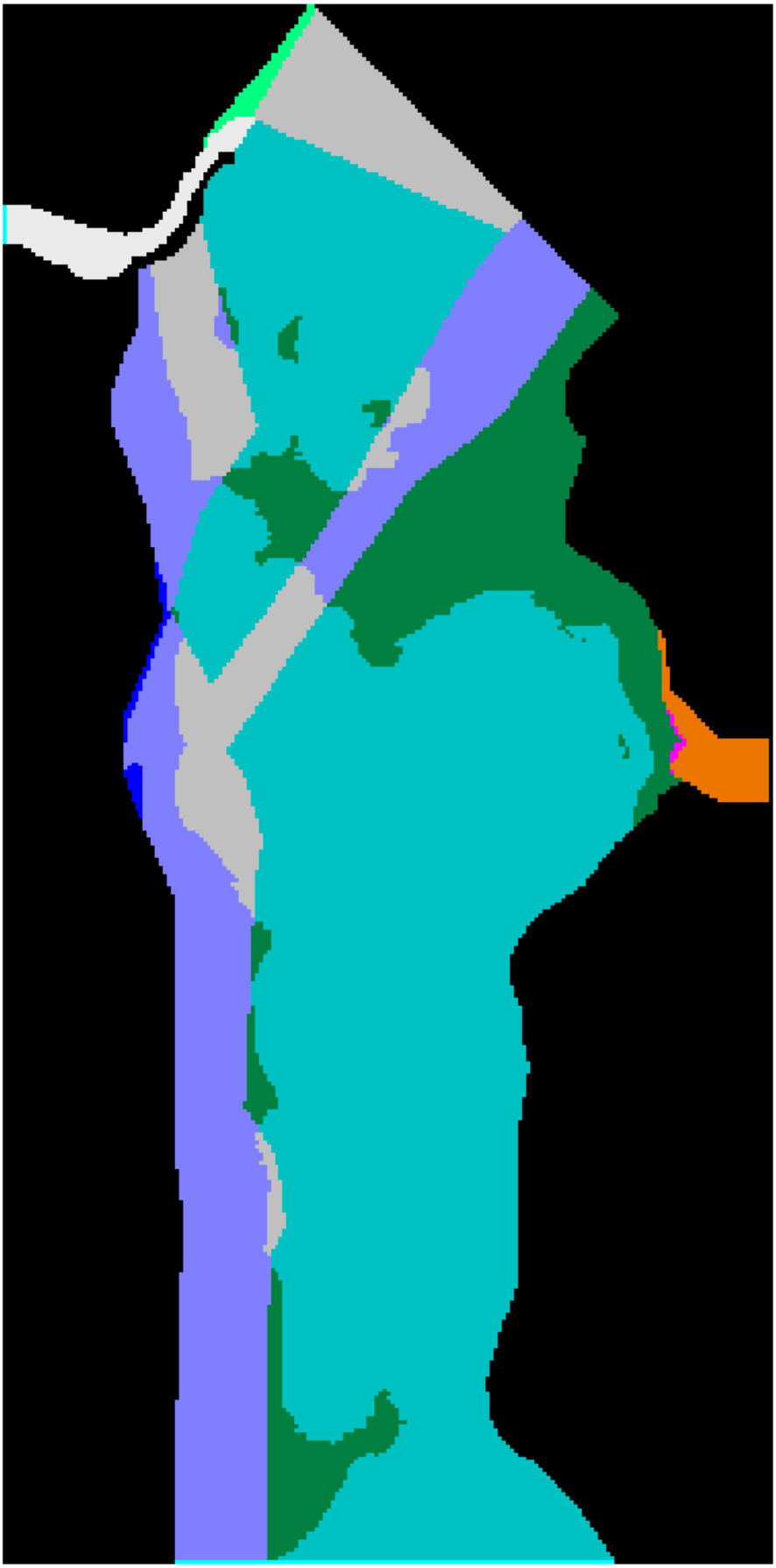

Legend:

- Weathered Boolgeeda Formation
- Boolgeeda Formation
- Weathered Weeli Wooli Formation
- Weeli Wooli Formation
- Brockman Formation
- Brockman Formation
- Weathered Wittenoom Formation
- Wittenoom Formation
- Weathered Marra Mamba Formation
- Marra Mamba Formation

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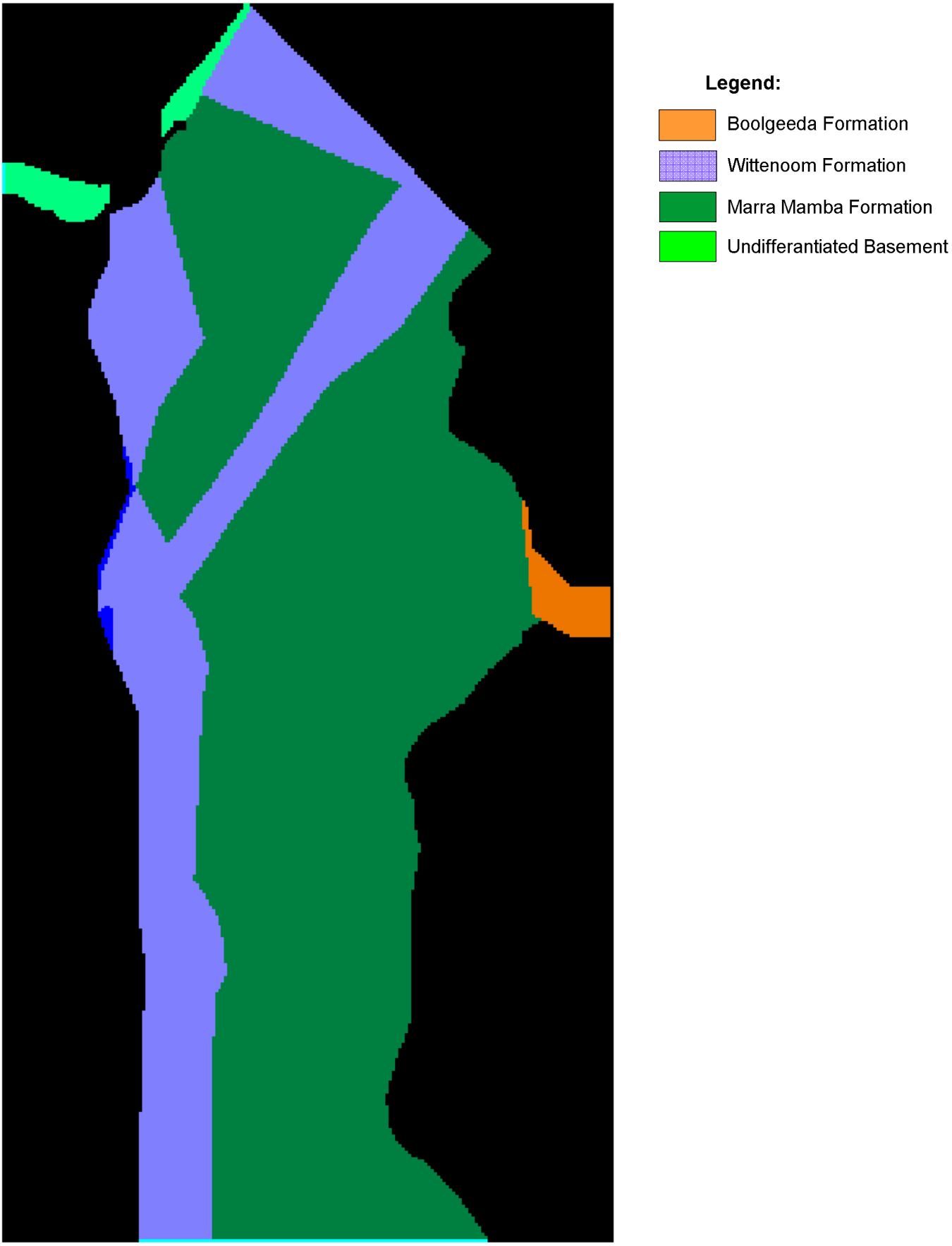
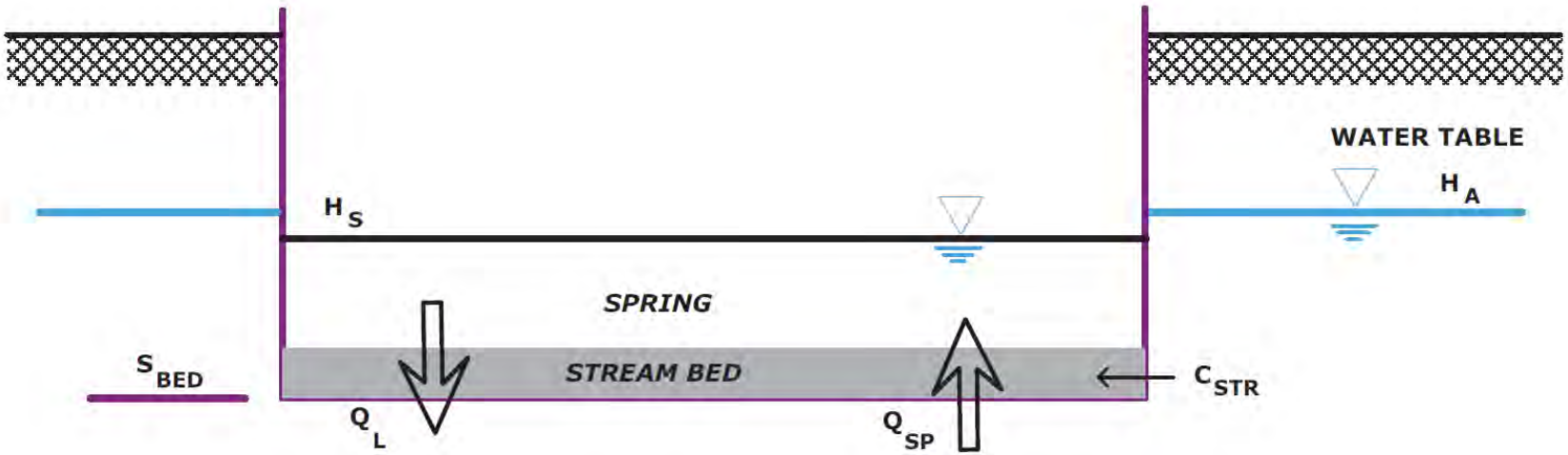
HYDRAULIC CONDUCTIVITY DISTRIBUTION (LAYER 5) FIGURE 9

K:/08_WRE&S/09_Groundwater Modelling/02_Projects/Mesa_H/2018/Groundwater Model/Spatial Data/Surfer/Figure 09.srf



HYDRAULIC CONDUCTIVITY DISTRIBUTION (LAYERS 6 AND 7) FIGURE 10

K:/08_WRE&S/09_Groundwater Modelling/02_Projects/Mesa_H/2018/Groundwater Model/Spatial Data/Surfer/Figure 10.srf



LEGEND

Q_L = STREAM LEAKAGE = C_{STR} $(H_S - S_{BED})$ FOR $H_A < S_{BED}$

Q_{SP} = STREAM LEAKAGE OR SPRING FLOW
= $C_{STR}(H_S - H_A)$ FOR $H_A > S_{BED}$

C_{STR} = STREAM BED CONDUCTANCE (CALIBRATION PARAMETER)

H_A = AQUIFER HEAD

H_S = STREAM WATER LEVELS = $S_{BED} + \left[\frac{Q\,n}{CWS^{0.5}}\right]^{0.6}$

S_{BED} = STREAM BED BOTTOM ELEVATION

Q = Stream Flow (m^3/d)

n = Manning's "n"

C = Constant (86400 $m^{0.33}/d$)

W = Stream Width (m)

S = Stream Slope (m/m)

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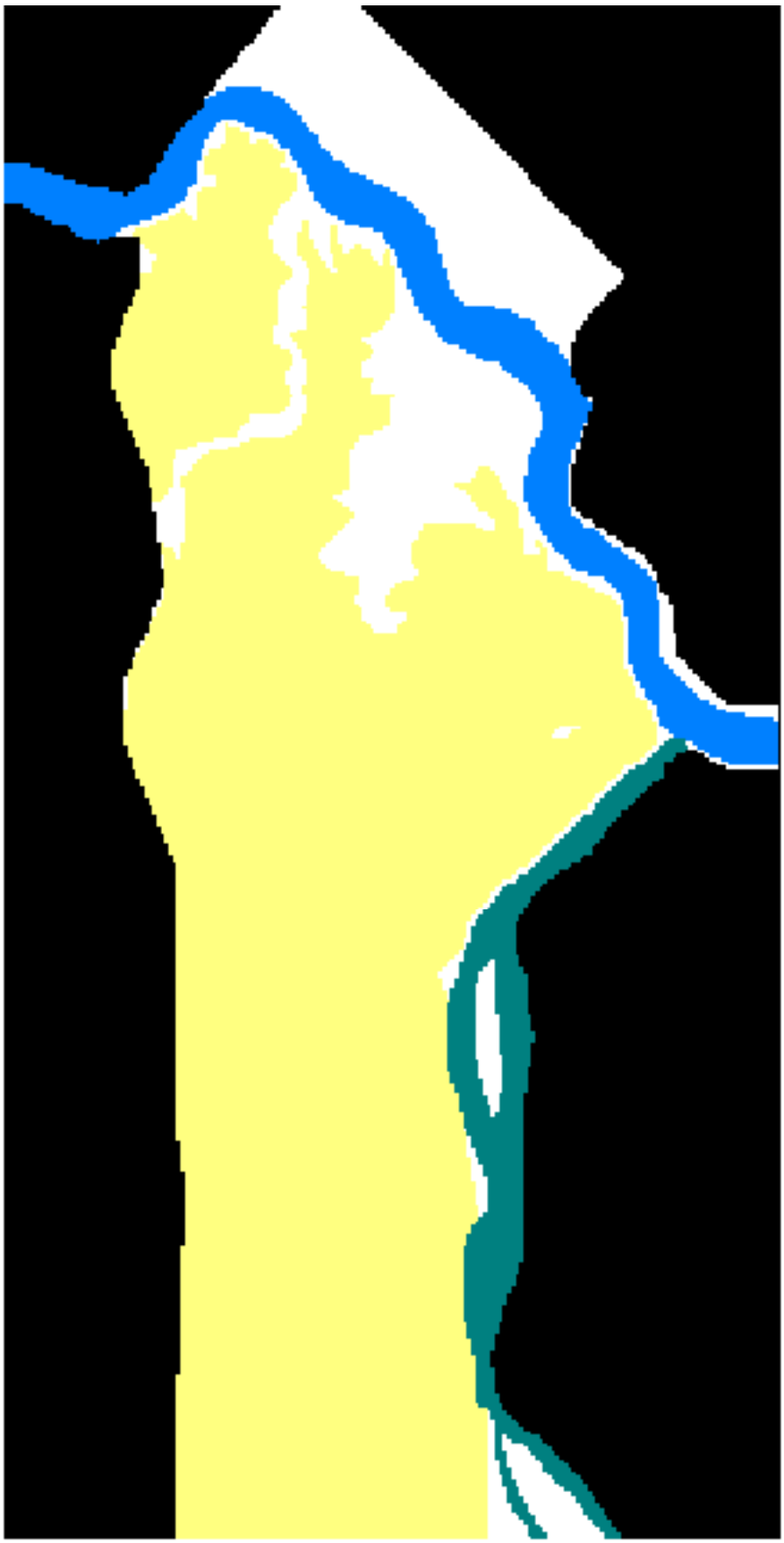
MODFLOW STREAM PACKAGE (SCHEMATIC SECTION) FIGURE 11

K:/08_WRE&S/09_Groundwater Modelling/02_Projects/Mesa_H/2018/Groundwater Model/Spatial Data/Surfer/Figure 11.srf



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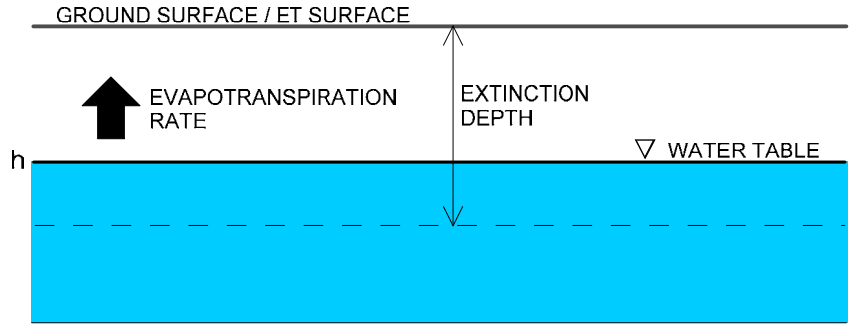
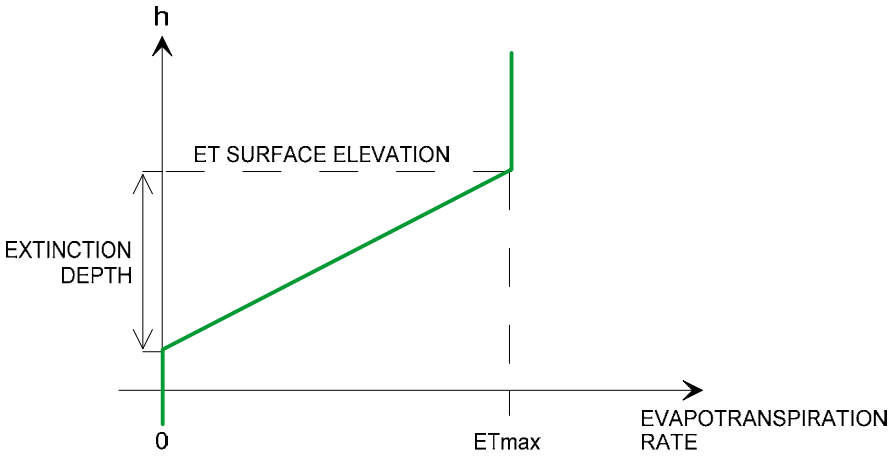
MODELLED RECHARGE DISTRIBUTION FIGURE 12

K:/08_WRE&S/09_Groundwater Modelling/02_Projects/Mesa_H/2018/Groundwater Model/Spatial Data/Surfer/Figure 12.srf



h = Predicted Water Table



SCHEMATIC EVT SETUP FIGURE 13

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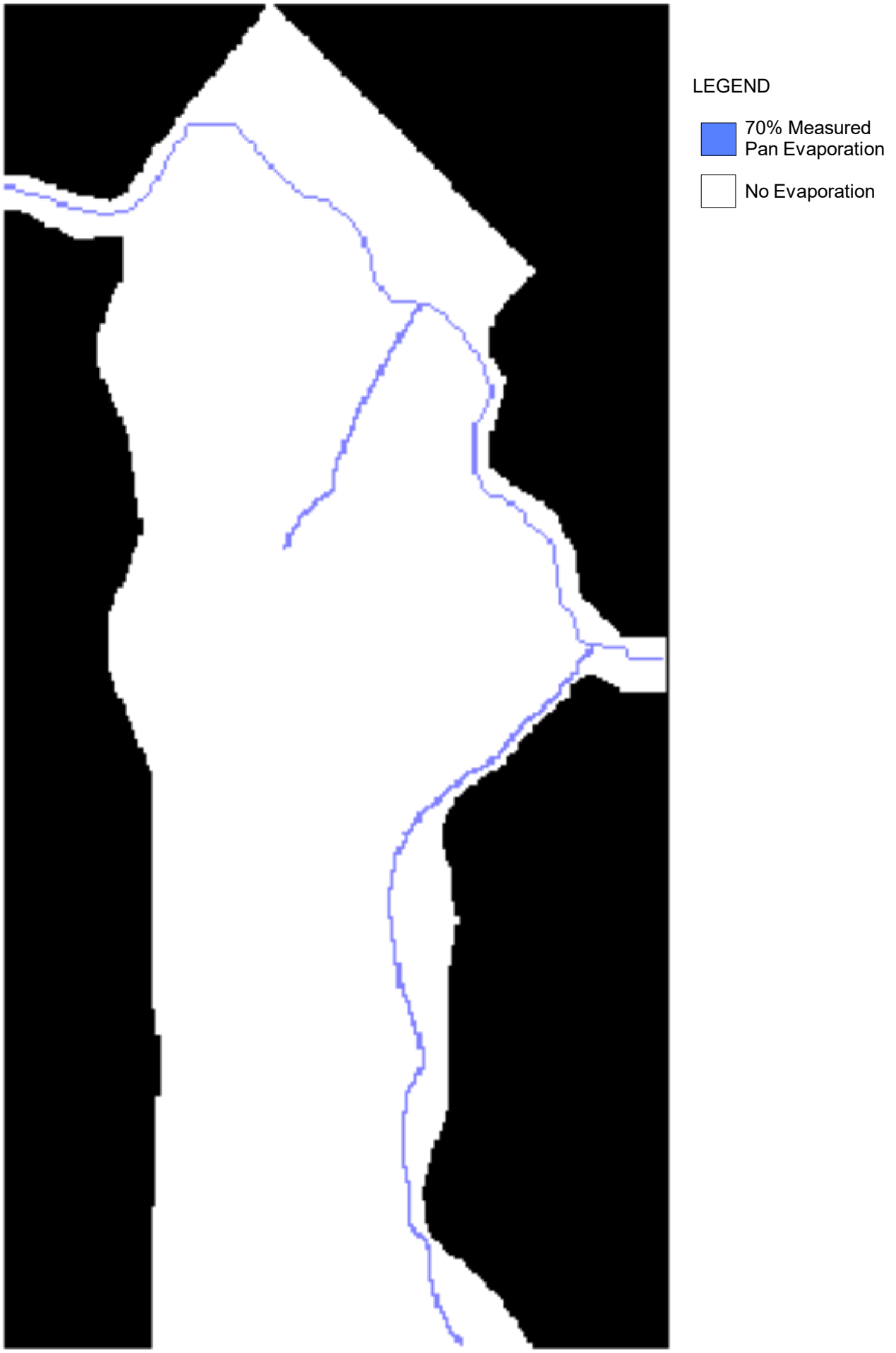
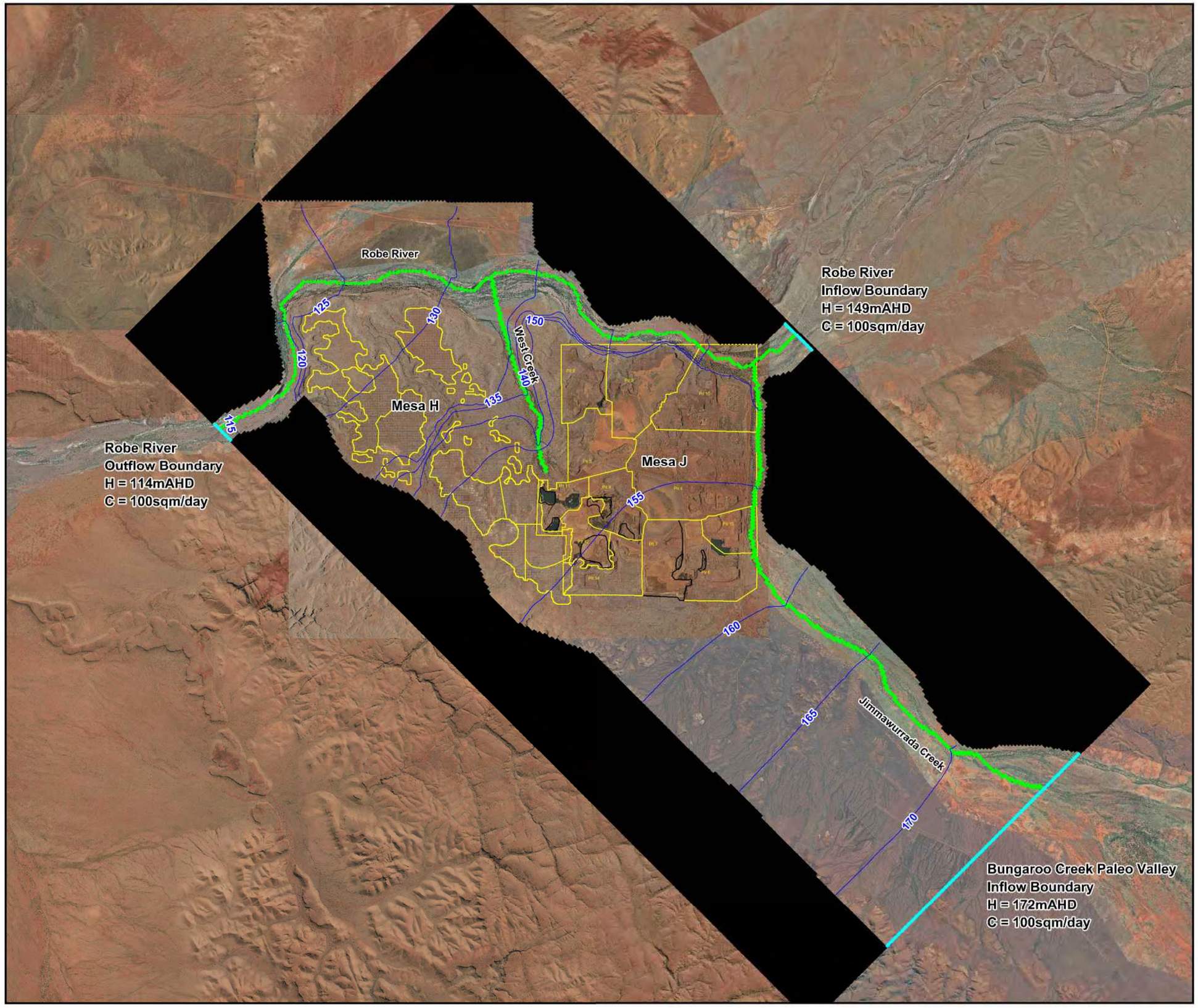


RioTinto

MODELLED EVAPOTRANSPIRATION FIGURE 14

K:/08_WRE&S/09_Groundwater Modelling/02_Projects/Mesa_H/2018/Groundwater Model/Spatial Data/Surfer/Figure 13.srf



LEGEND

- Modelled General Head Boundary
- Modelled Streams
- Inactive Area (No-Flow Cells)
- Pit Outline
- Predicted Water Level (mAHD)

N

SCALE

1:Scale @ A3

FIGURE 15

PREDICTED STEADY STATE GROUNDWATER LEVEL CONTOURS

Drawn: MILOS PAVLOVIC
Date: 9/03/2018

Plan No:
Proj: MESA H GROUNDWATER MODELLING

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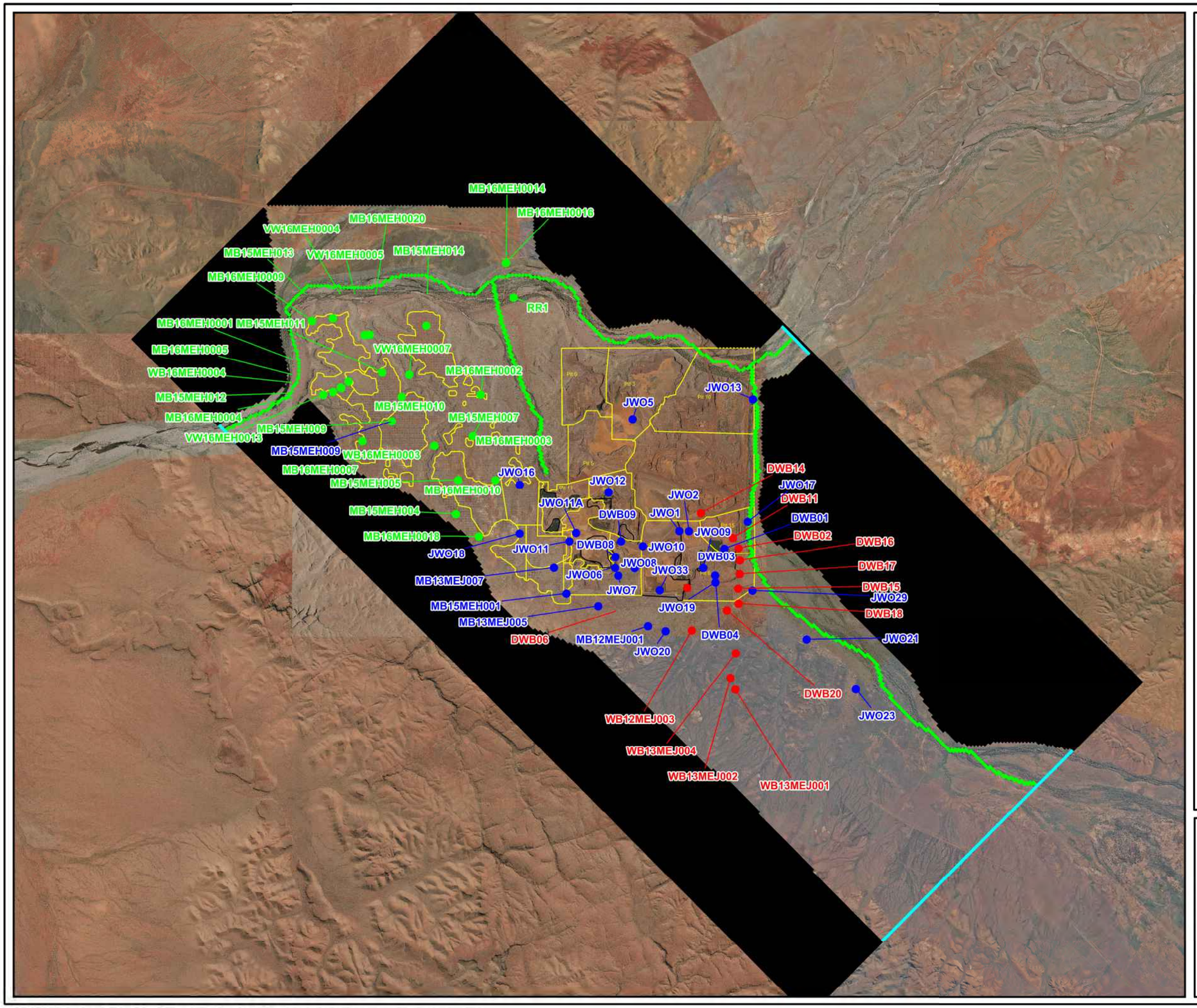


LEGEND

- Modelled General Head Boundary
- Modelled Streams
- Inactive Area (No-Flow Cells)
- Bores With Long Term Monitoring Records
- Bores With Short Term Monitoring Records
- Abstraction Bores
- Pit Cutline

N

SCALE

1:Scale @ A3

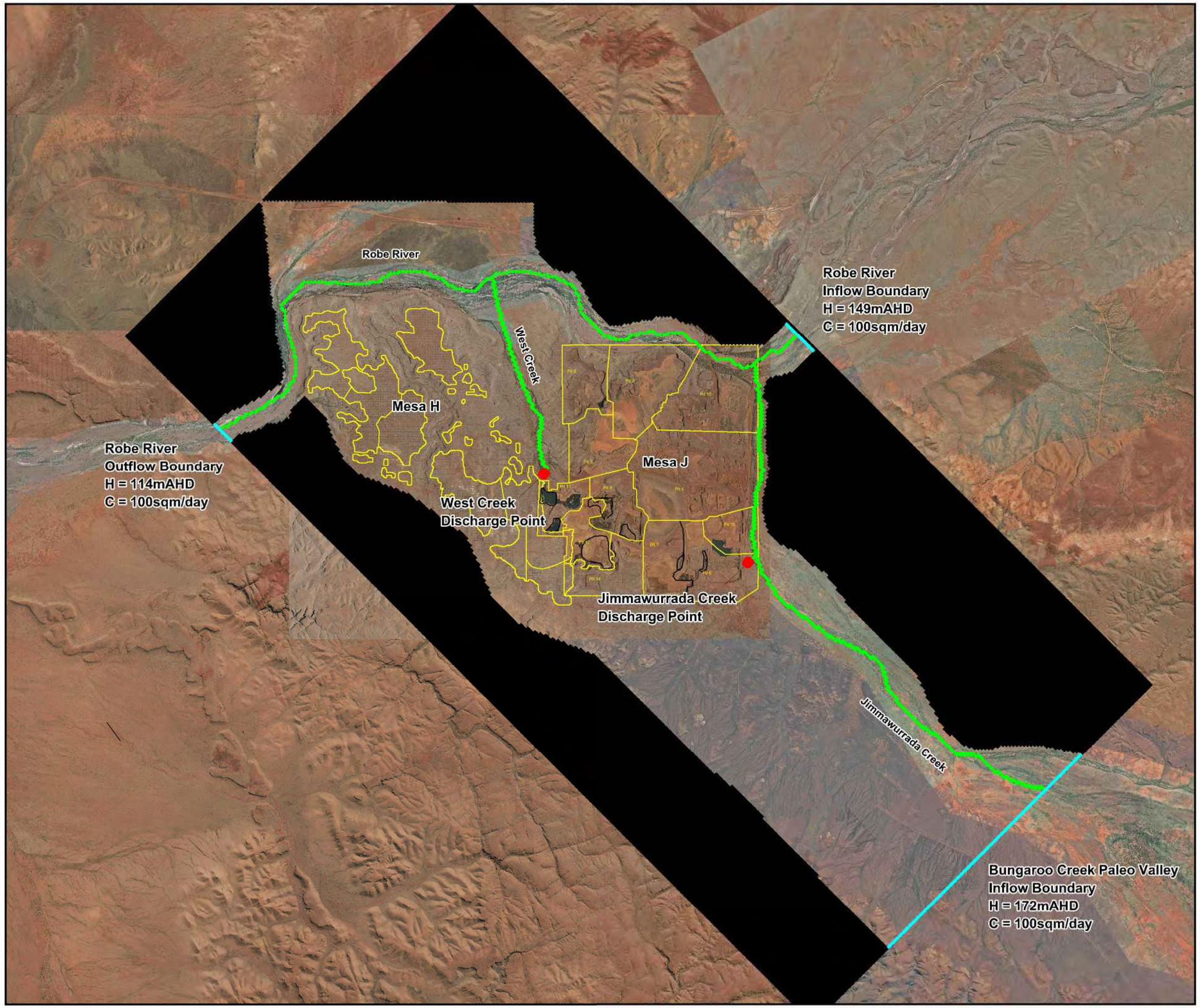
FIGURE 16

BORE LOCATION TRANSIENT MODEL CALIBRATION DATASET

Drawn: MILOS PAVLOVIC
Date: 12/03/2018

Plan No:
Proj: Mesa H Groundwater Modelling

K:\08_WRE&S\09_Groundwater Modelling\02_Projects\Mesa_H\2018\Groundwater Model\Spatial Data\MapInfo\Workspaces\Figure 16 - Calibration Bores.WOR



LEGEND

- Modelled General Head Boundary
- Modelled Streams
- Inactive Area (No-Flow Cells)
- Pit Outline
- Discharge Location

Location Map

N

SCALE

1:Scale @ A3

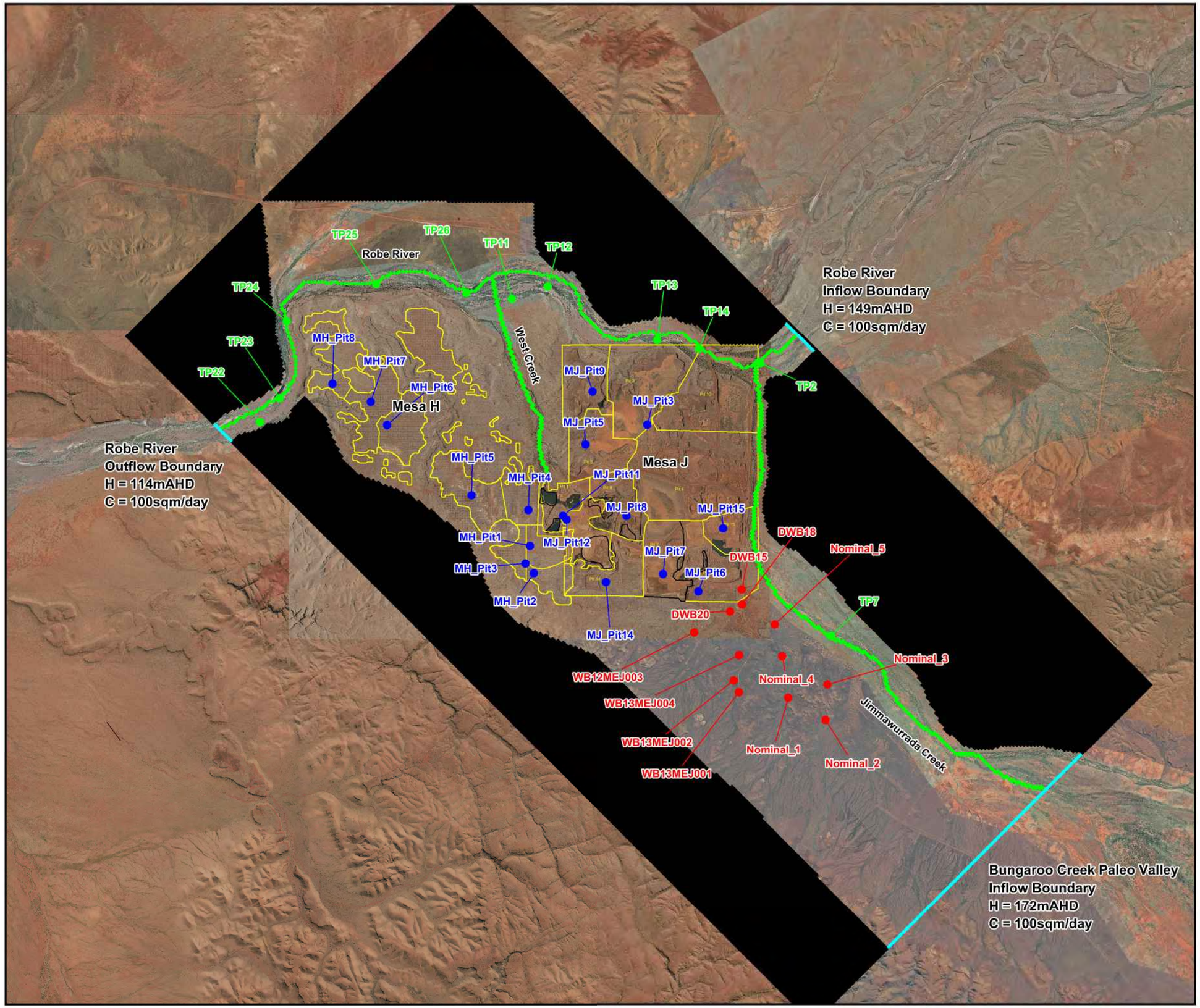
FIGURE 17

SURFACE WATER DISCHARGE LOCATIONS

Drawn: MILOS PAVLOVIC
Date: 9/03/2018

Plan No:
Proj: MESA H GROUNDWATER MODELLING

K:\08_WRE&S\09_Groundwater Modelling\02_Projects\Mesa_H\2018\Groundwater Model\Spatial Data\MapInfo\Workspaces\Figure 17 - Discharge Locations.WOR



LEGEND

- Modelled General Head Boundary
- Modelled Streams
- Inactive Area (No-Flow Cells)
- Pit Outline
- Nominal Tracking Point
- Nominal Monitoring Bore
- Abstraction Bore

Location Map

N

SCALE

1:Scale @ A3

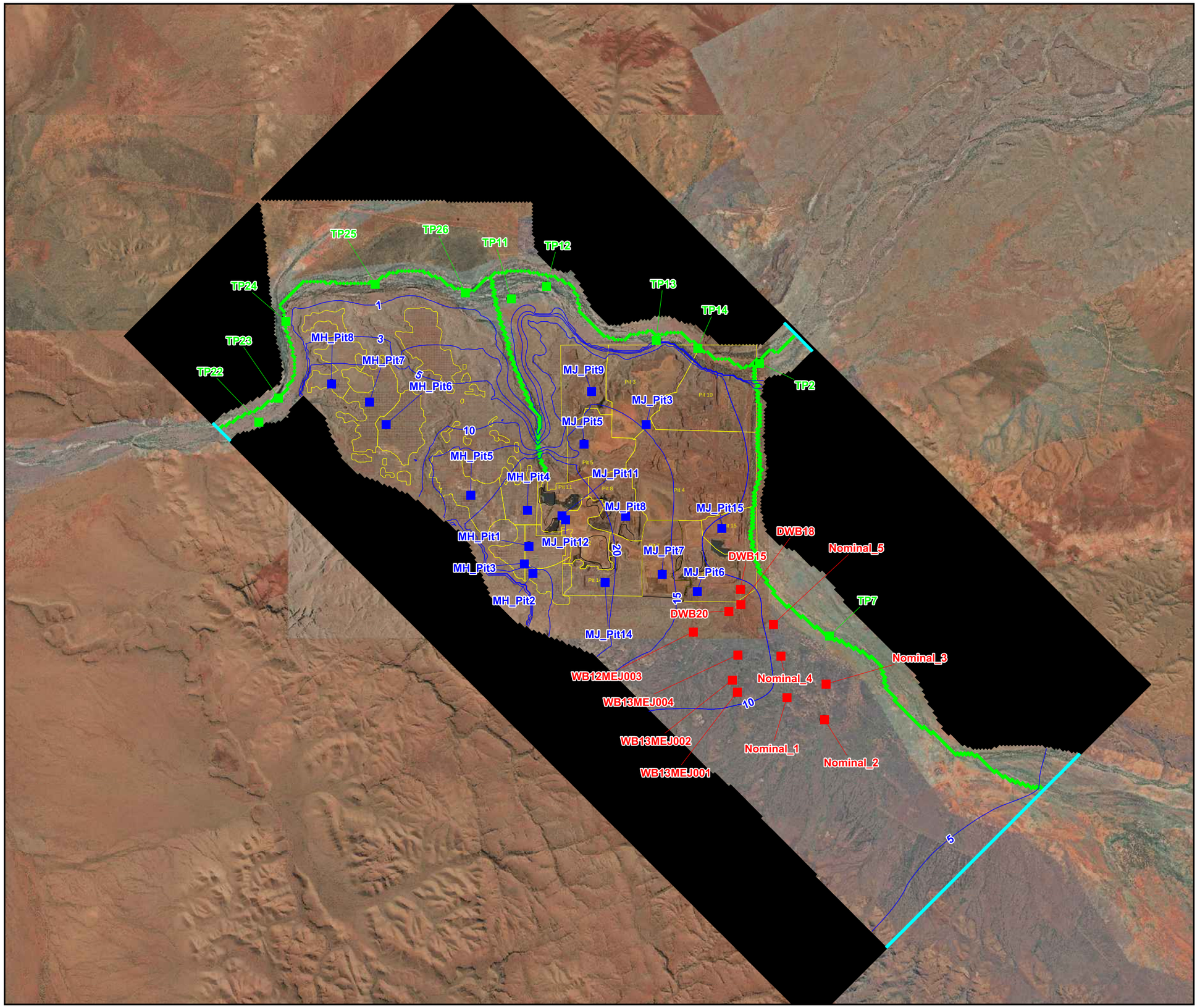
FIGURE 18

PREDICTION BORES

Drawn: MILOS PAVLOVIC
Date: 9/03/2018

Plan No:
Proj: MESA H GROUNDWATER MODELLING

K:\08_WRE&S\09_Groundwater Modelling\02_Projects\Mesa_H\2018\Groundwater Model\Spatial Data\MapInfo\Workspaces\Figure 18 - Prediction Bores.WOR



LEGEND

- Modelled General Head Boundary
- Modelled Streams
- Inactive Area (No-Flow Cells)
- Nominal Monitoring Bore
- Tracking Point
- Abstraction Bore
- Pit Outline
- 1 Predicted Drawdown (m) - Case 1
- 1 Predicted Drawdown (m) - Case 2

N

SCALE

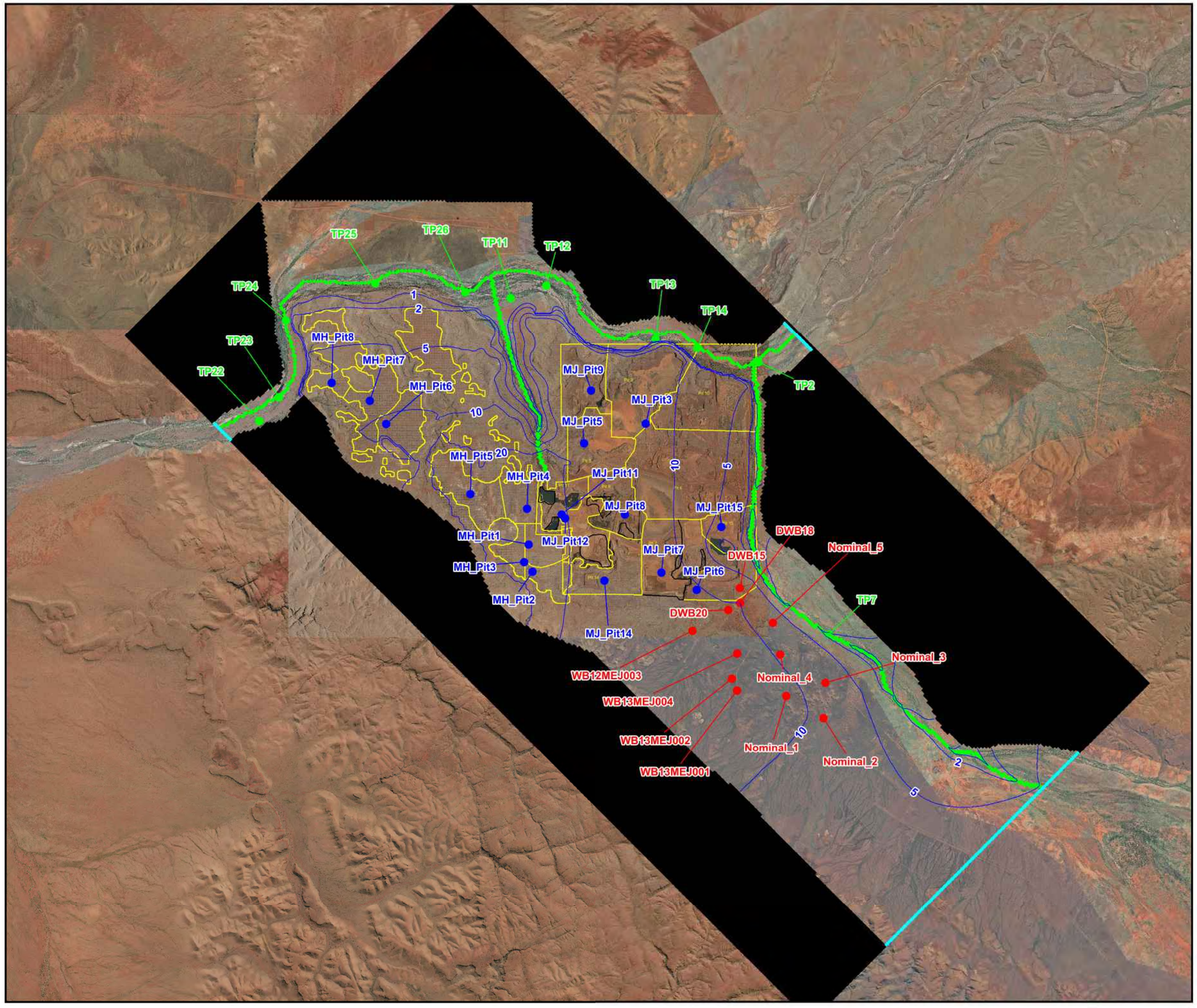
1:Scale @ A3

FIGURE 19

PREDICTED DRAWDOWN DEWATERING CASES 1 DECEMBER 2029

Drawn: MILOS PAVLOVIC
Date: 31/10/2017

Plan No:
Proj:



LEGEND

- Modelled General Head Boundary
- Modelled Streams
- Inactive Area (No-Flow Cells)
- Nominal Monitoring Bore
- Tracking Point
- Abstraction Bore
- Pit Outline
- —1— Predicted Drawdown (m) - Case 1 (December 2037)

N

SCALE

1:Scale @ A3

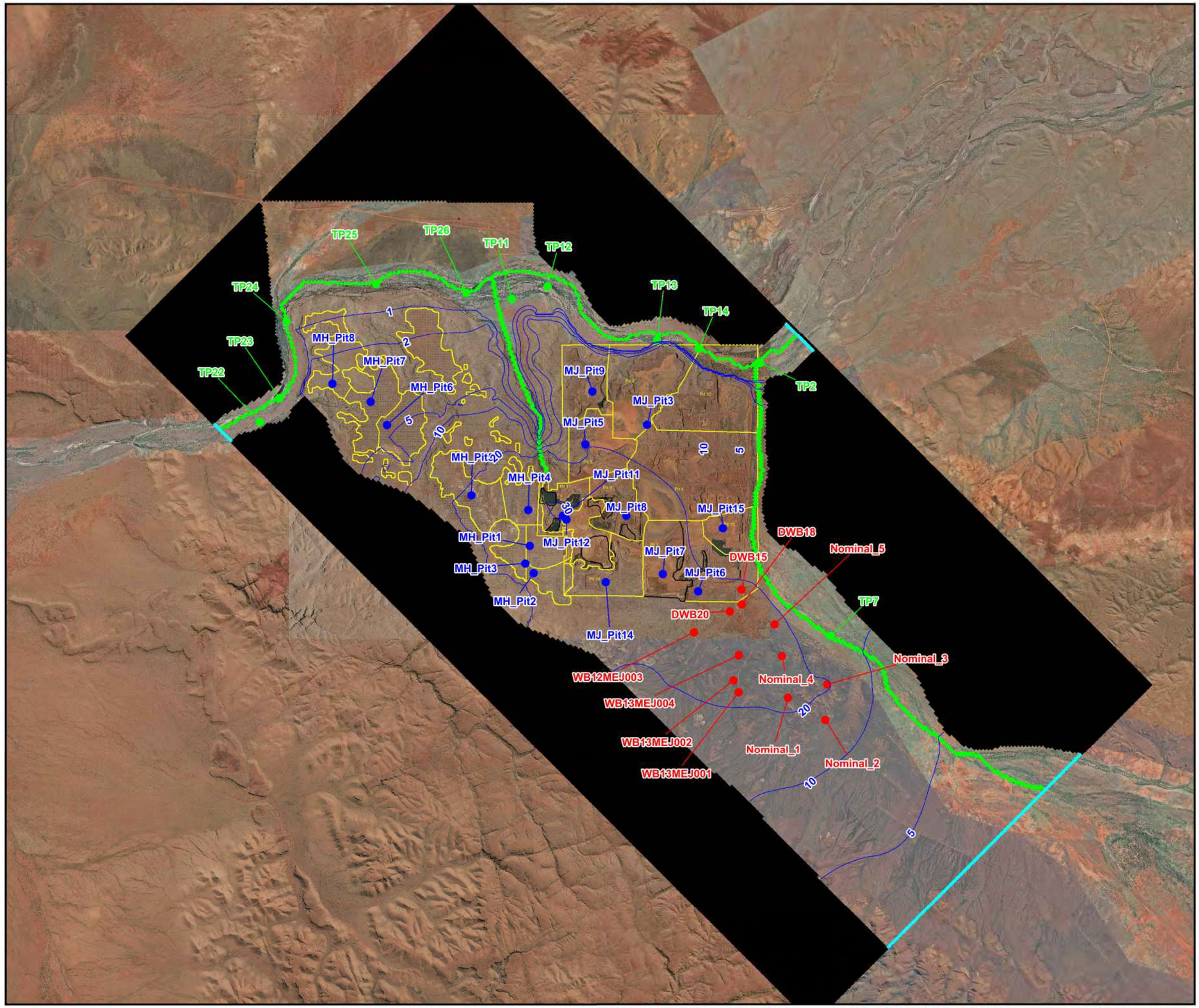
FIGURE 20

PREDICTED DRAWDOWN DEWATERING CASE 1 DECEMBER 2037

Drawn: MILOS PAVLOVIC
Date: 2/7/2018

Plan No:
Proj: Mesa H Groundwater Modelling

K:\08_WRE&S\09_Groundwater Modelling\02_Projects\Mesa_H\2018\Groundwater Model\Spatial Data\MapInfo\Workspaces\Figure 19 - Predicted Drawdown - Base Case (End 2029).WOR



LEGEND

- Modelled General Head Boundary
- Modelled Streams
- Inactive Area (No-Flow Cells)
- Nominal Monitoring Bore
- Tracking Point
- Abstraction Bore
- Pit Outline
- 1 — Predicted Drawdown (m) - Case 2 (December 2029)

Location Map

N

SCALE

1:Scale @ A3

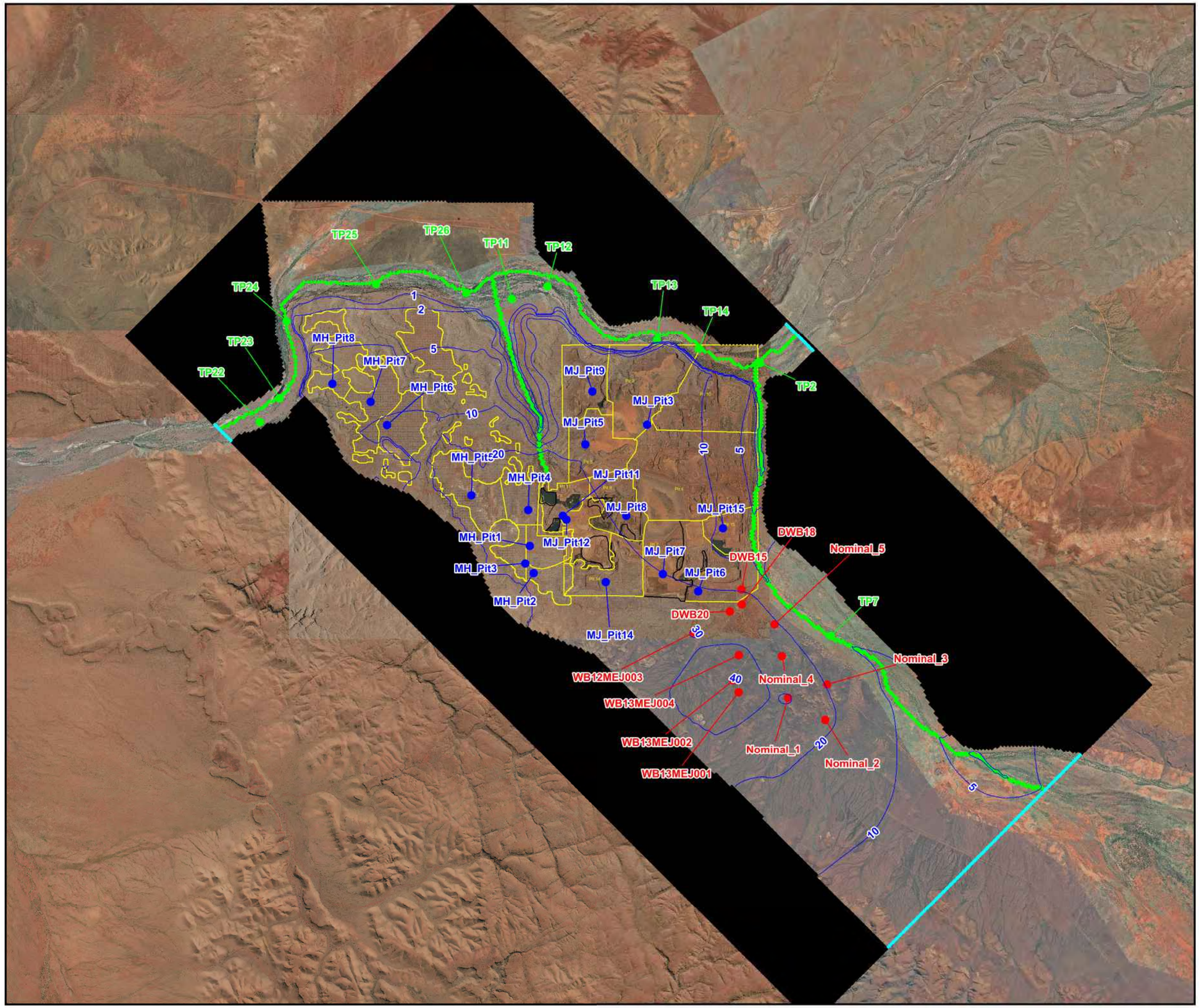
FIGURE 21

PREDICTED DRAWDOWN DEWATERING CASE 2 DECEMBER 2029

Drawn: MILOS PAVLOVIC
Date: 2/7/2018

Plan No:
Proj: Mesa H Groundwater Modelling

K:\08_WRE&S\09_Groundwater Modelling\02_Projects\Mesa_H\2018\Groundwater Model\Spatial Data\MapInfo\Workspaces\Figure 19 - Predicted Drawdown - Base Case (End 2029).WOR



LEGEND

- Modelled General Head Boundary
- Modelled Streams
- Inactive Area (No-Flow Cells)
- Nominal Monitoring Bore
- Tracking Point
- Abstraction Bore
- Pit Outline
- 1 — Predicted Drawdown (m) - Case 2 (December 2037)

N

SCALE

1:Scale @ A3

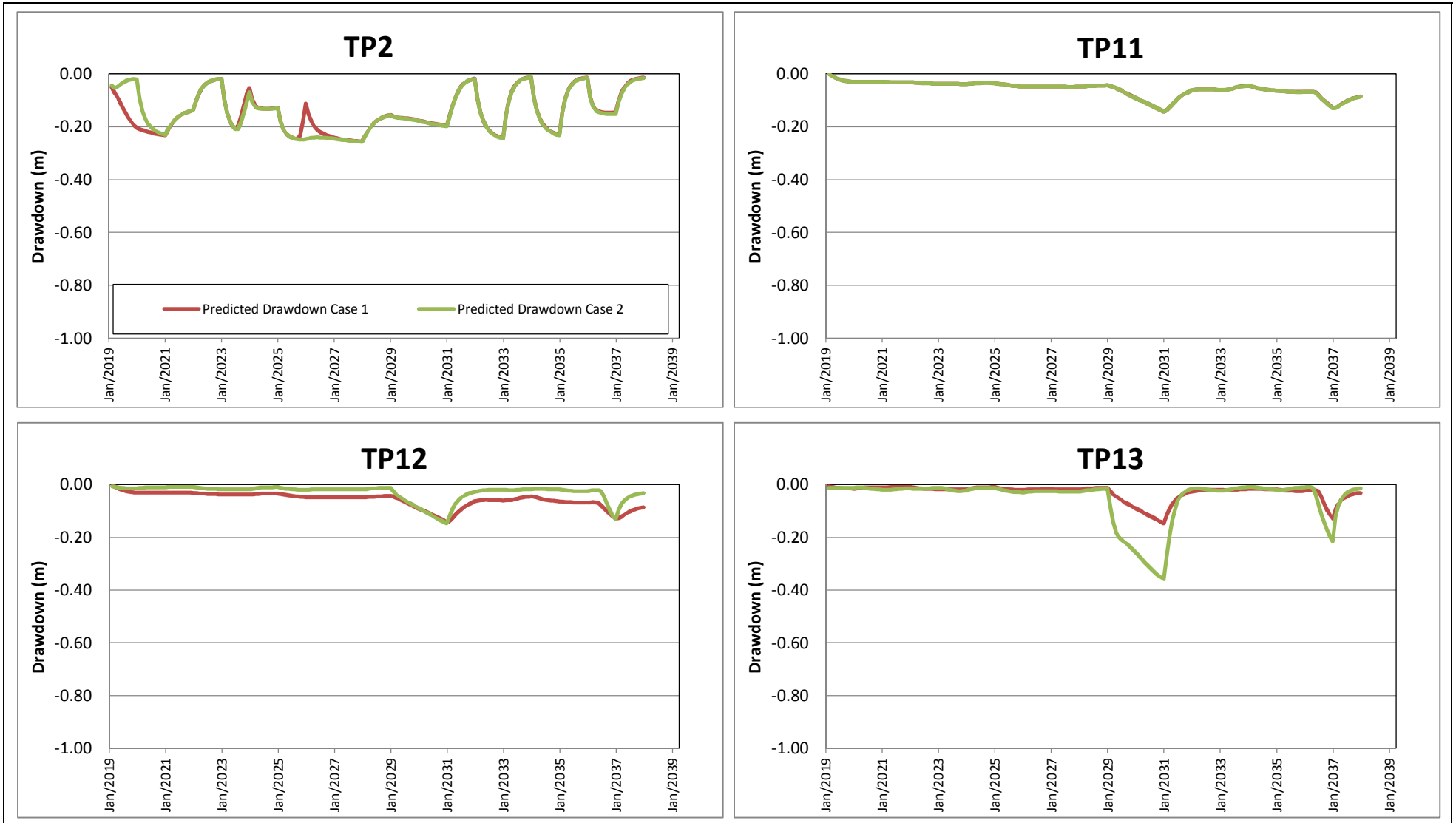
FIGURE 22

PREDICTED DRAWDOWN DEWATERING CASE 2 DECEMBER 2037

Drawn: MILOS PAVLOVIC
Date: 2/7/2018

Plan No:
Proj: Mesa H Groundwater Modelling

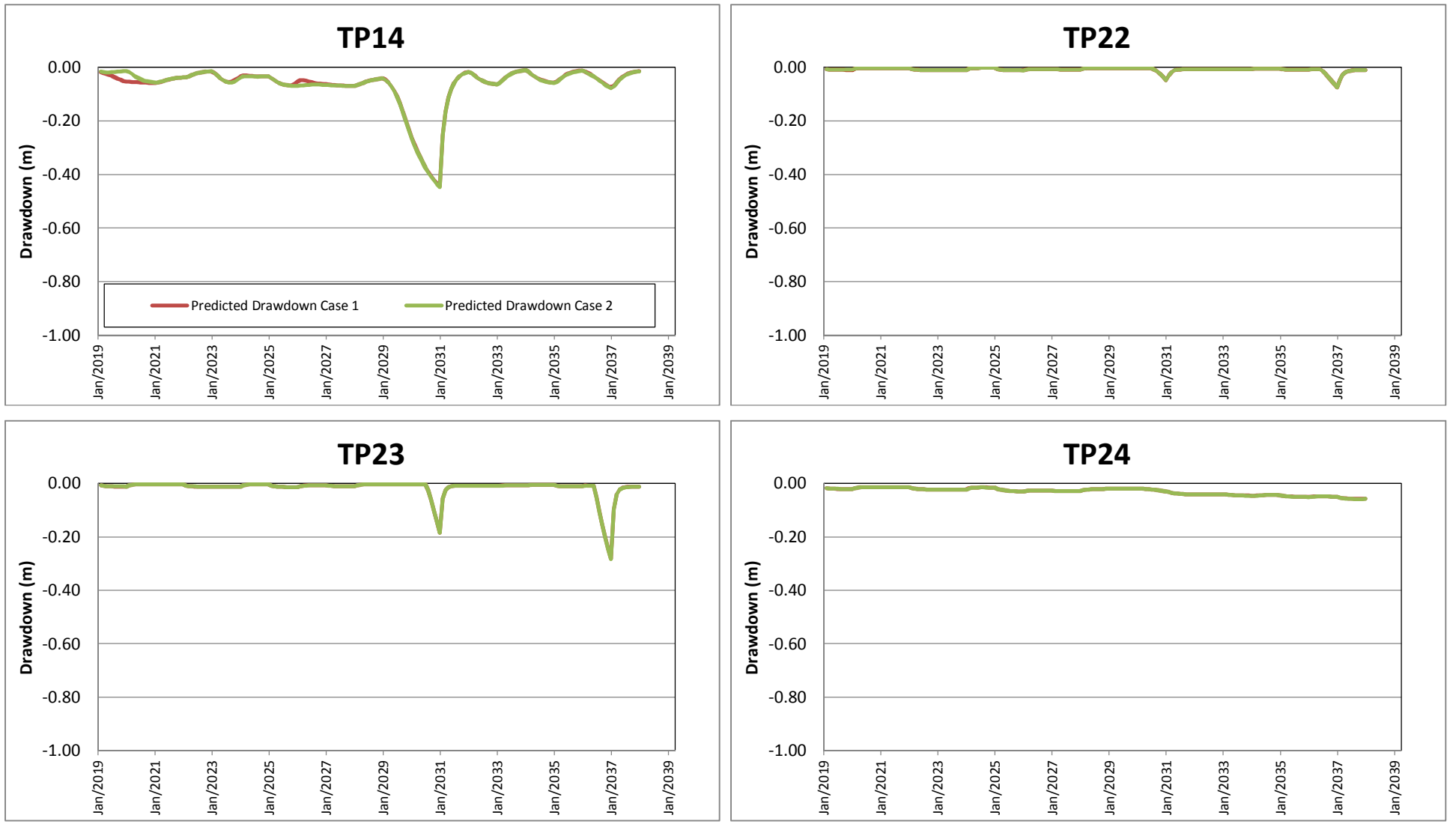
K:\08_WRE&S\09_Groundwater Modelling\02_Projects\Mesa_H\2018\Groundwater Model\Spatial Data\MapInfo\Workspaces\Figure 19 - Predicted Drawdown - Base Case (End 2029).WOR



RioTinto

PREDICTED DRAWDOWN AT TRACKING POINTS - ROBE RIVER AND JIMMAWURRADA CREEK (DEWATERING CASES 1 AND 2) FIGURE 23

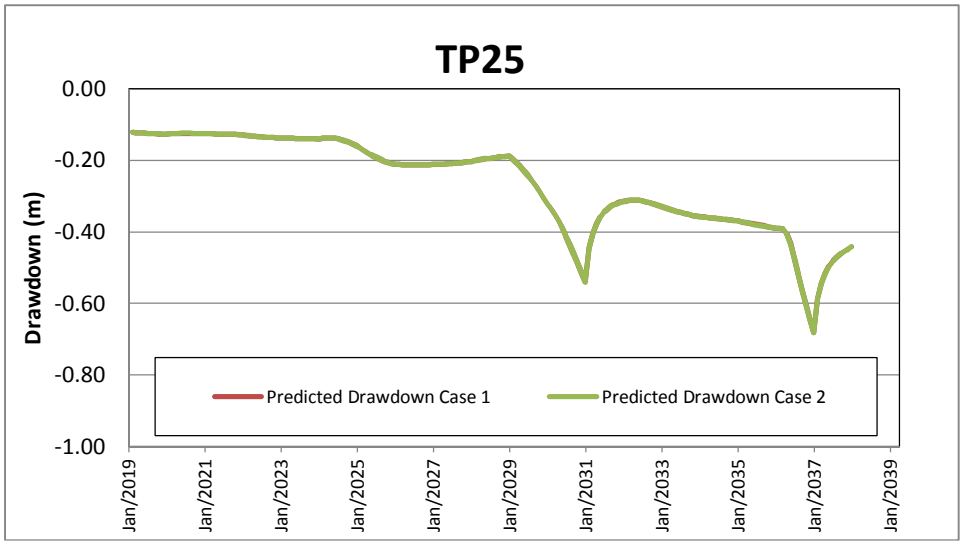
K:\08_WRE&S\09_Groundwater Modelling\02_Projects\Mesa_H\2018\Groundwater Model\Modelling\Model Results\prediction\[Case 1 and 2_Tracking Points PT90.xlsx]Fig 23

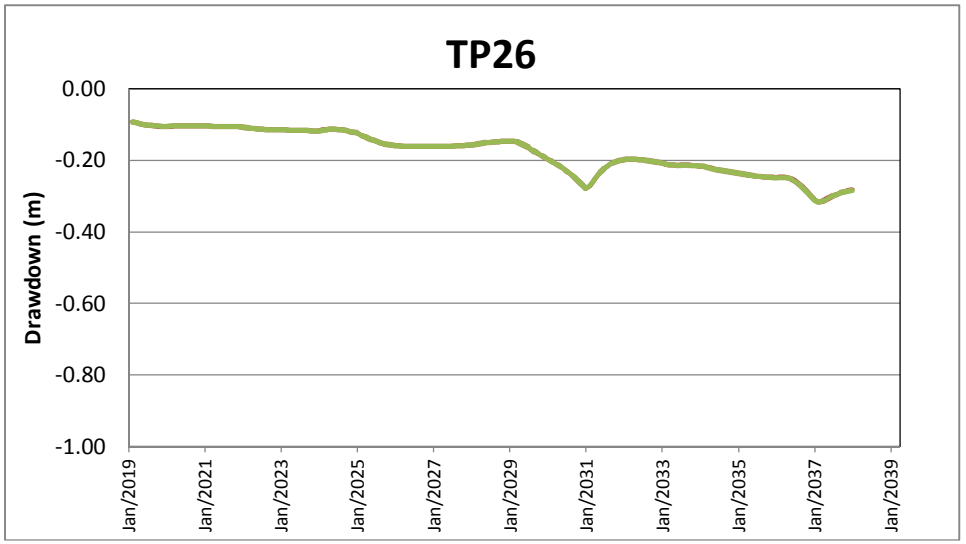


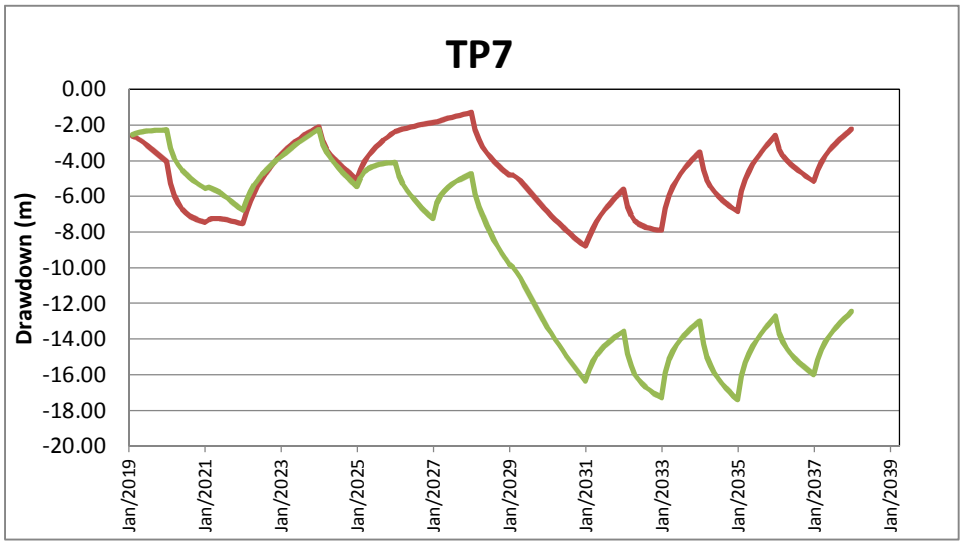
RioTinto

PREDICTED DRAWDOWN AT TRACKING POINTS - ROBE RIVER AND JIMMAWURRADA CREEK (DEWATERING CASES 1 AND 2) FIGURE 24

K:\08_WRE&S\09_Groundwater Modelling\02_Projects\Mesa_H\2018\Groundwater Model\Modelling\Model Results\prediction\[Case 1 and 2_Tracking Points PT90.xlsx]Fig 24







RioTinto

PREDICTED DRAWDOWN AT TRACKING POINTS - ROBE RIVER AND JIMMAWURRADA CREEK (DEWATERING CASES 1 AND 2) FIGURE 25

K:\08_WRE&S\09_Groundwater Modelling\02_Projects\Mesa_H\2018\Groundwater Model\Modelling\Model Results\prediction\[Case 1 and 2_Tracking Points PT90.xlsx]Fig 25

APPENDIX A
CALIBRATION HYDROGRAPHS

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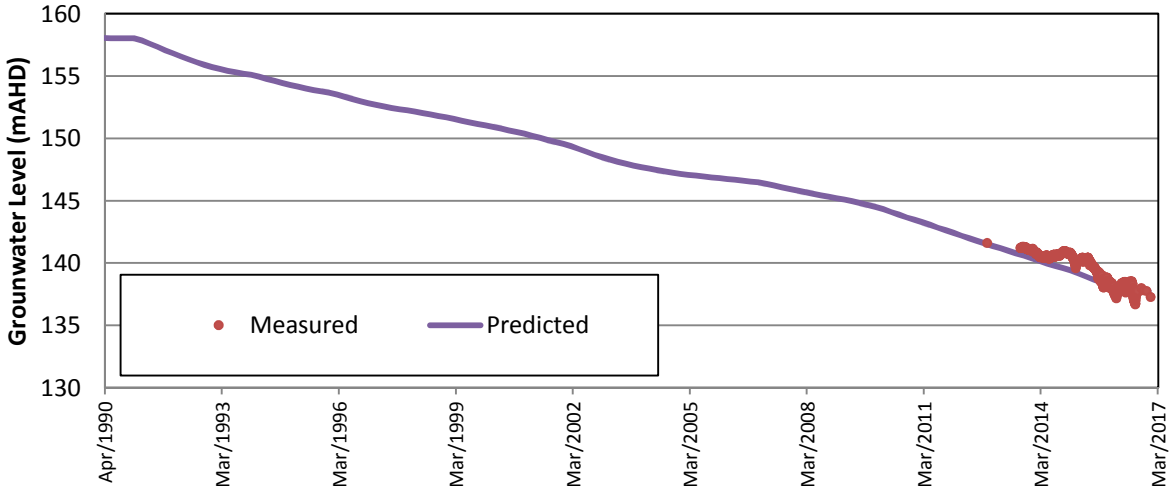

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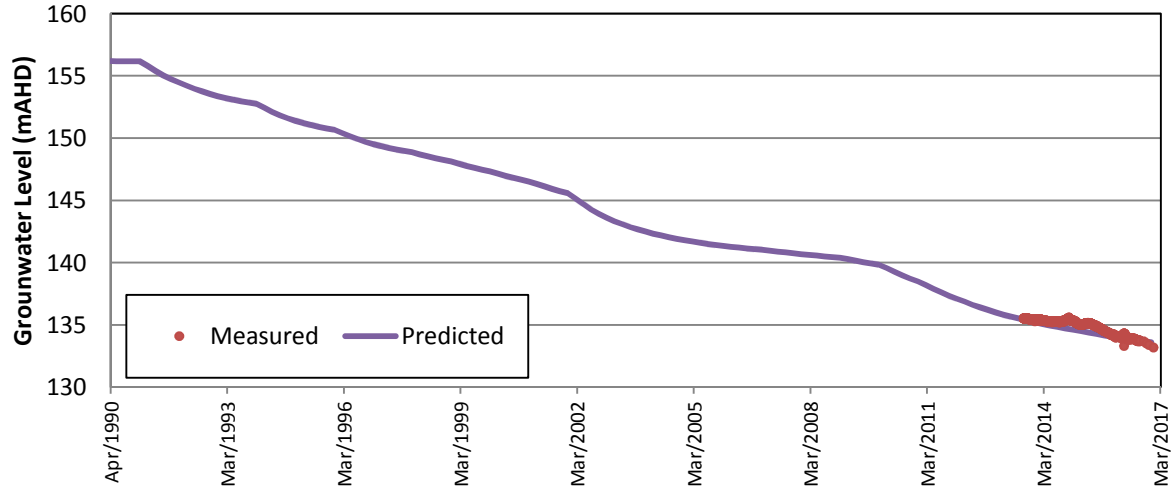

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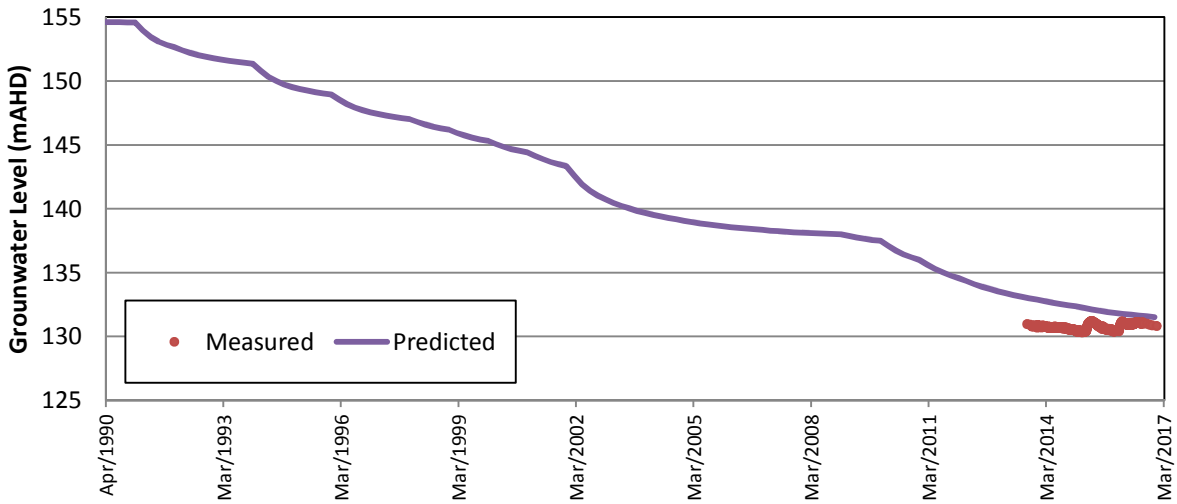

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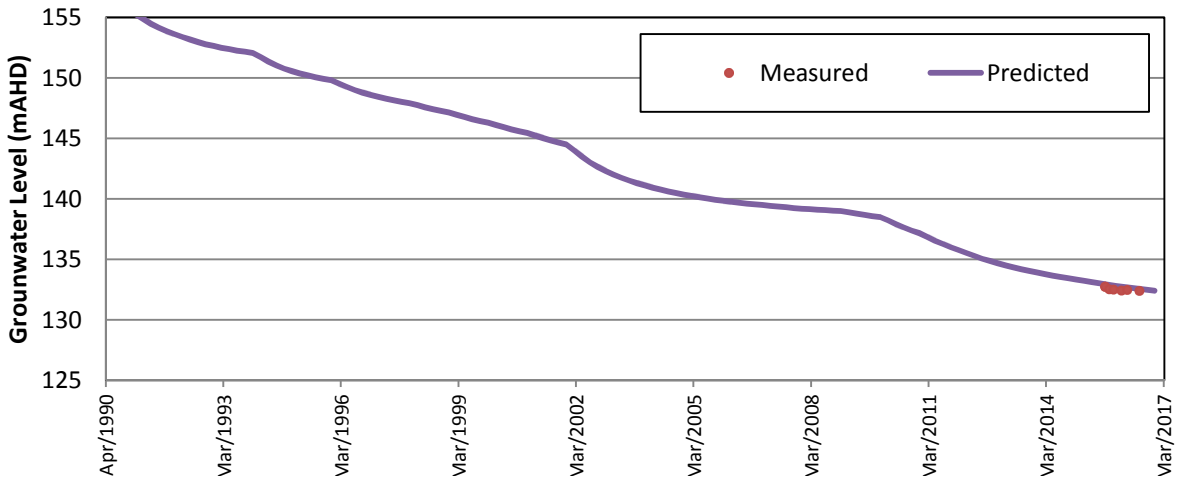

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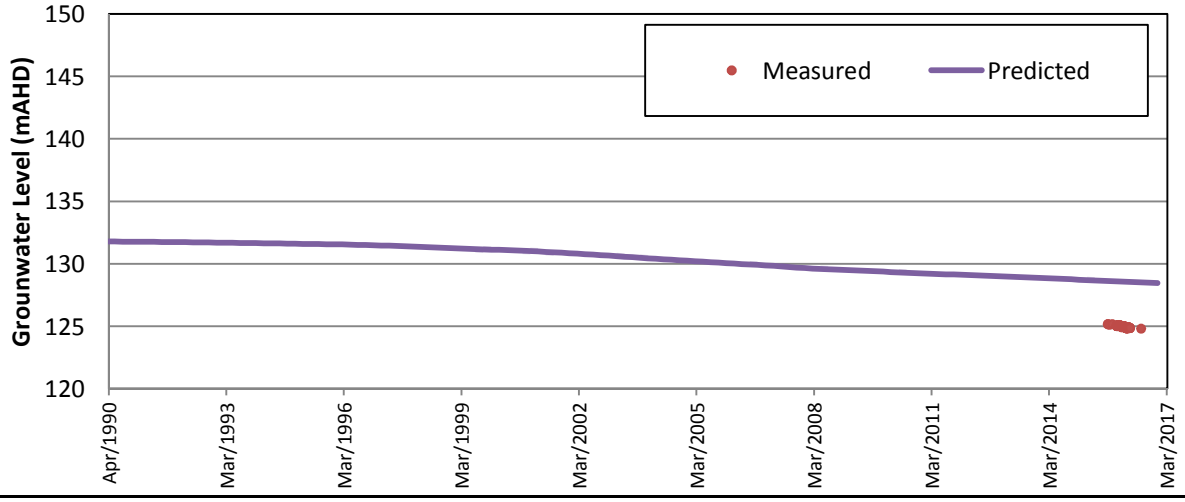

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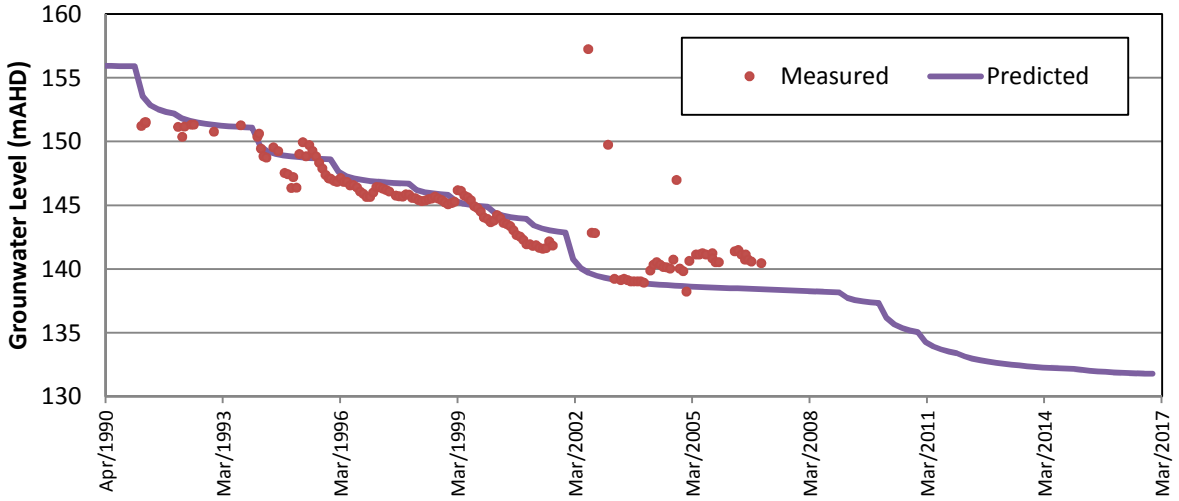

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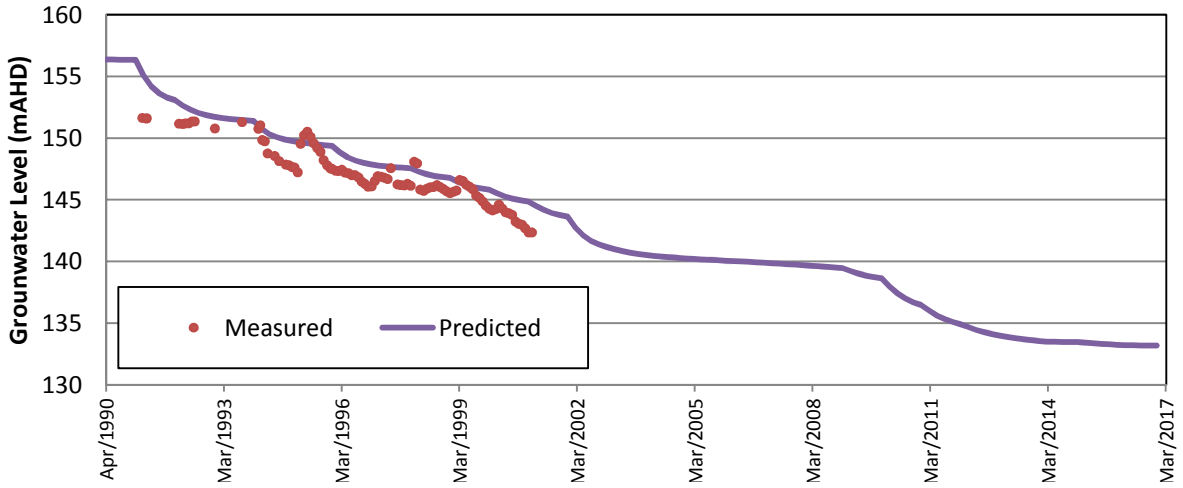

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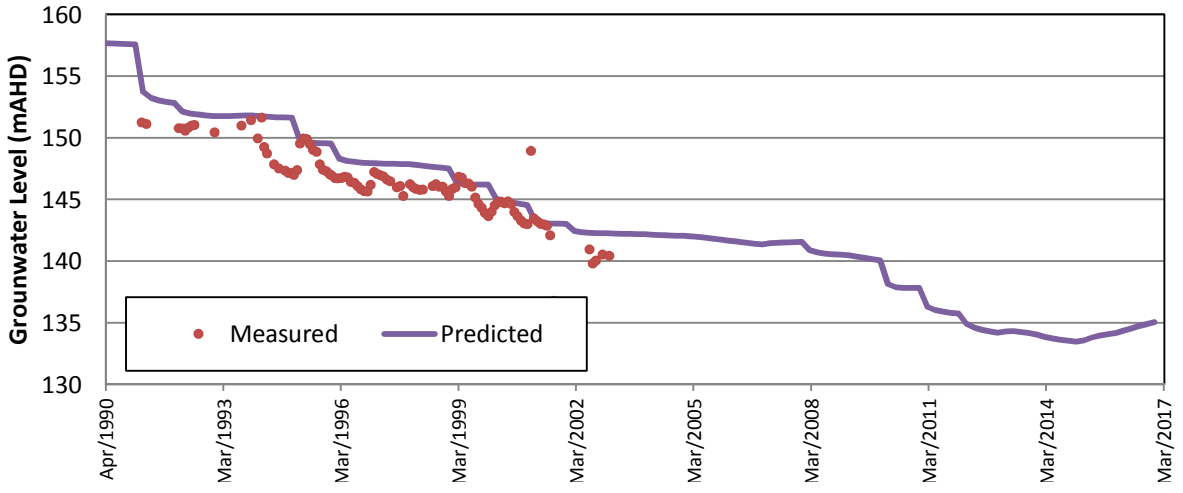

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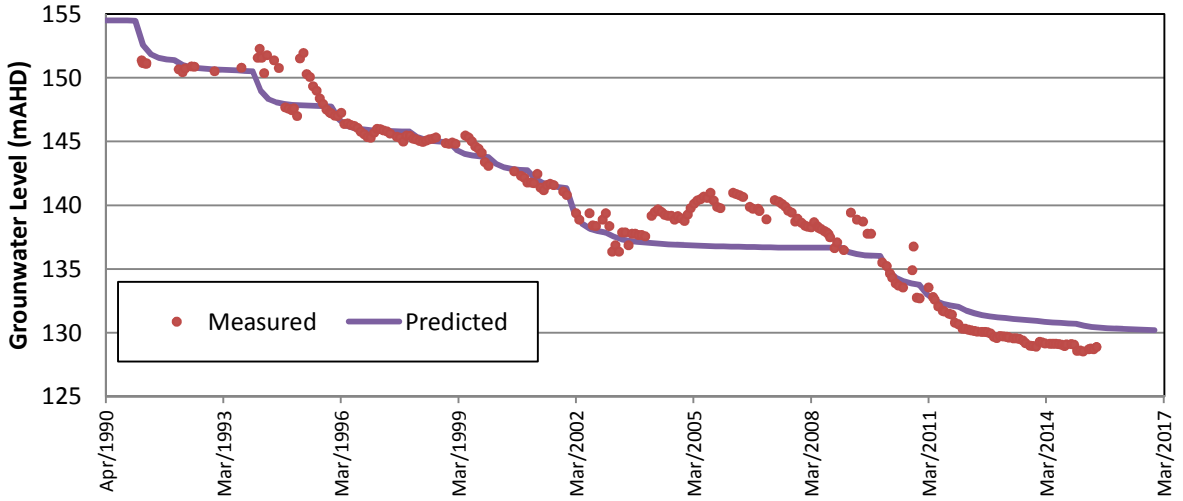

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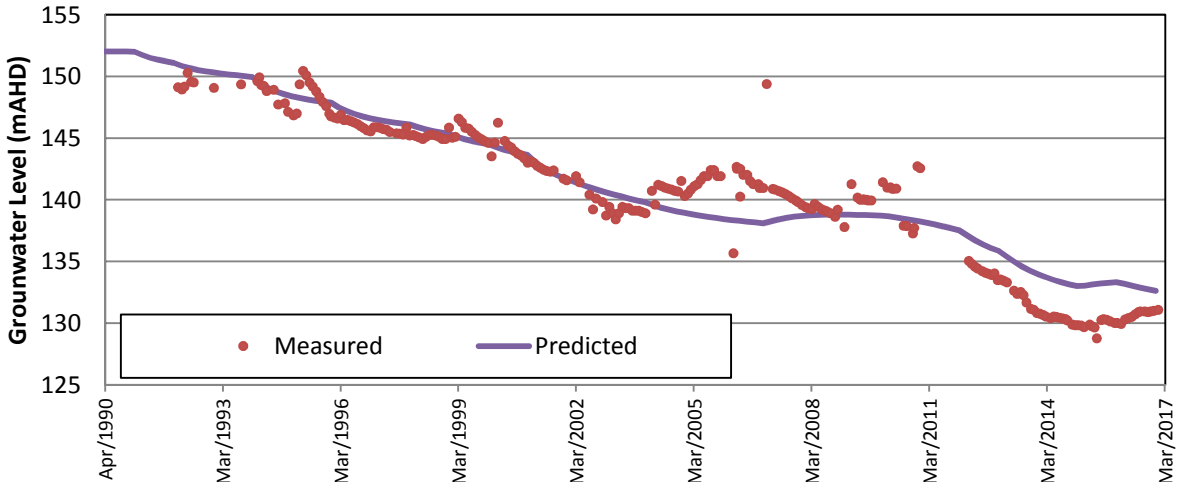

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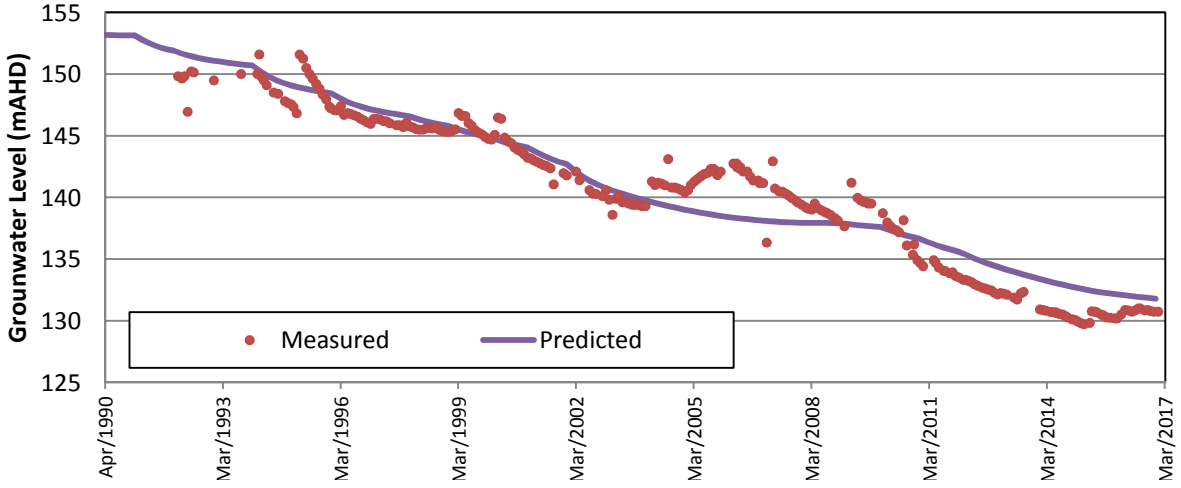

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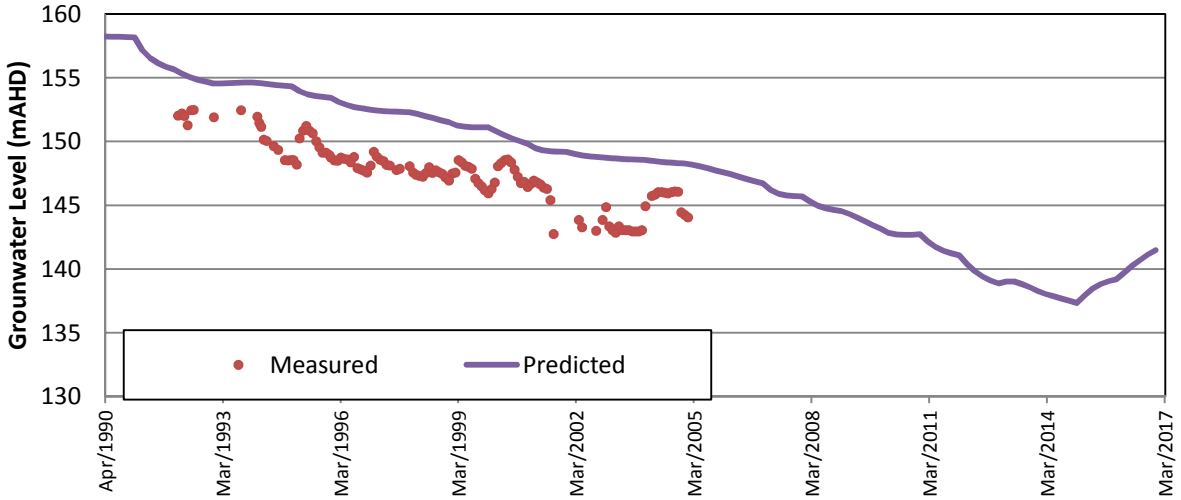

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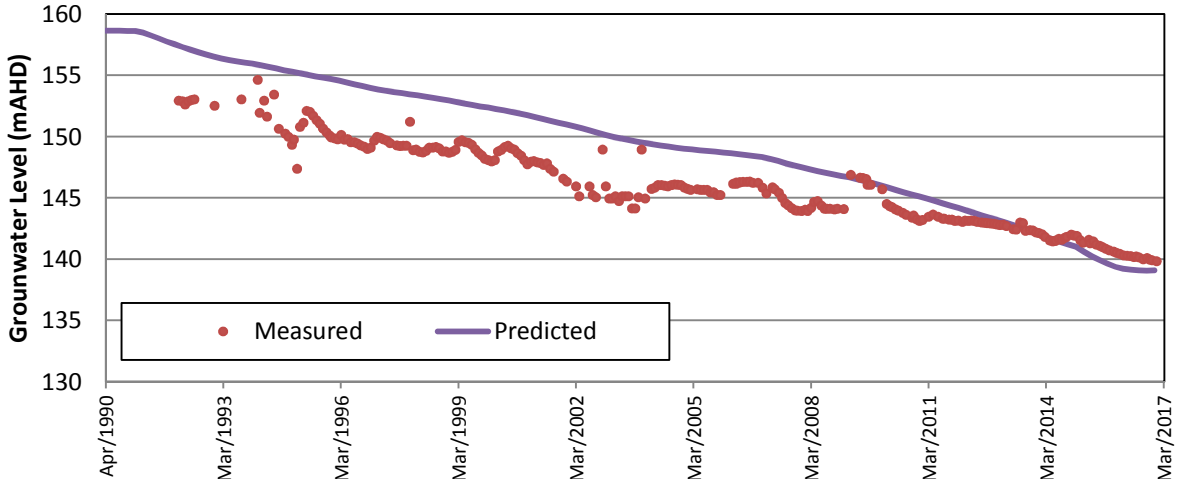

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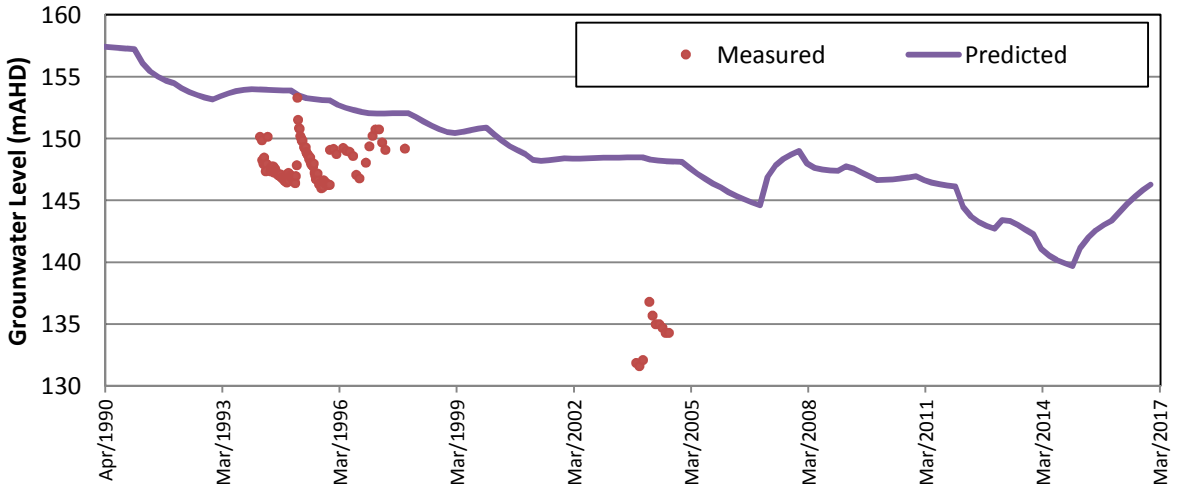

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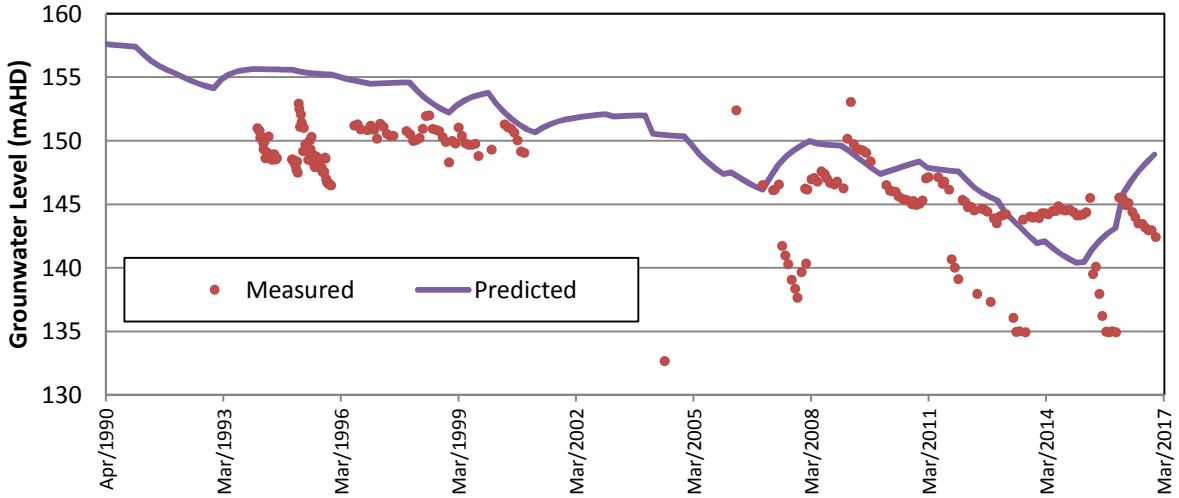

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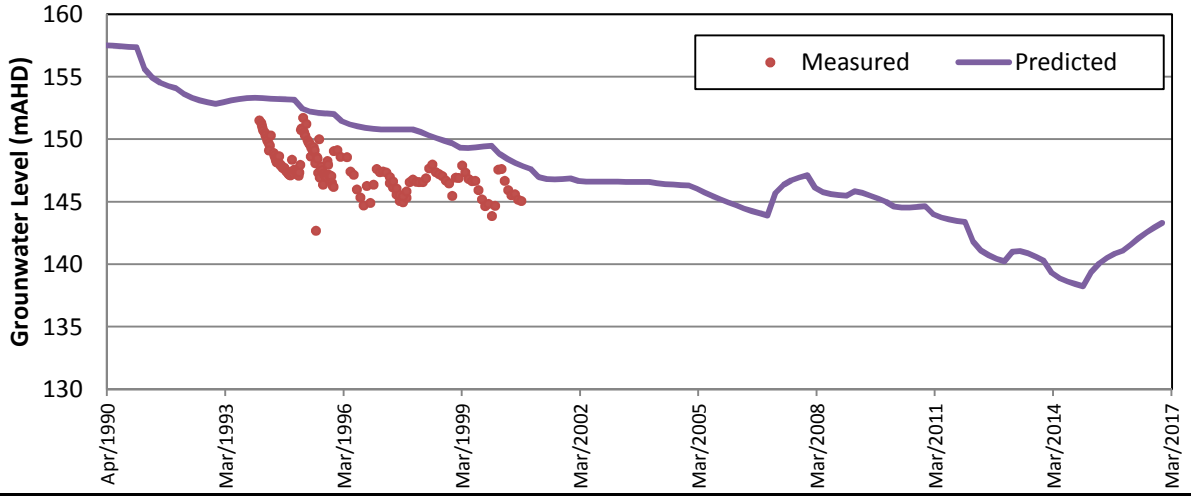

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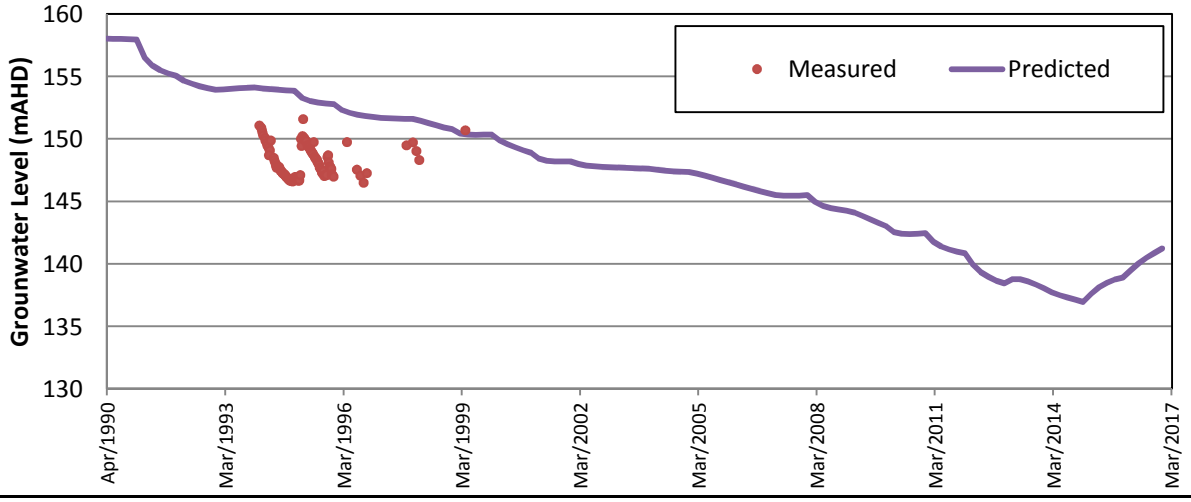

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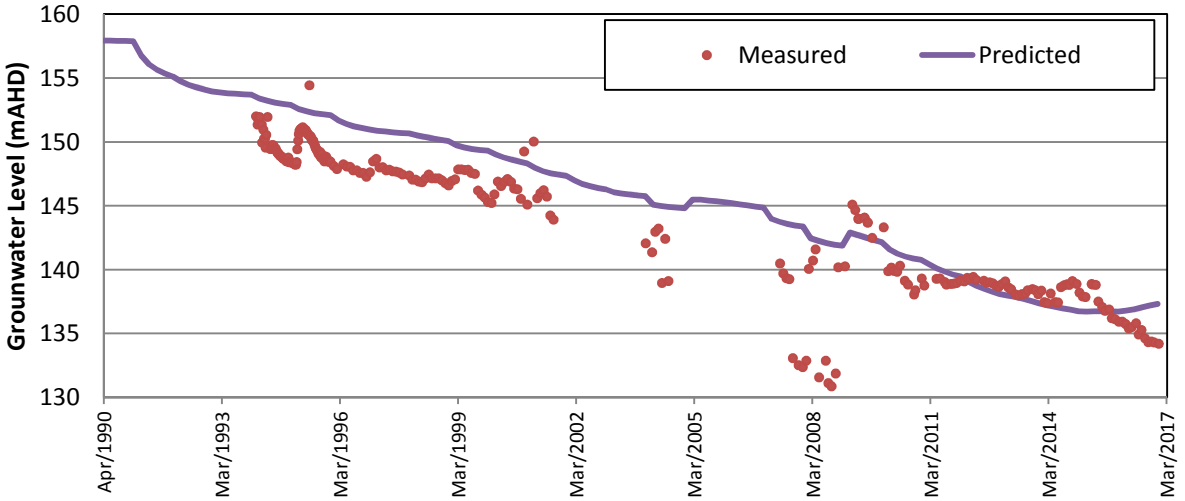

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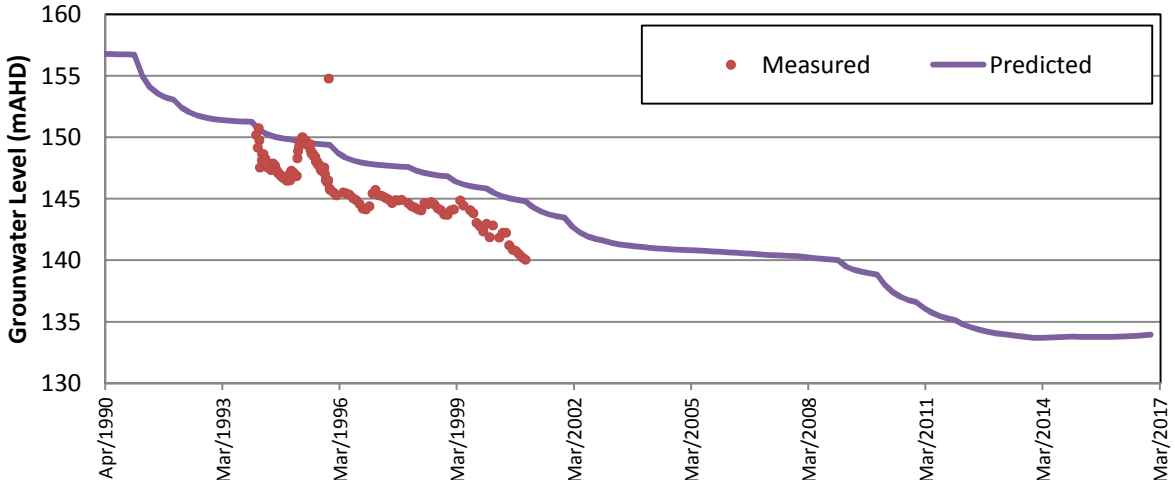

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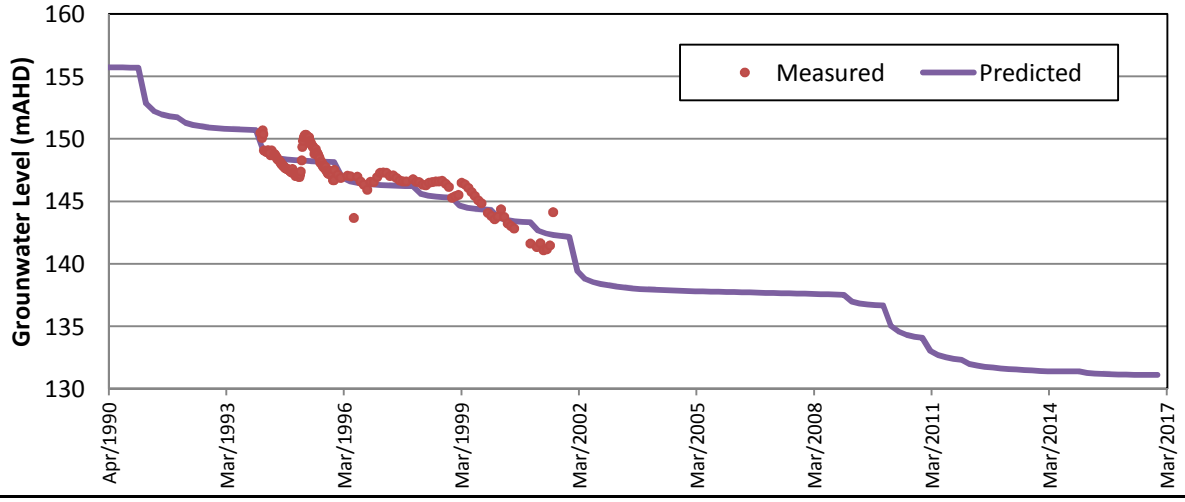

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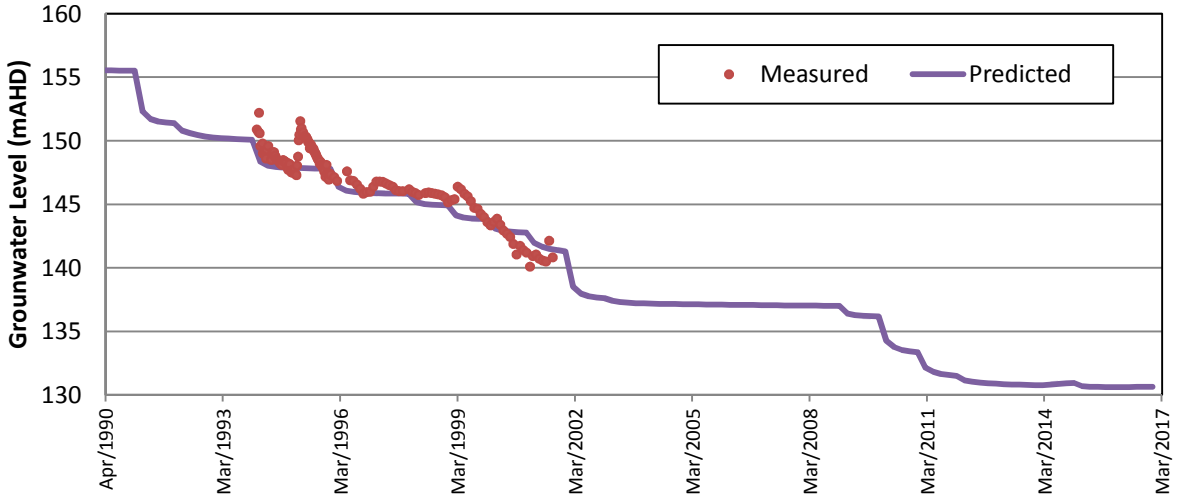

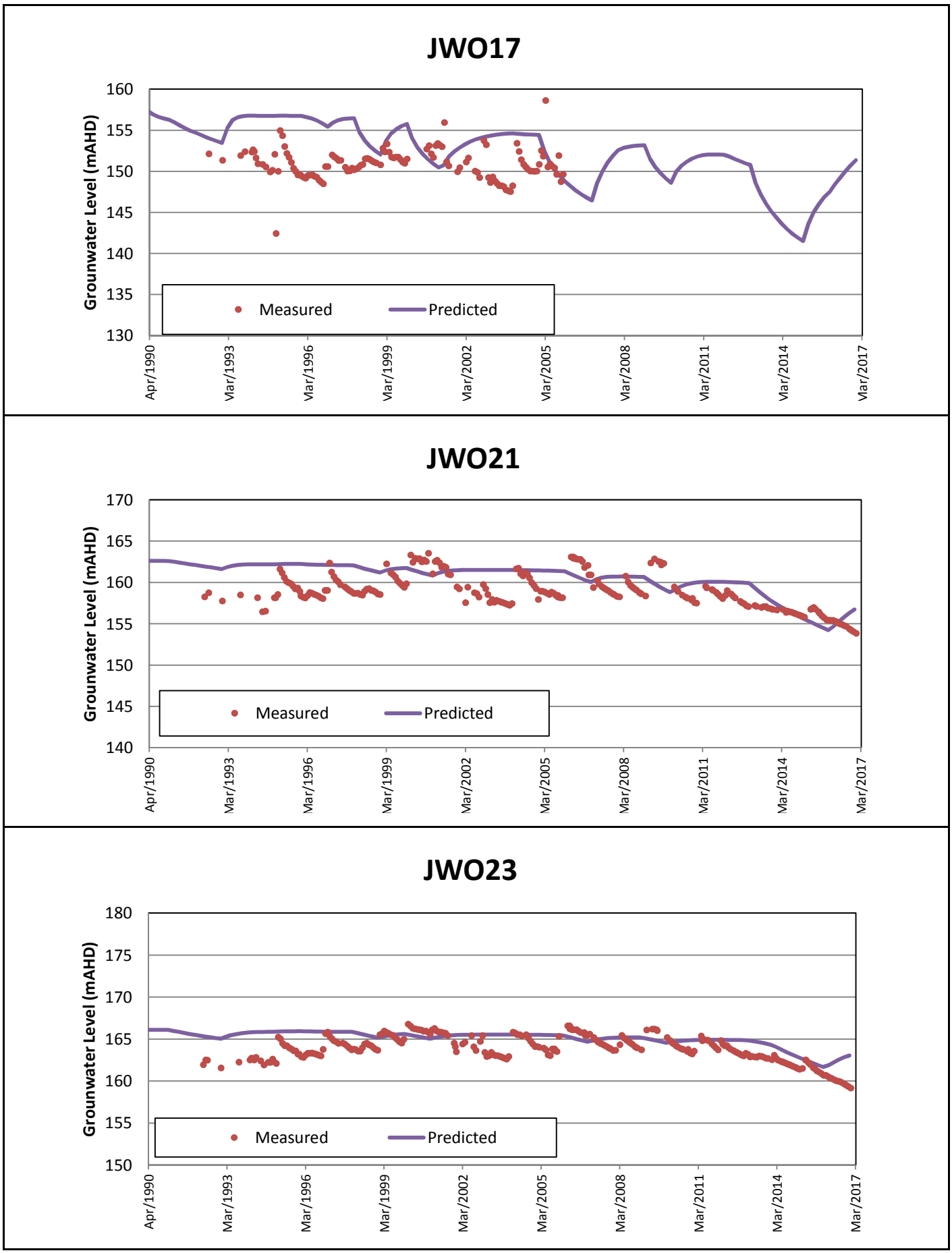
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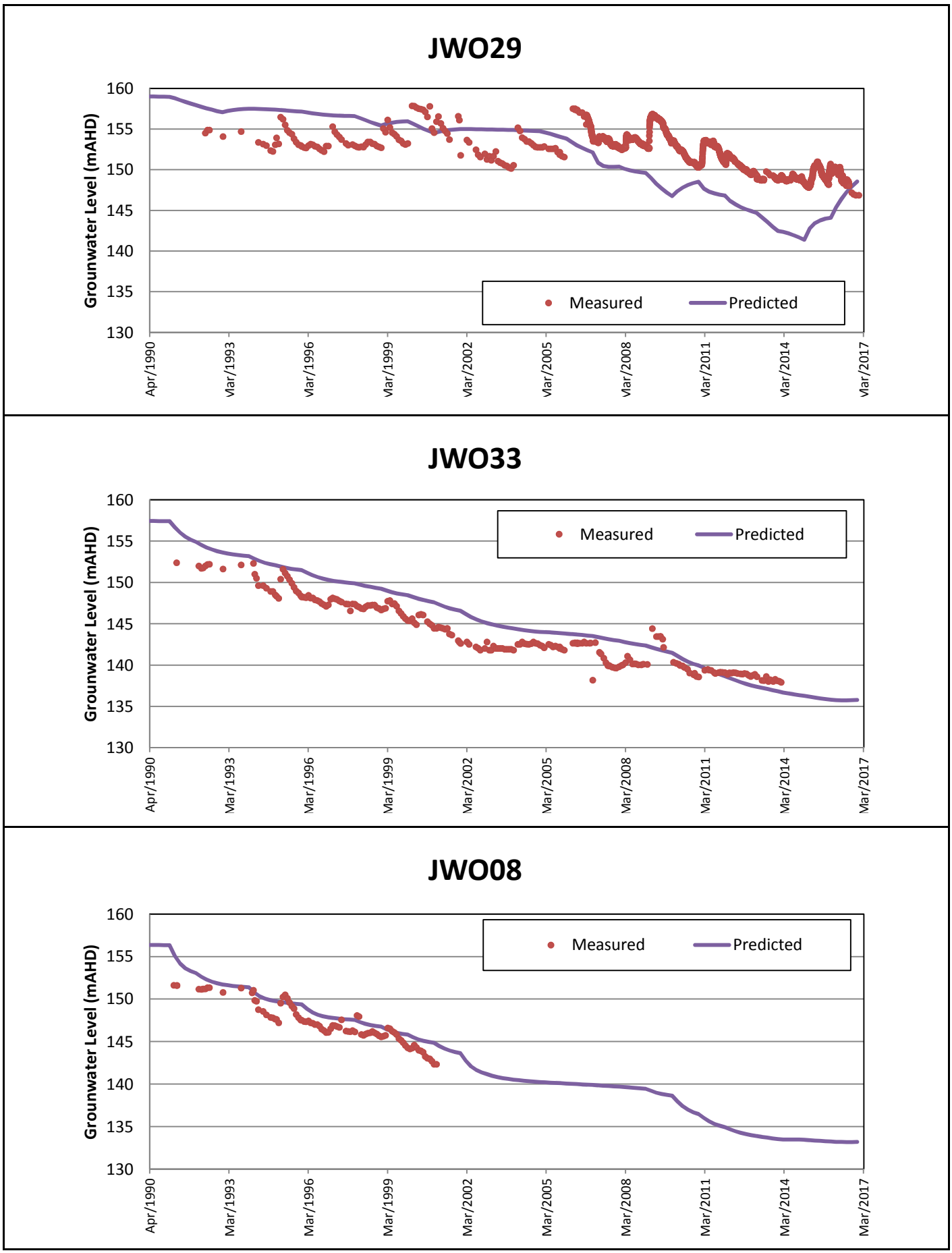
Grounwater Level (mAHD)
160
155
150
145
140
135
130
Measured
Predicted
Apr/1990
Mar/1993
Mar/1996
Mar/1999
Mar/2002
Mar/2005
Mar/2008
Mar/2011
Mar/2014
Mar/2017
JWO21
Grounwater Level (mAHD)
170
165
160
155
150
145
140
Measured
Predicted
Apr/1990
Mar/1993
Mar/1996
Mar/1999
Mar/2002
Mar/2005
Mar/2008
Mar/2011
Mar/2014
Mar/2017
JWO23
Grounwater Level (mAHD)
180
175
170
165
160
155
150
Measured
Predicted
Apr/1990
Mar/1993
Mar/1996
Mar/1999
Mar/2002
Mar/2005
Mar/2008
Mar/2011
Mar/2014
Mar/2017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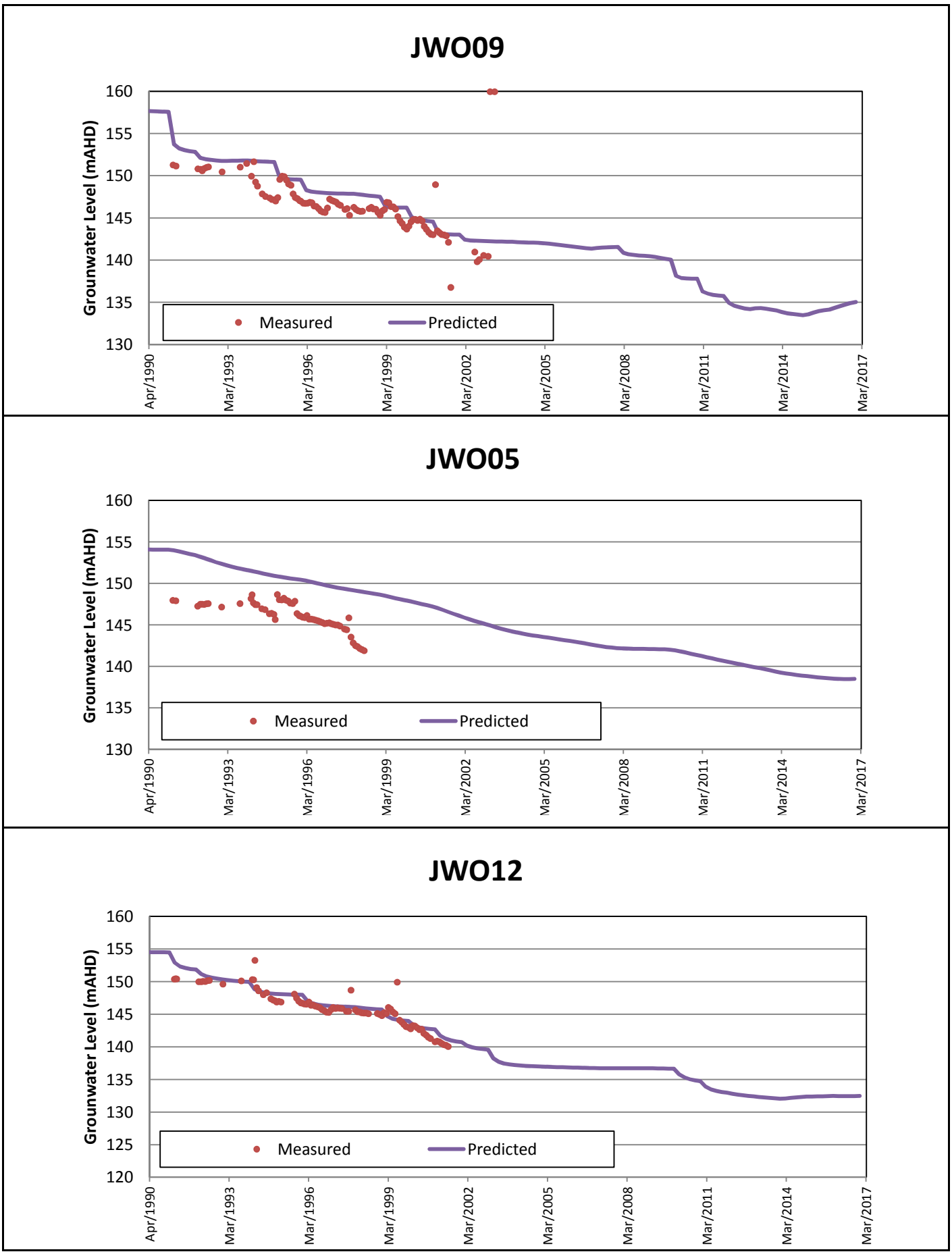
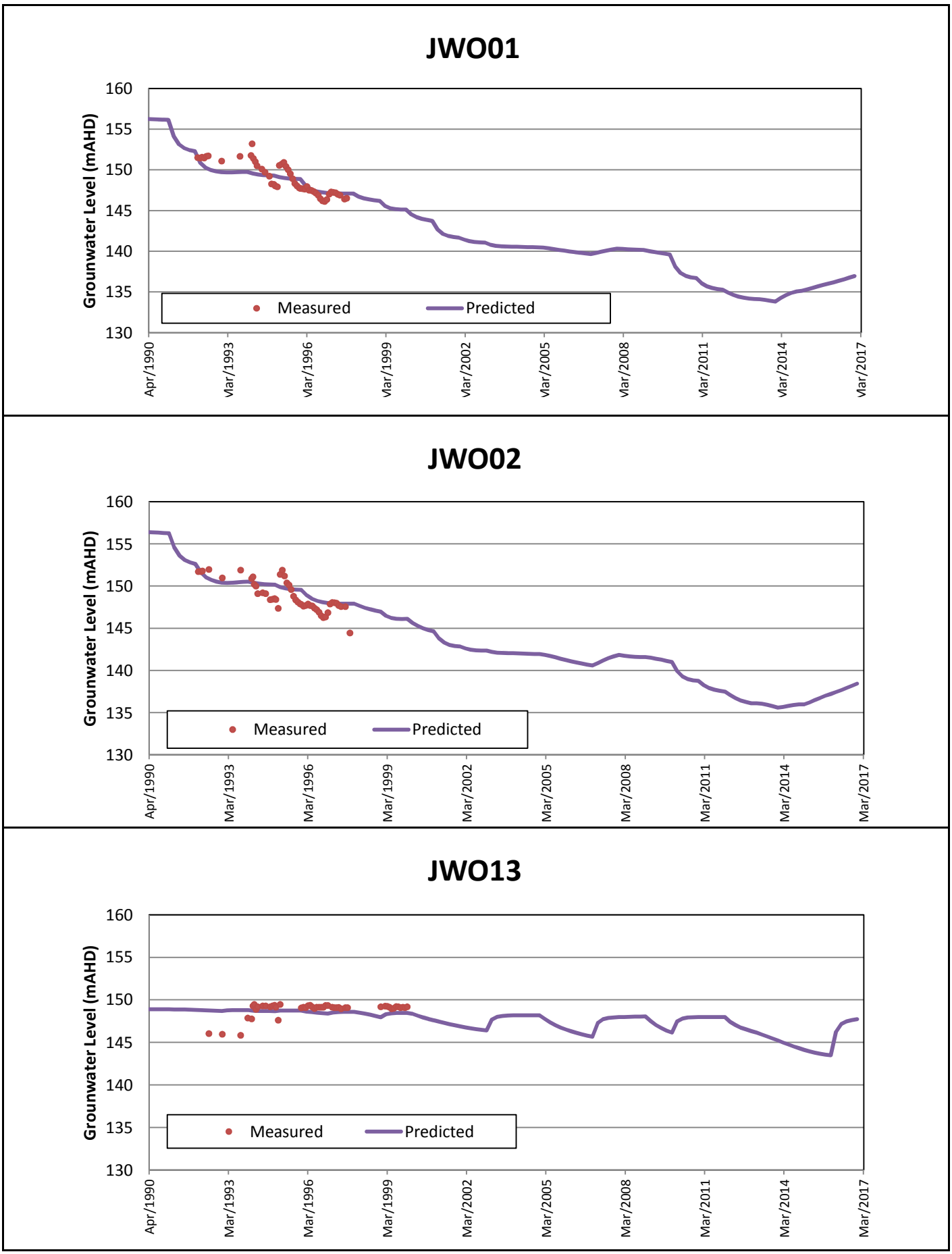
Grounwater Level (mAHD)
160
155
150
145
140
135
130
Measured
Predicted
Apr/1990
Mar/1993
Mar/1996
Mar/1999
Mar/2002
Mar/2005
Mar/2008
Mar/2011
Mar/2014
Mar/2017
JWO33
Grounwater Level (mAHD)
160
155
150
145
140
135
130
Measured
Predicted
Apr/1990
Mar/1993
Mar/1996
Mar/1999
Mar/2002
Mar/2005
Mar/2008
Mar/2011
Mar/2014
Mar/2017
JWO08
Grounwater Level (mAHD)
160
155
150
145
140
135
130
Measured
Predicted
Apr/1990
Mar/1993
Mar/1996
Mar/1999
Mar/2002
Mar/2005
Mar/2008
Mar/2011
Mar/2014
Mar/2017



CALIBRATION HYDROGRAPHS FIGURE A10

S\09_Groundwater Modelling\02_Projects\Mesa_H\2018\Groundwater Model\Modelling\Model Results\calibration\[CT47revc Calibration_Hydrographs.xlsx]Figure A10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135
130
Measured
Predicted
Apr/1990
Mar/1993
Mar/1996
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Mar/2002
Mar/2005
Mar/2008
Mar/2011
Mar/2014
Mar/2017
JWO02
Grounwater Level (mAHD)
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Measured
Predicted
Apr/1990
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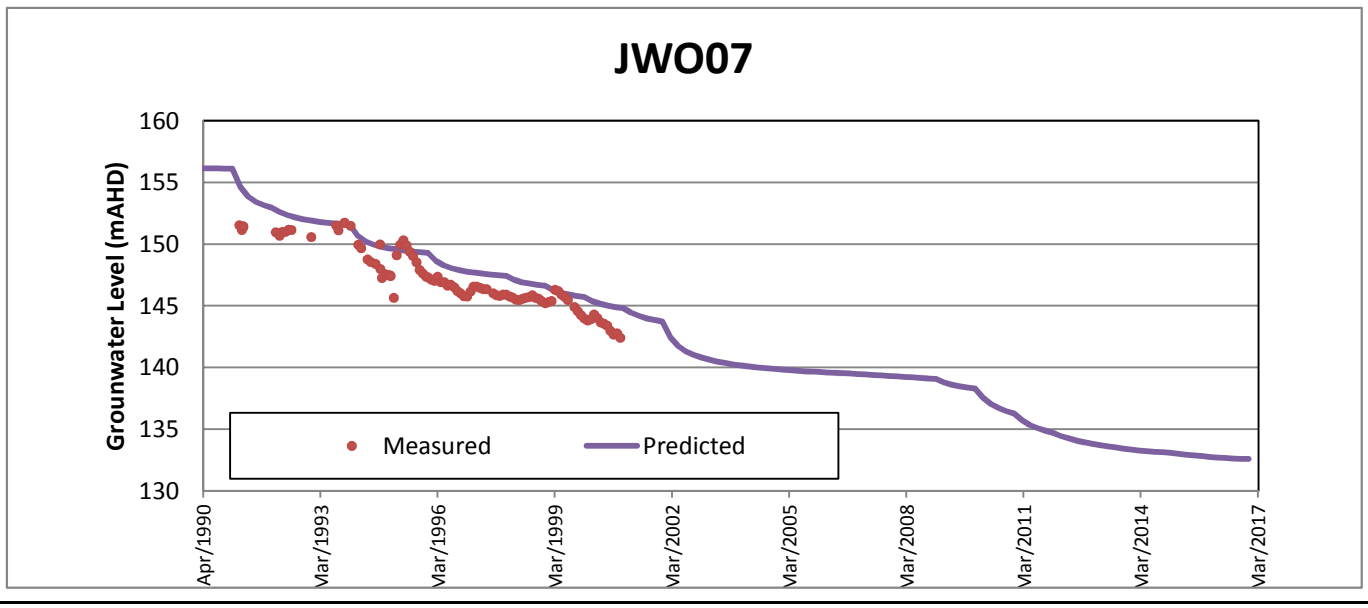
Mar/1999
Mar/2002
Mar/2005
Mar/2008
Mar/2011
Mar/2014
Mar/2017
JWO13
Grounwater Level (mAHD)
160
155
150
145
140
135
130
Measured
Predicted
Apr/1990
Mar/1993
Mar/1996
Mar/1999
Mar/2002
Mar/2005
Mar/2008
Mar/2011
Mar/2014
Mar/2017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Grounwater Level (mAHD)
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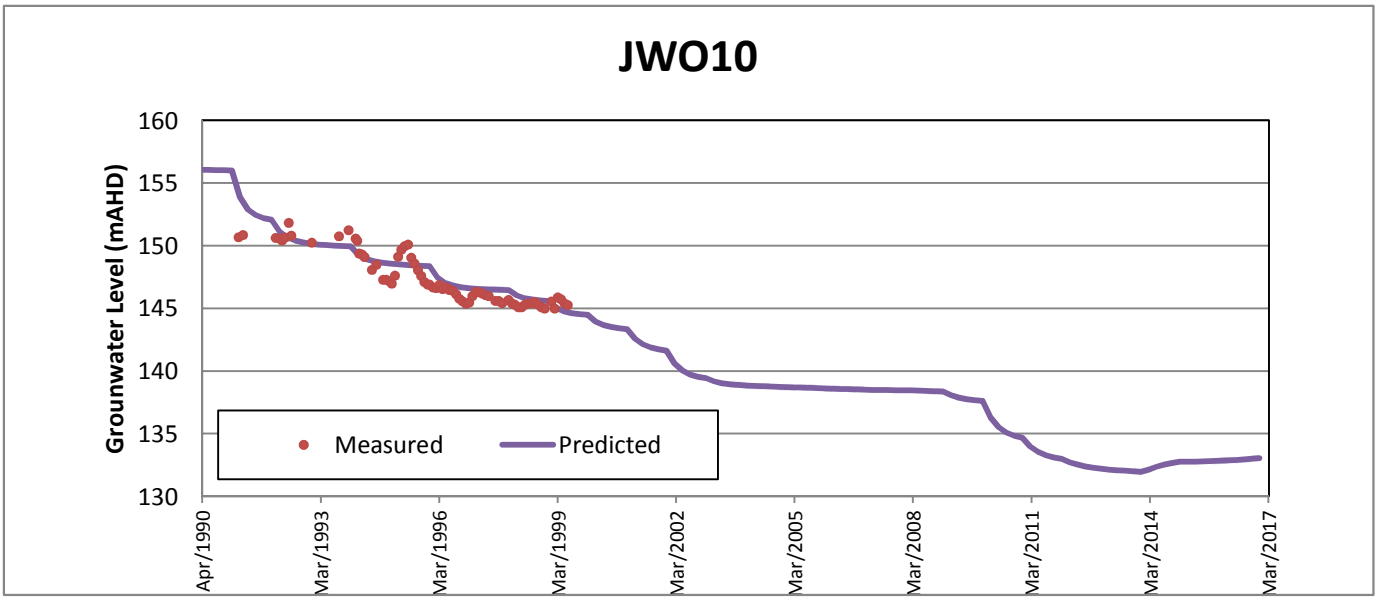
145
140
135
130
Measured
Predicted
Apr/1990
Mar/1993
Mar/1996
Mar/1999
Mar/2002
Mar/2005
Mar/2008
Mar/2011
Mar/2014
Mar/2017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Grounwater Level (mAHD)
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150
145
140
135
130
Measured
Predicted
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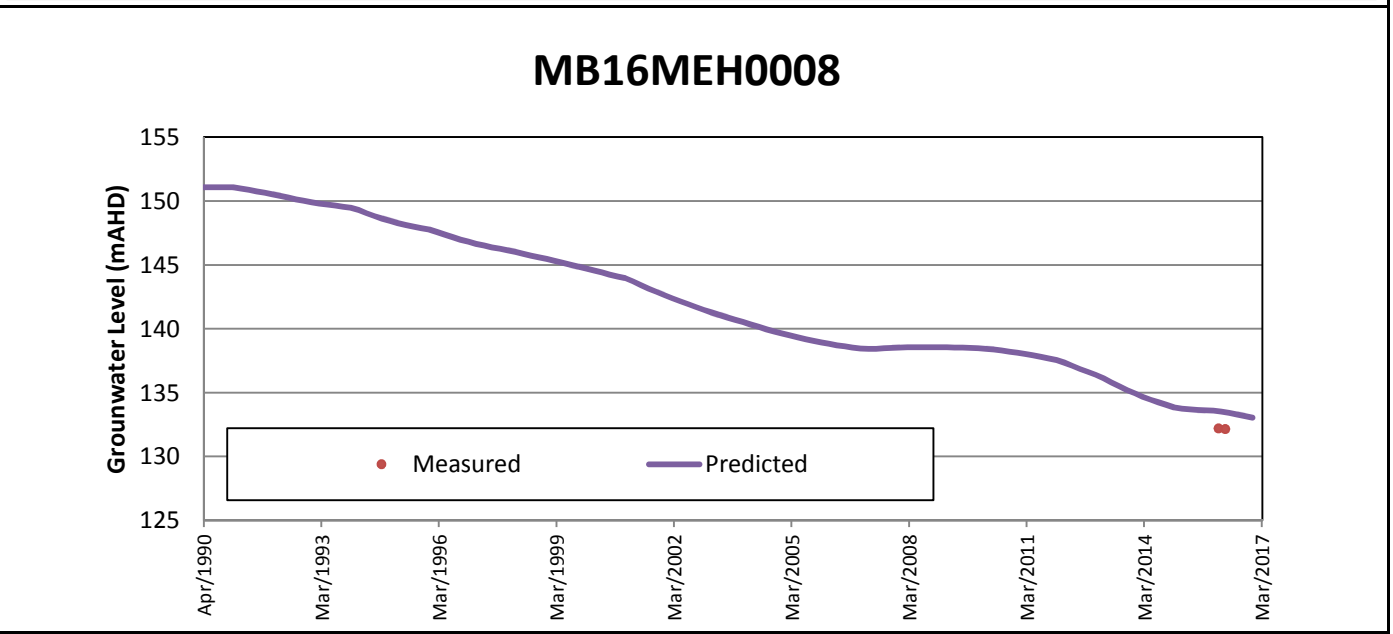
Mar/1993
Mar/1996
Mar/1999
Mar/2002
Mar/2005
Mar/2008
Mar/2011
Mar/2014
Mar/2017


MB16MEH0008
Grounwater Level (mAHD)
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Measured
Predicted
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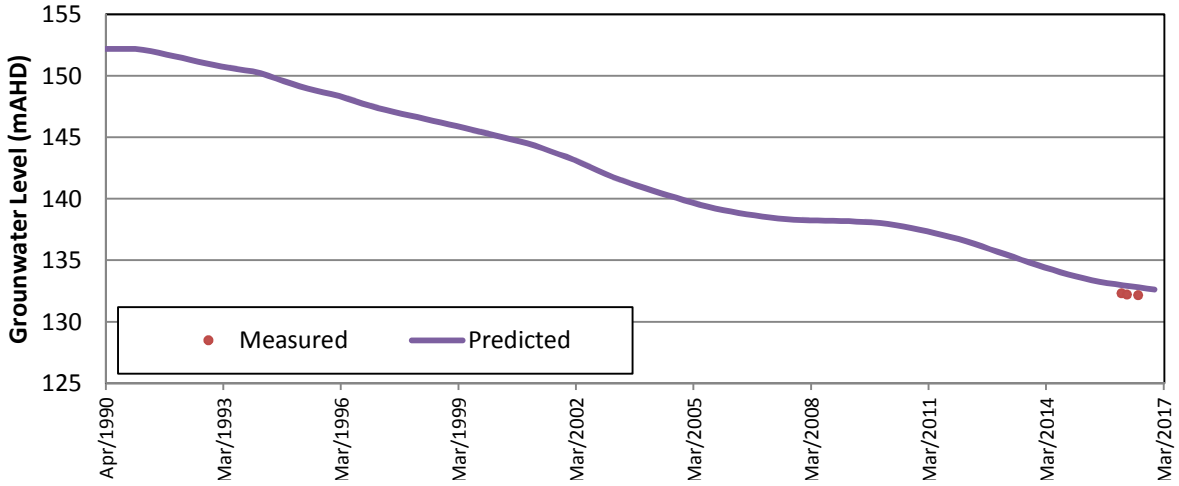
Mar/2002
Mar/2005
Mar/2008
Mar/2011
Mar/2014
Mar/2017

MB16MEH0018



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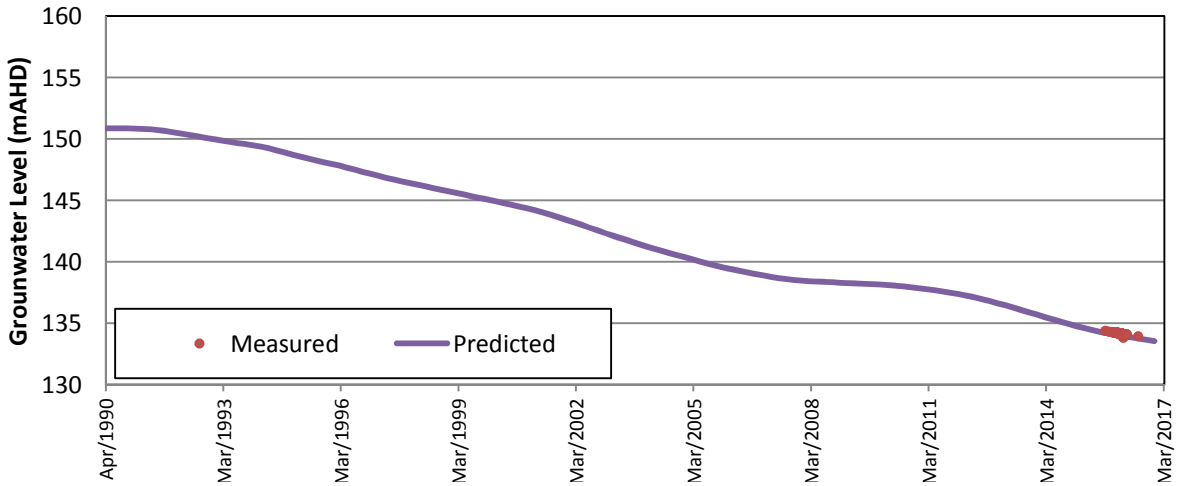

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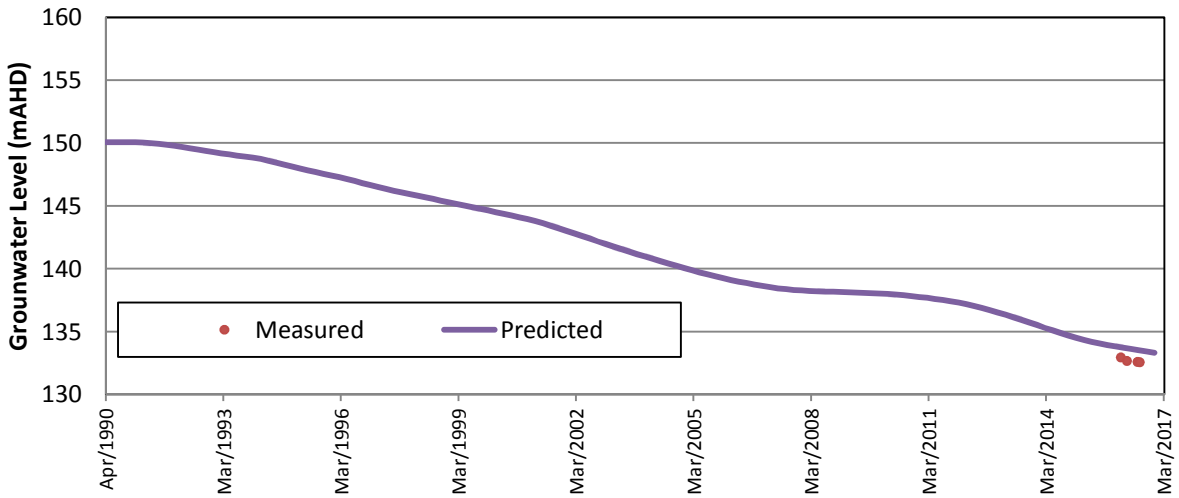

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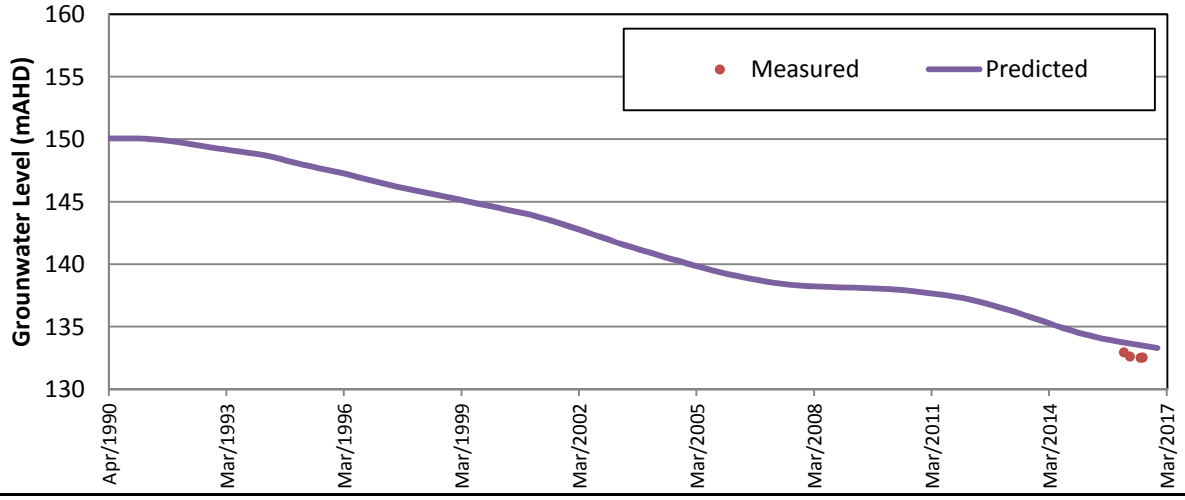

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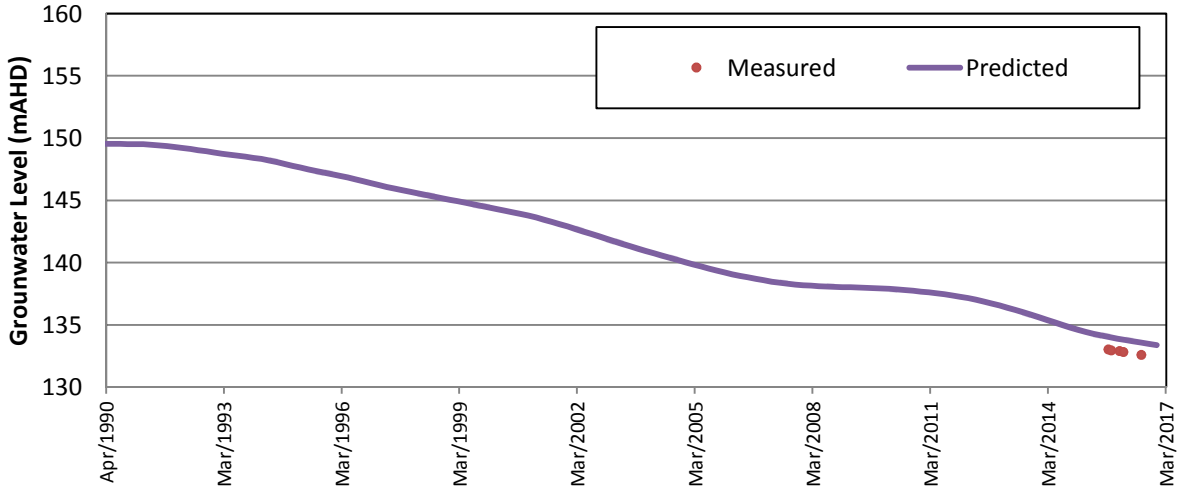

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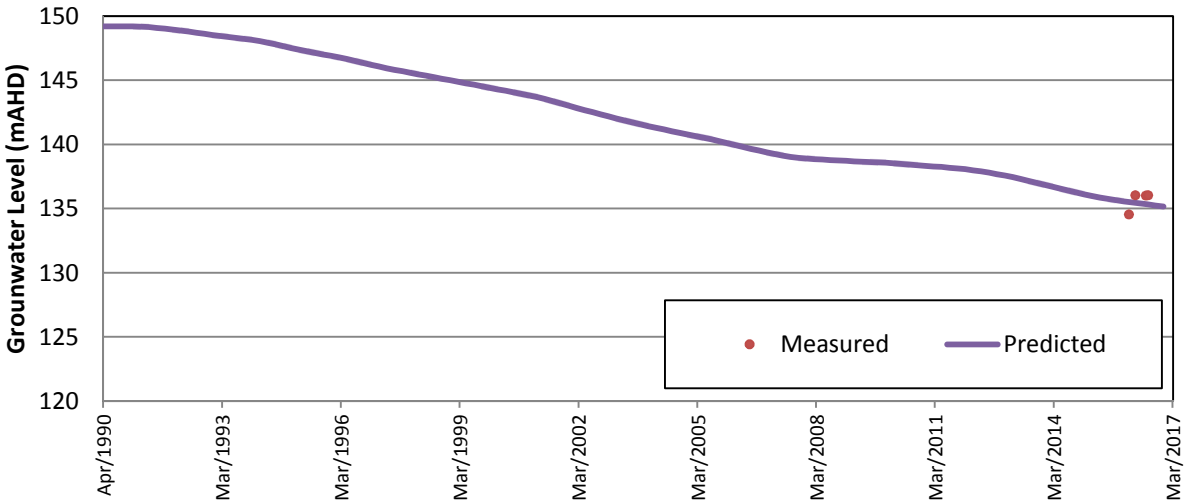

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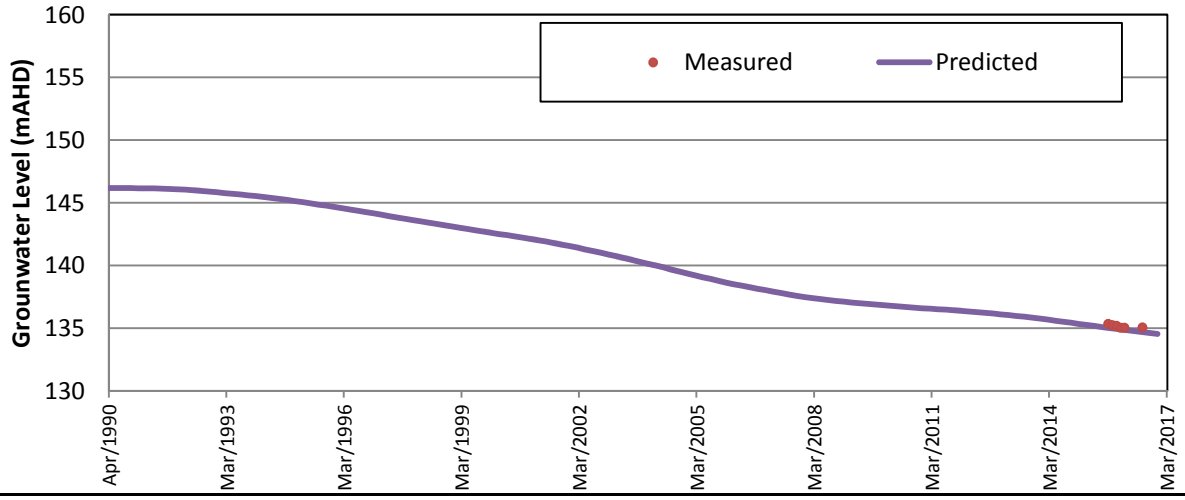

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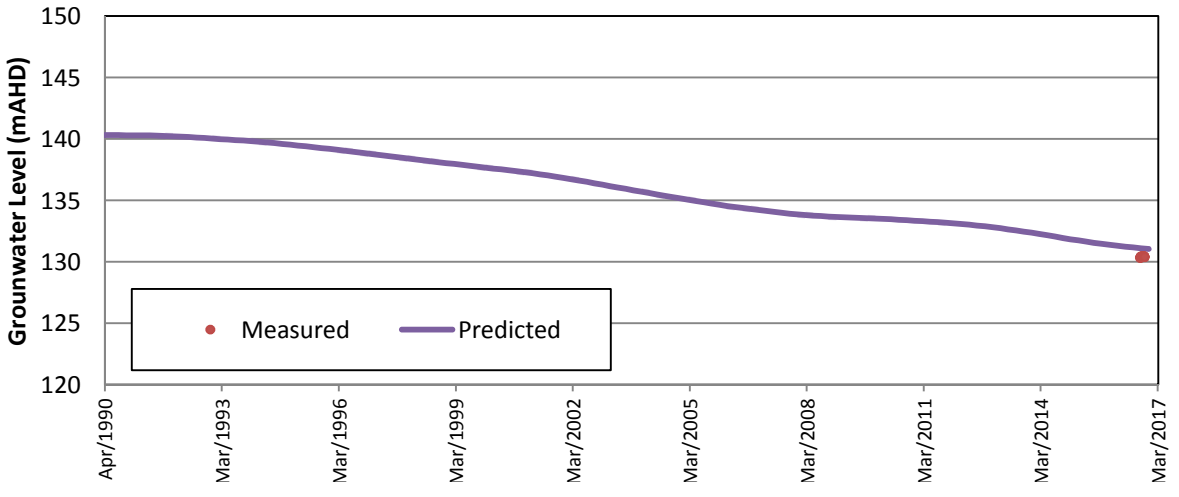

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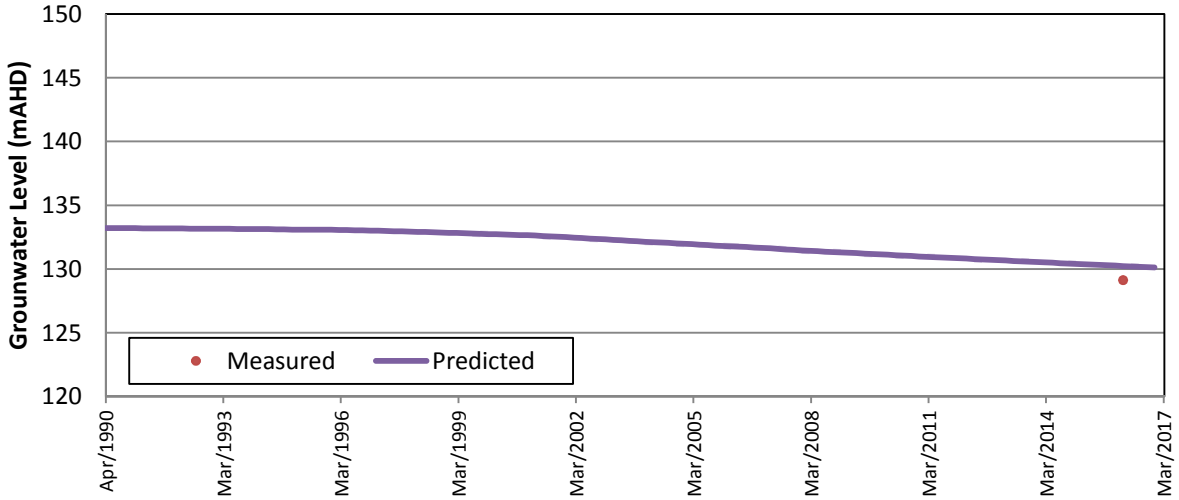

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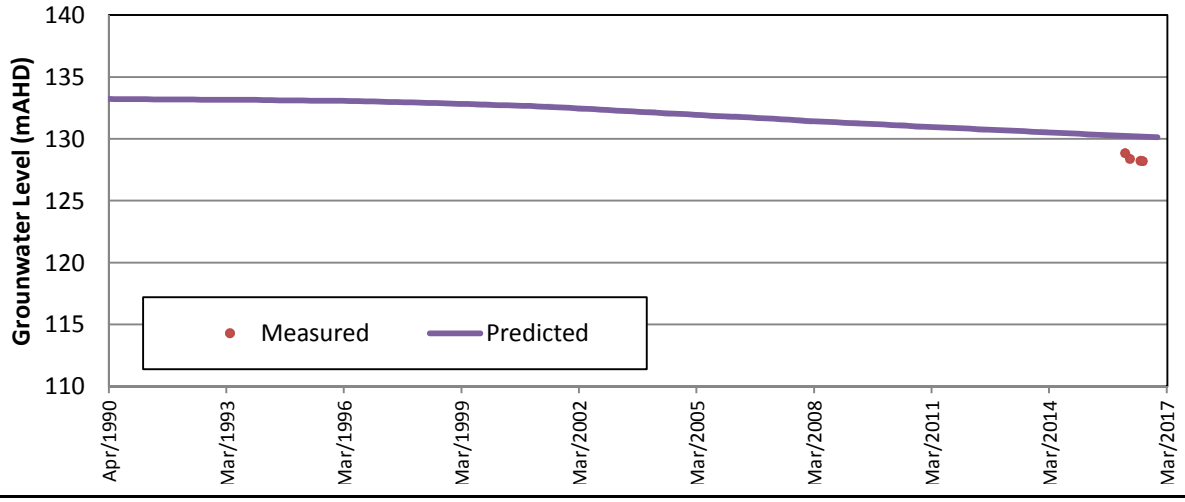

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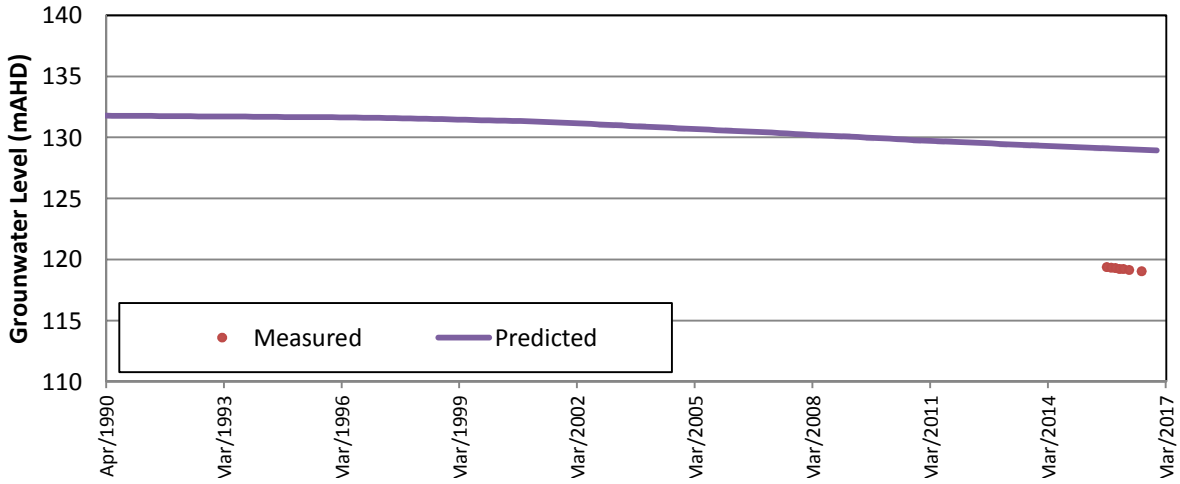

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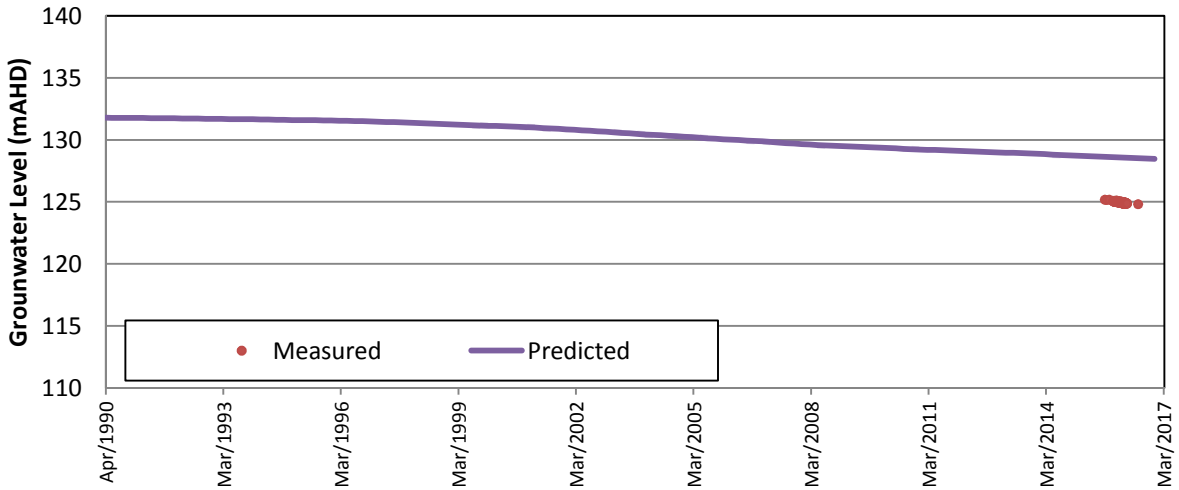

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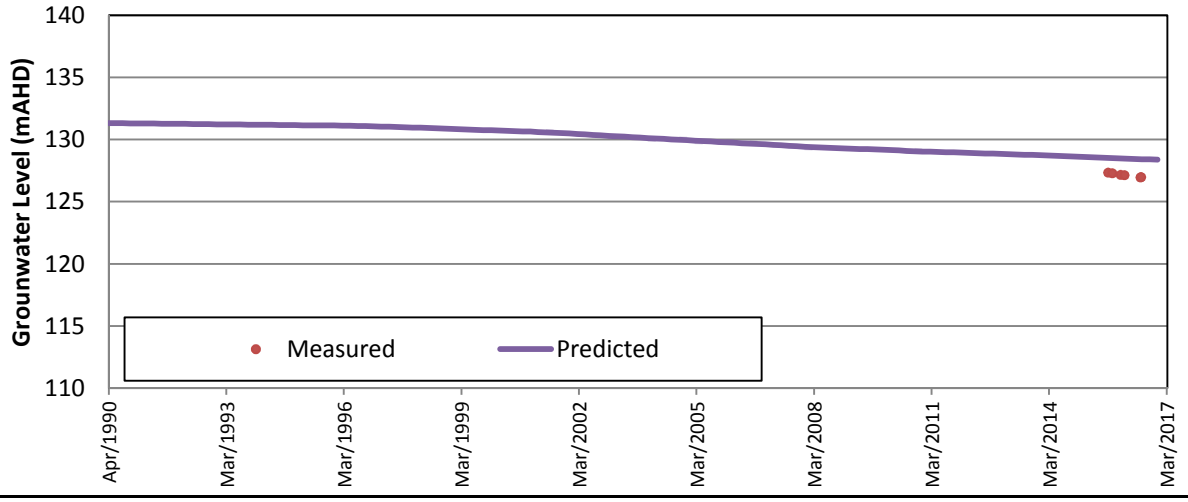

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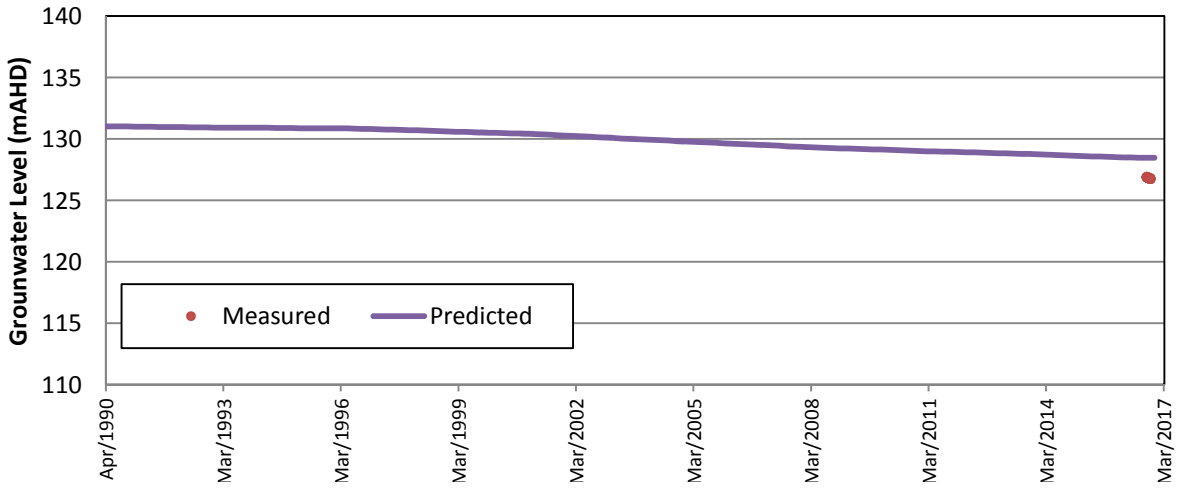

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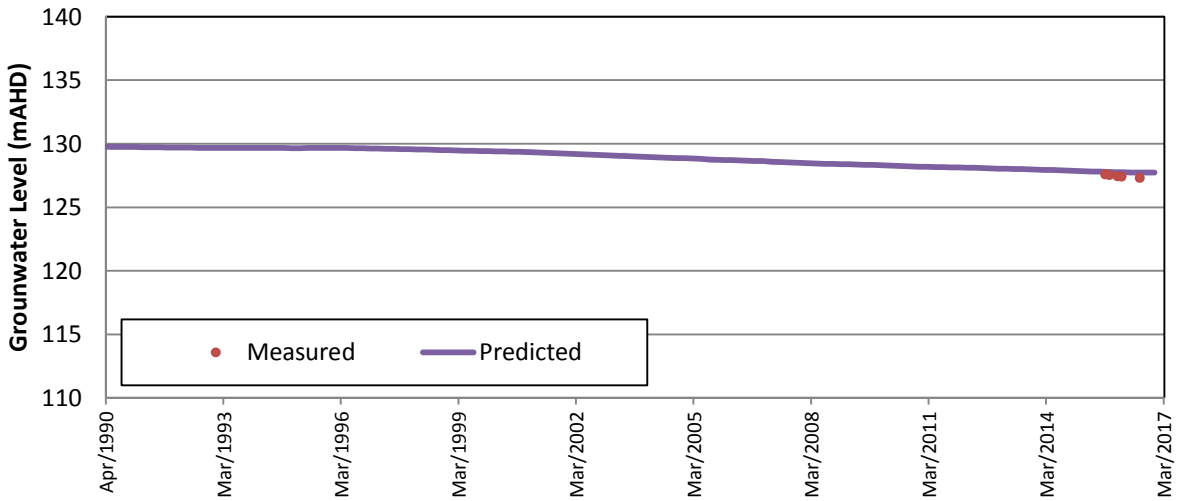

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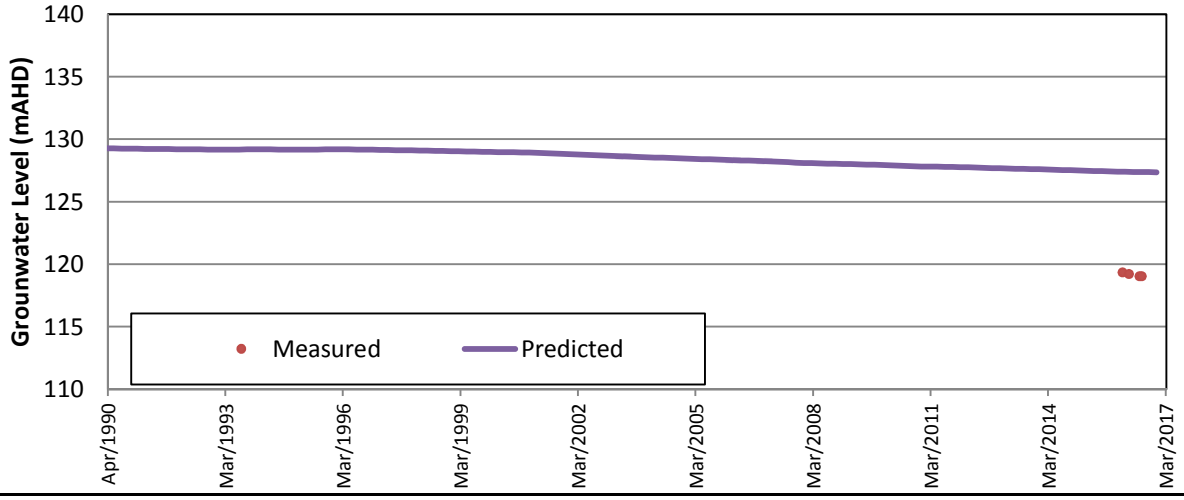

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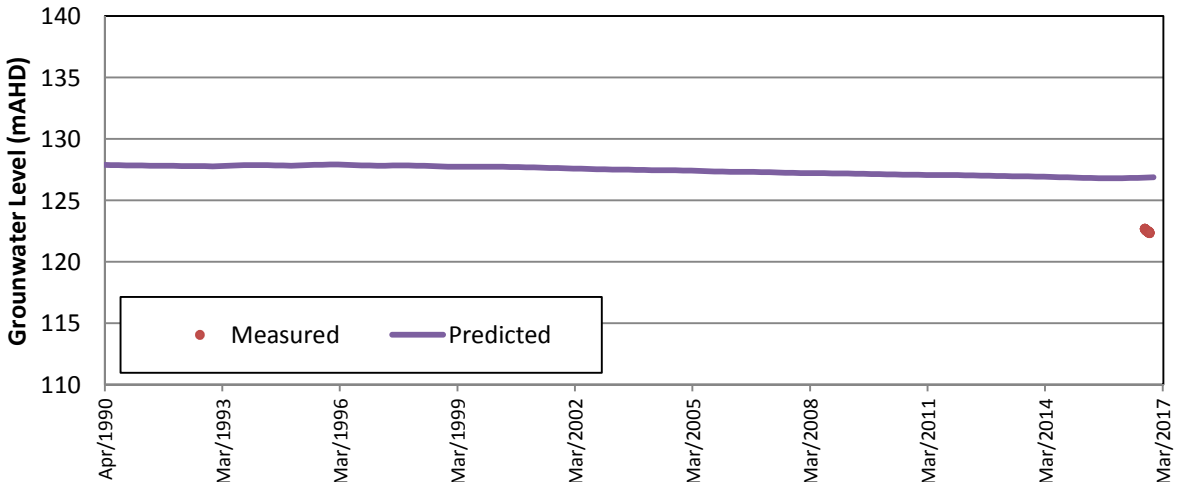

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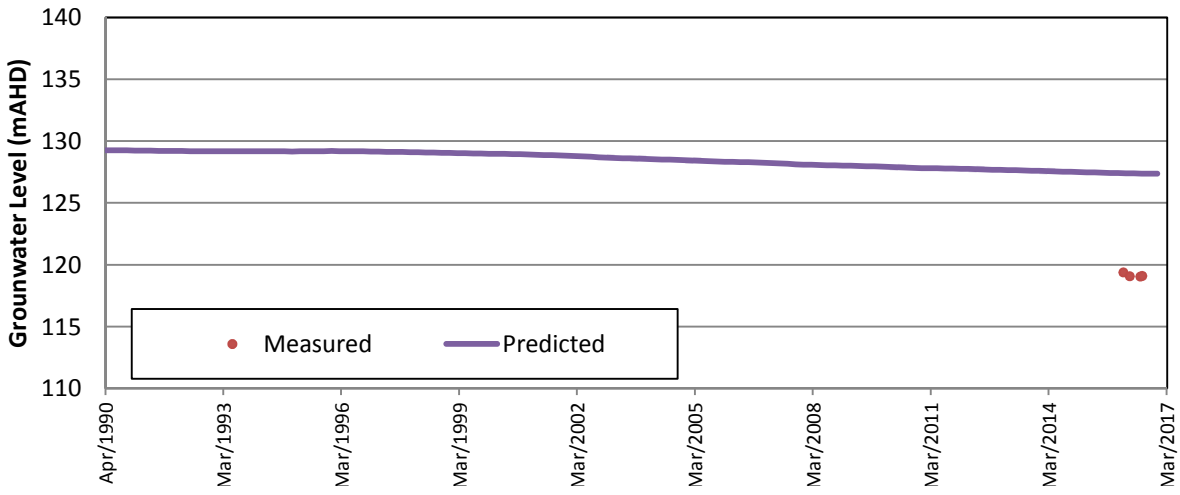

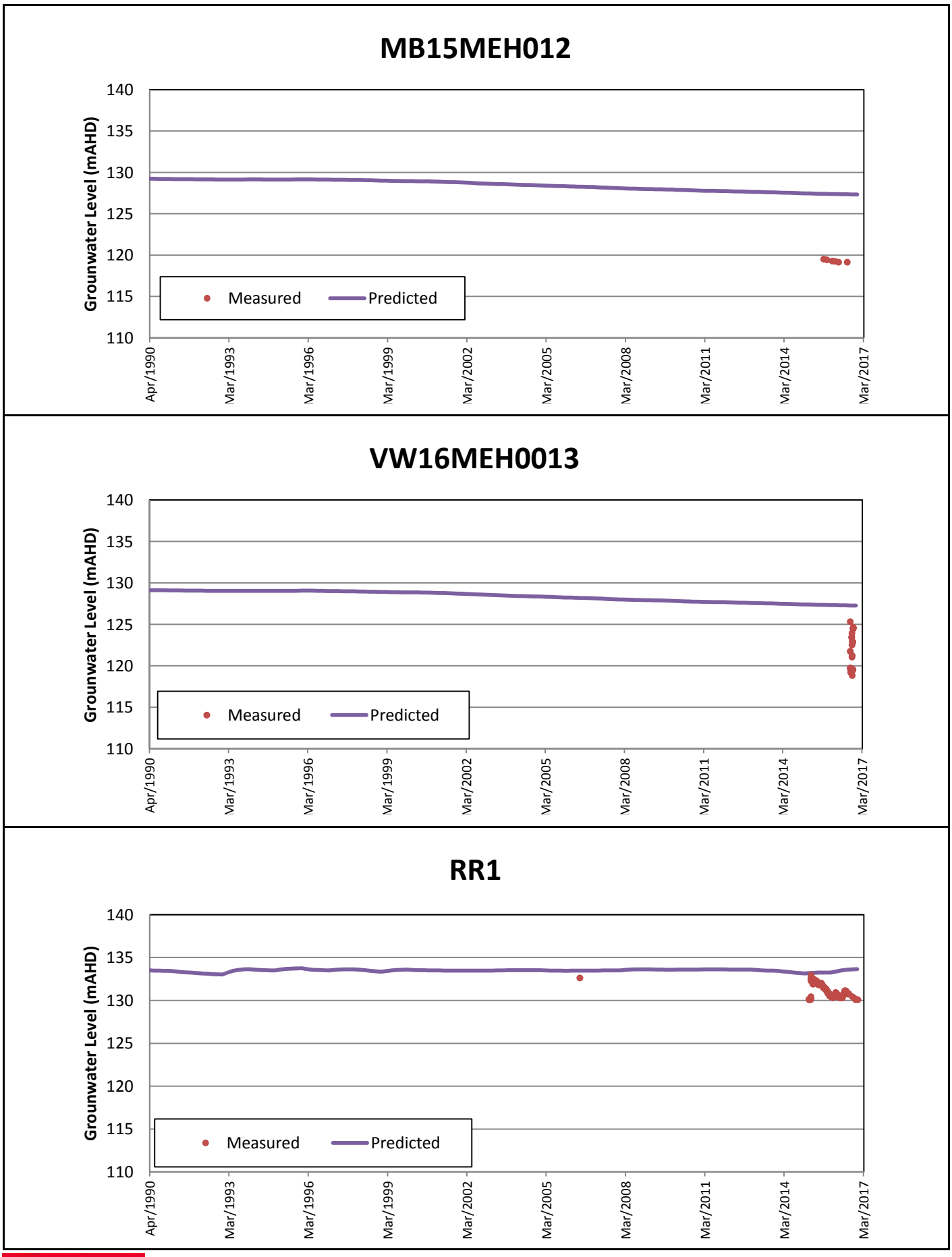
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135
130
125
120
115
110
Measured
Predicted
Apr/1990
Mar/1993
Mar/1996
Mar/1999
Mar/2002
Mar/2005
Mar/2008
Mar/2011
Mar/2014
Mar/2017
VW16MEH0013
Grounwater Level (mAHD)
140
135
130
125
120
115
110
Measured
Predicted
Apr/1990
Mar/1993
Mar/1996
Mar/1999
Mar/2002
Mar/2005
Mar/2008
Mar/2011
Mar/2014
Mar/2017
RR1
Grounwater Level (mAHD)
140
135
130
125
120
115
110
Measured
Predicted
Apr/1990
Mar/1993
Mar/1996
Mar/1999
Mar/2002
Mar/2005
Mar/2008
Mar/2011
Mar/2014
Mar/2017

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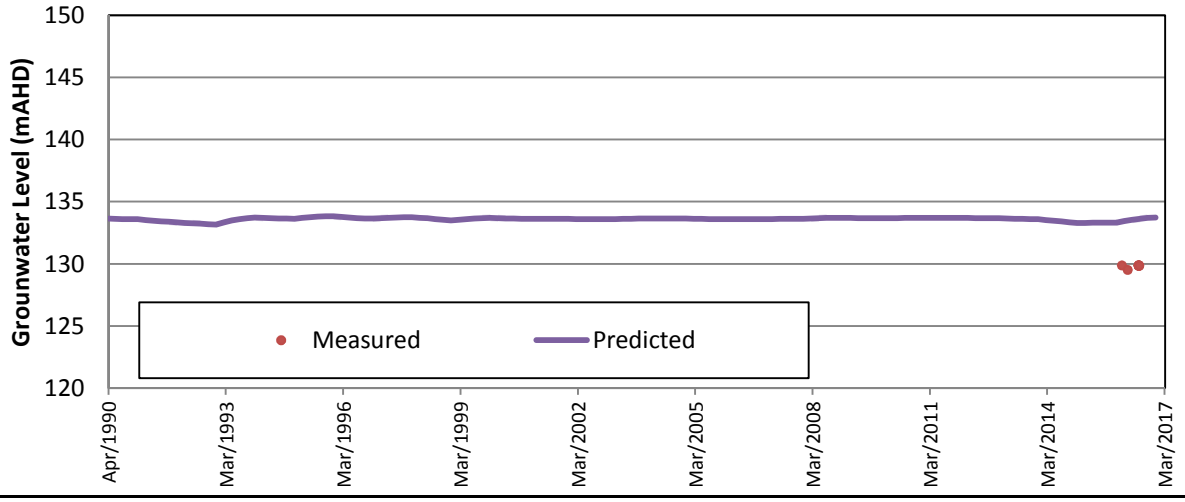

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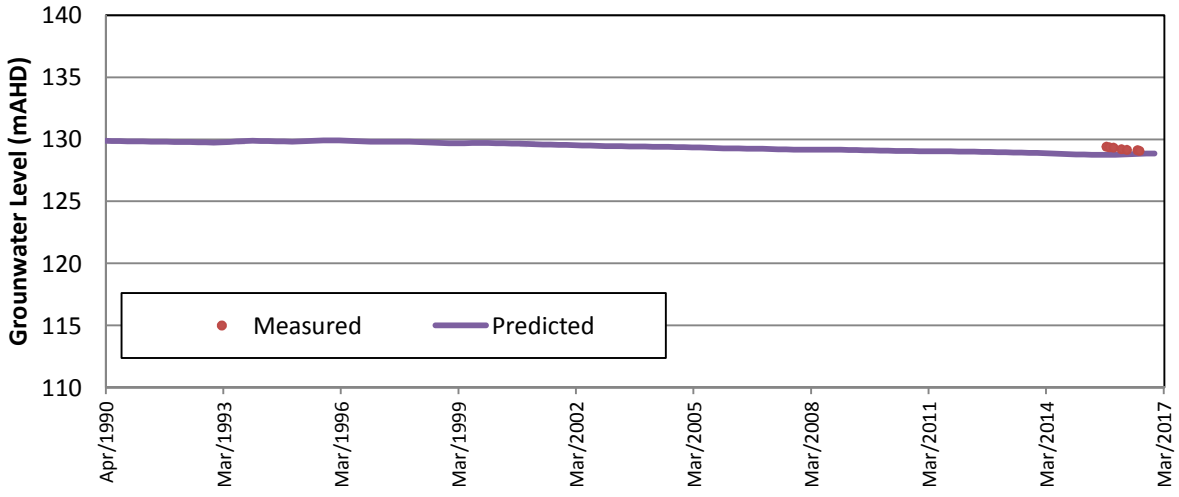

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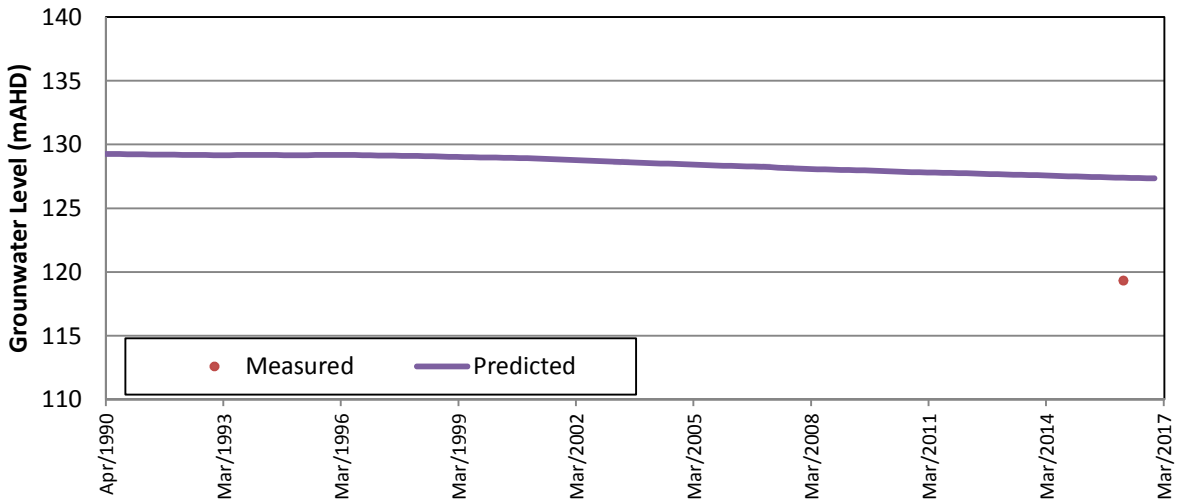

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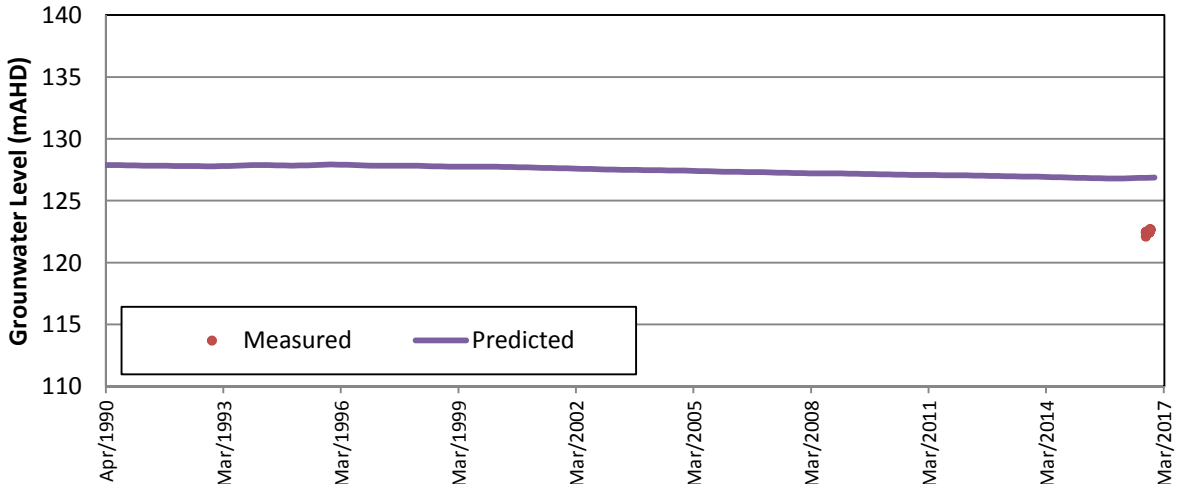

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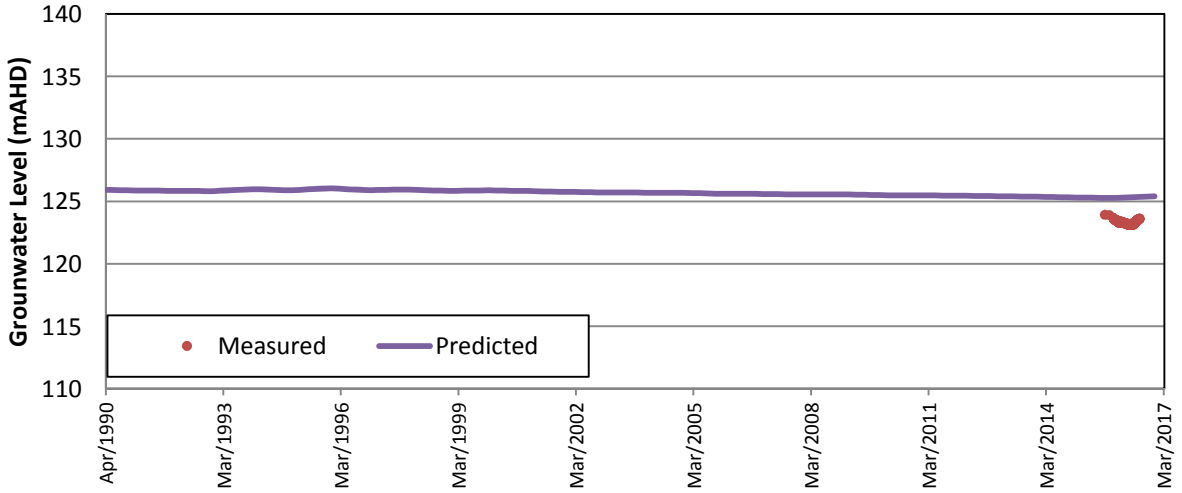

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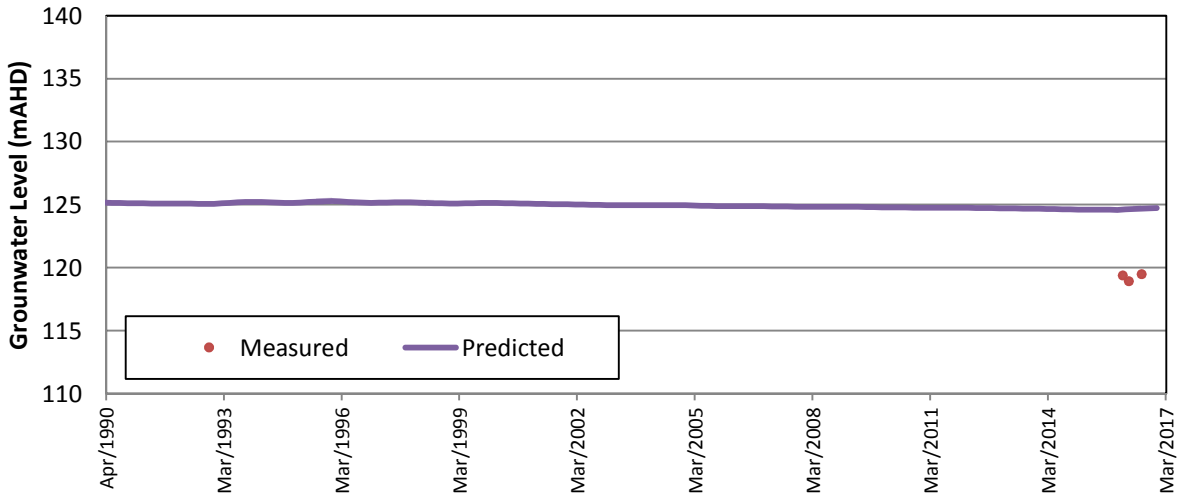
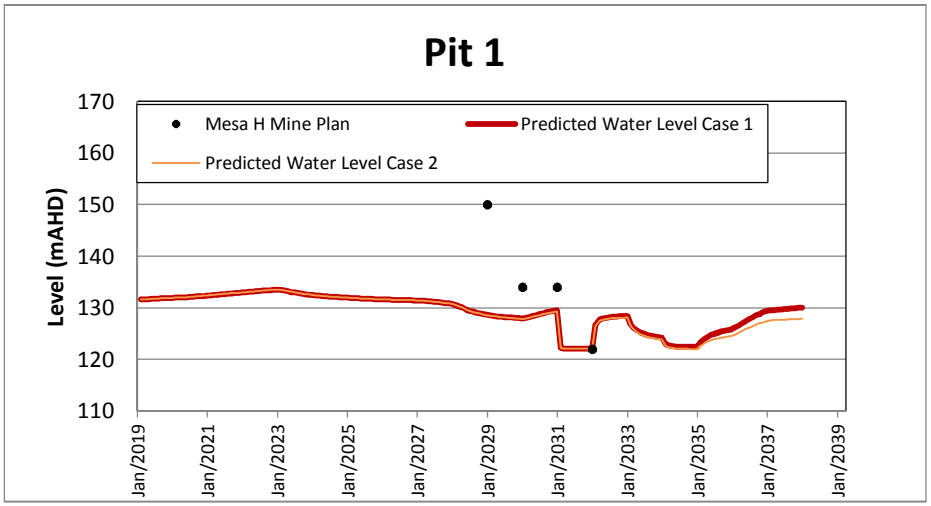
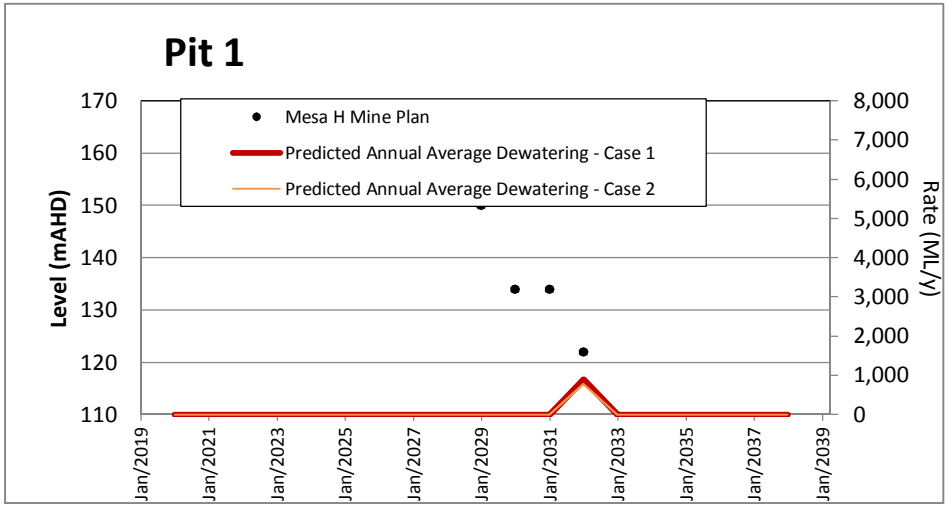
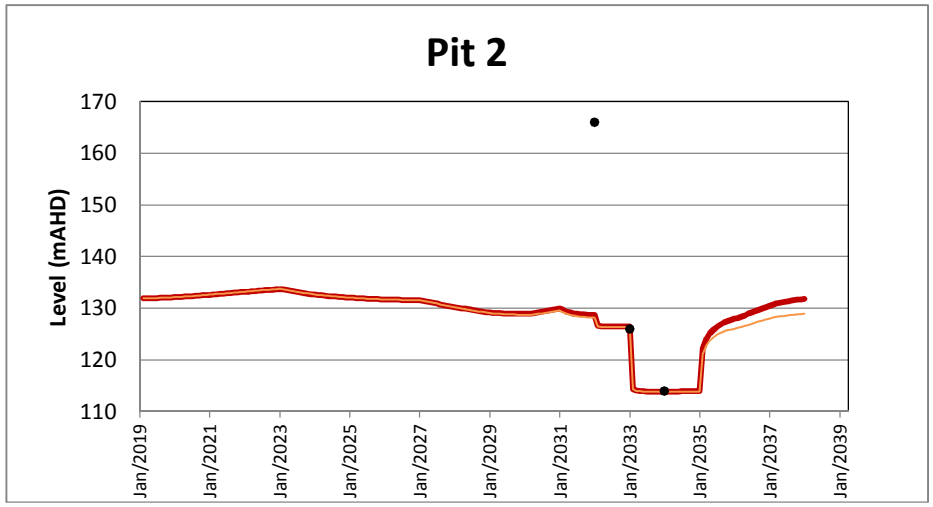
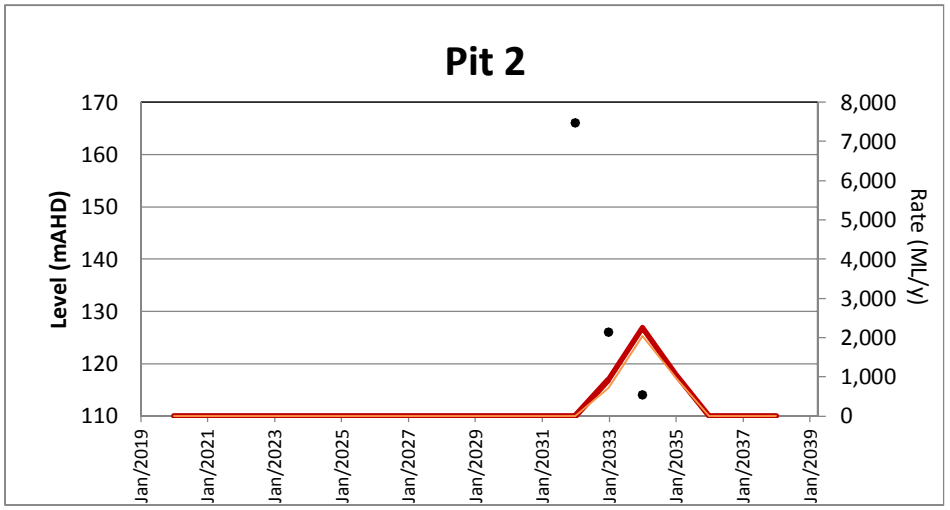


APPENDIX B
PREDICTED DEWATERING









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PREDICTION RESULTS - MESA H - DEWATERING PREDICTIONS FIGURE B1

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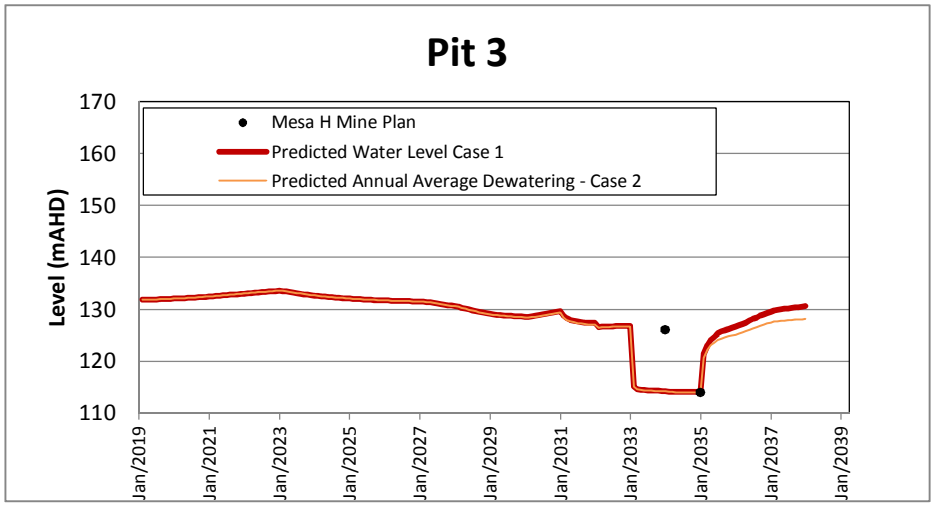

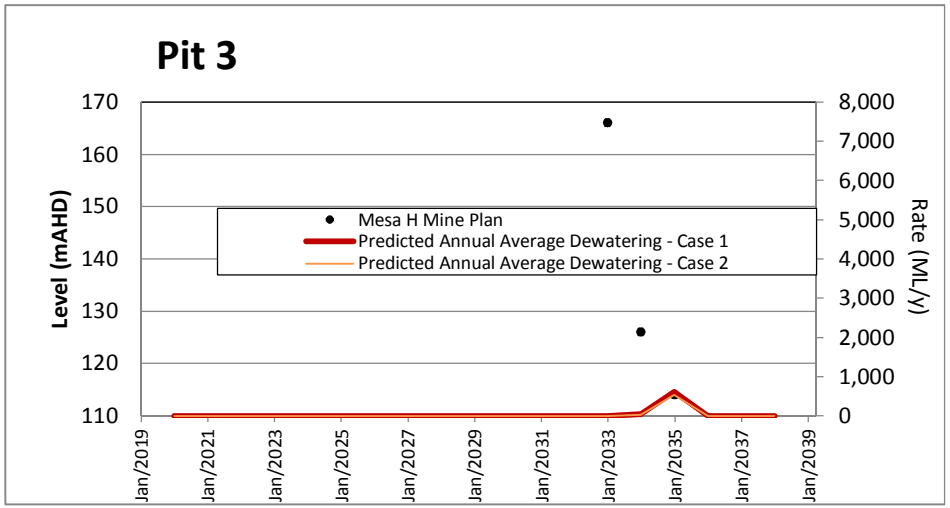

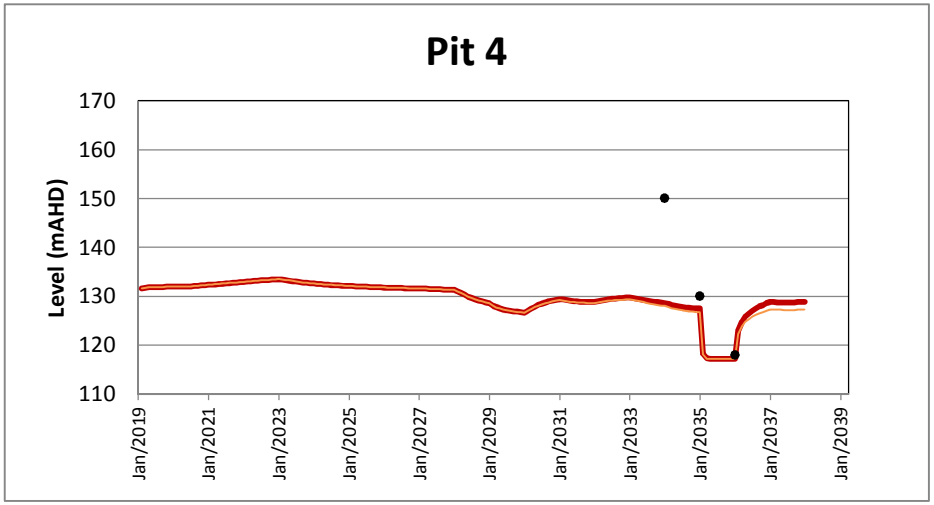

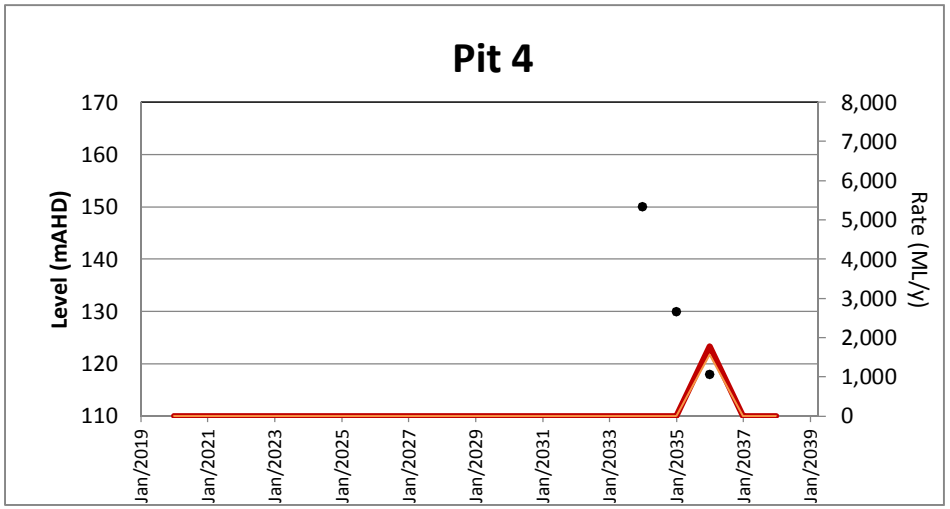

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PREDICTION RESULTS - MESA H - DEWATERING PREDICTIONS FIGURE B2

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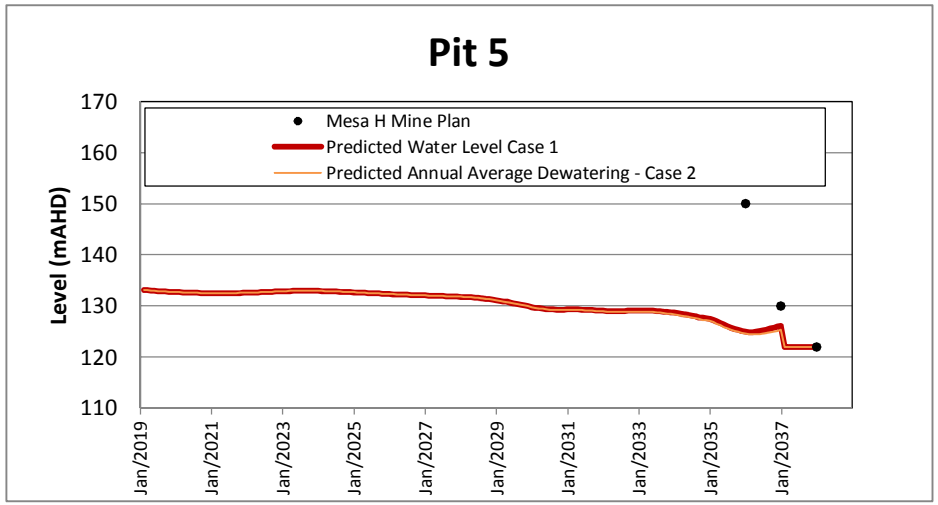

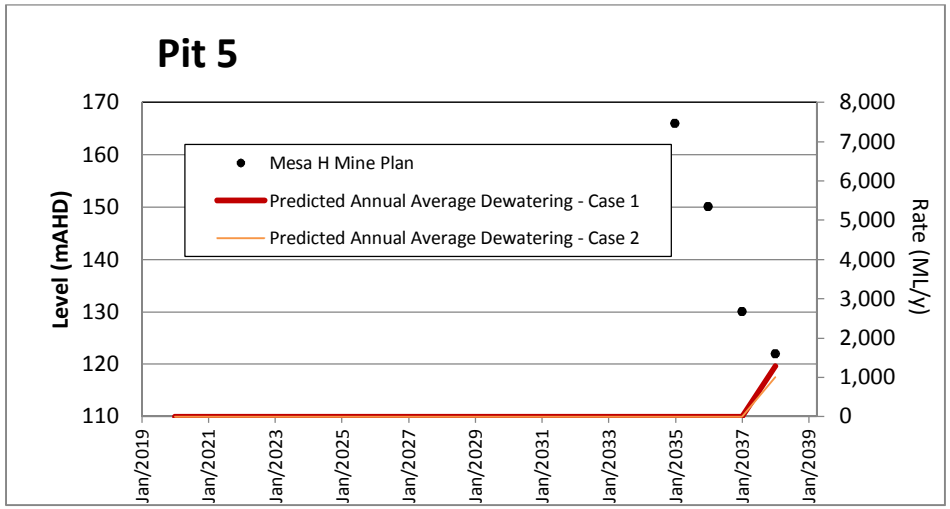

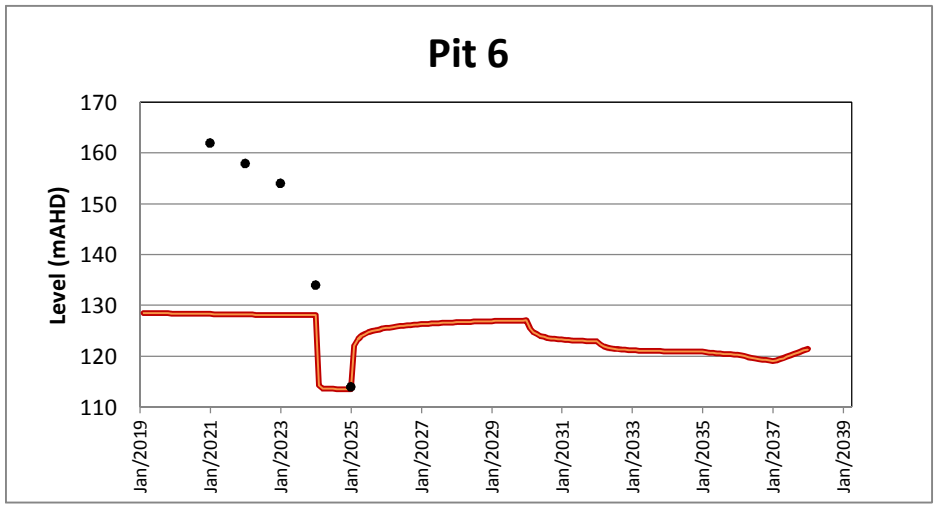

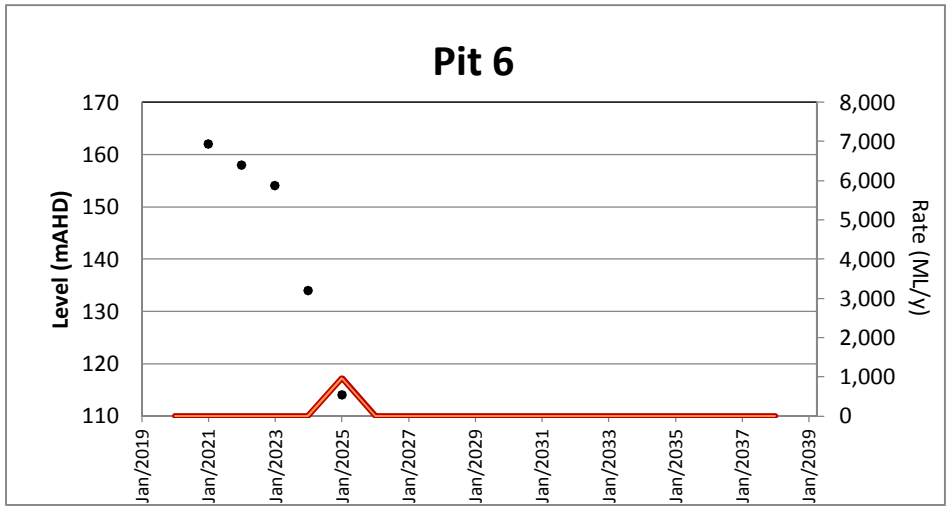

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PREDICTION RESULTS - MESA H - DEWATERING PREDICTIONS FIGURE B3

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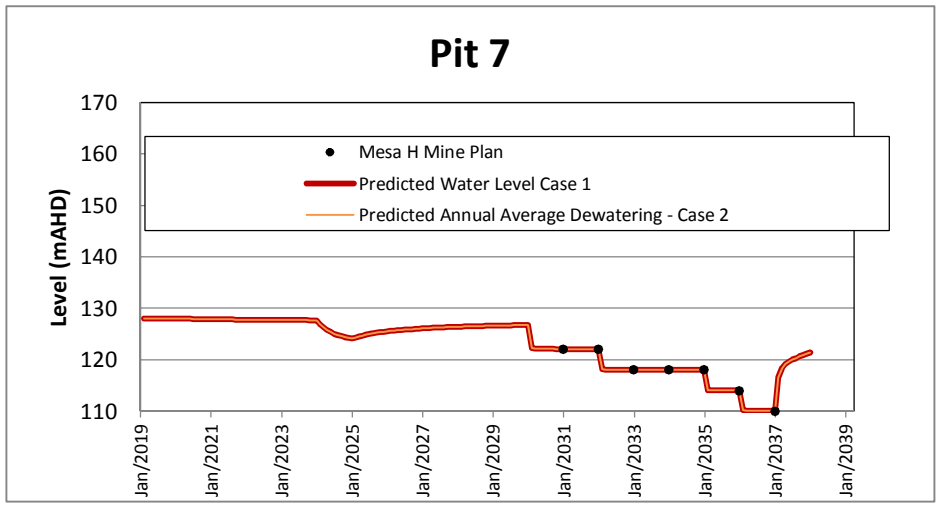

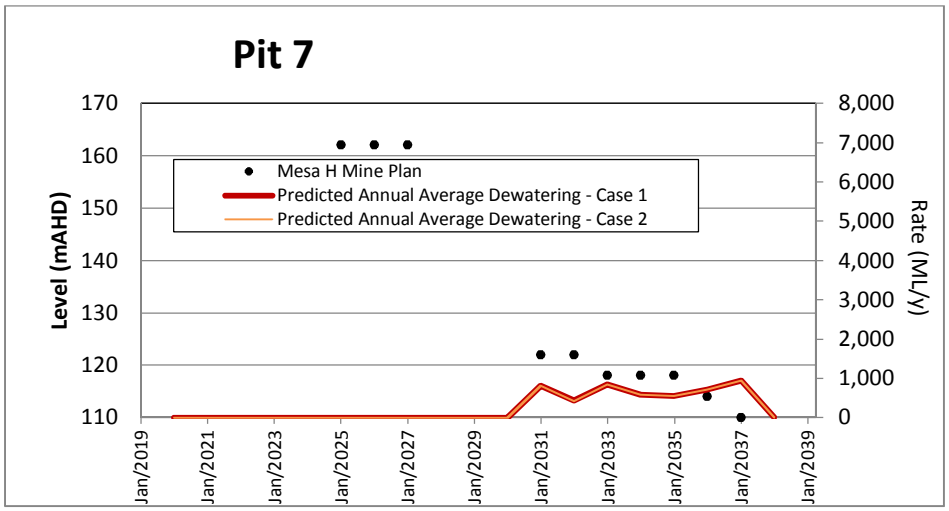

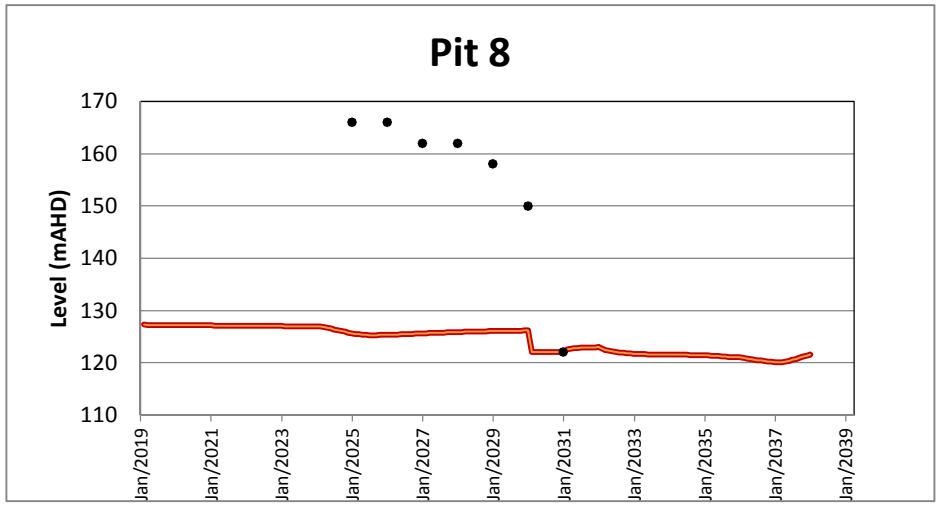

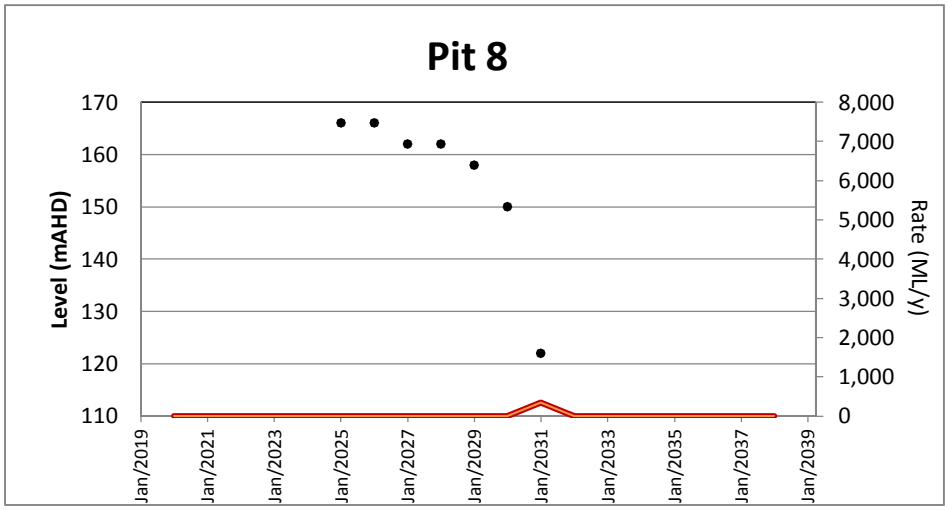

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PREDICTION RESULTS - MESA H - DEWATERING PREDICTIONS FIGURE B4

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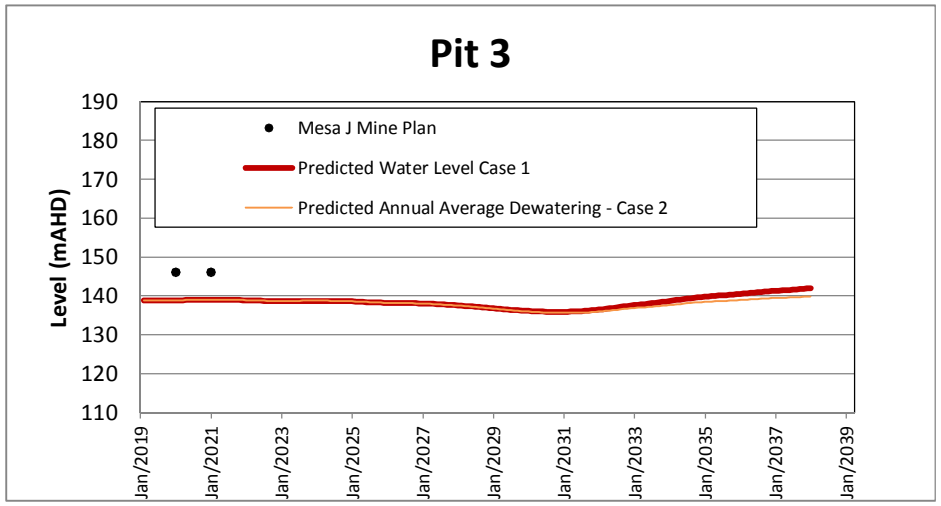

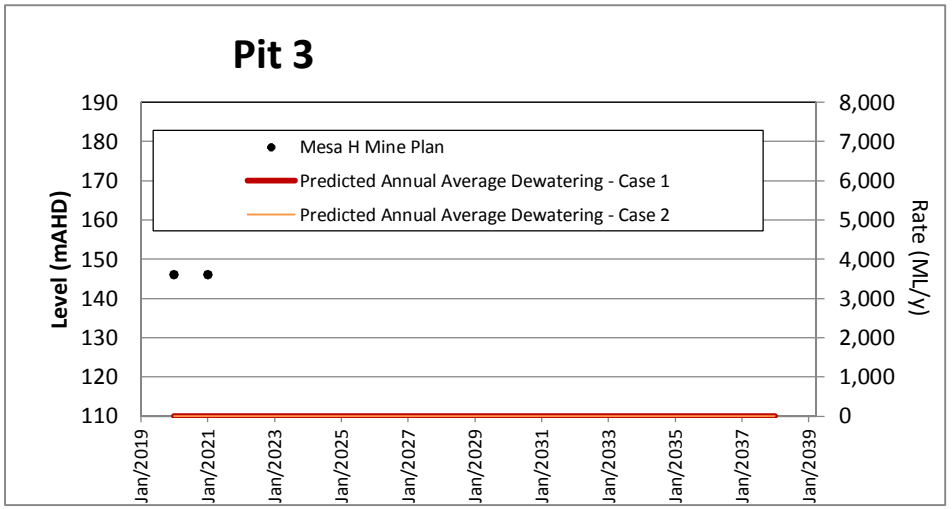

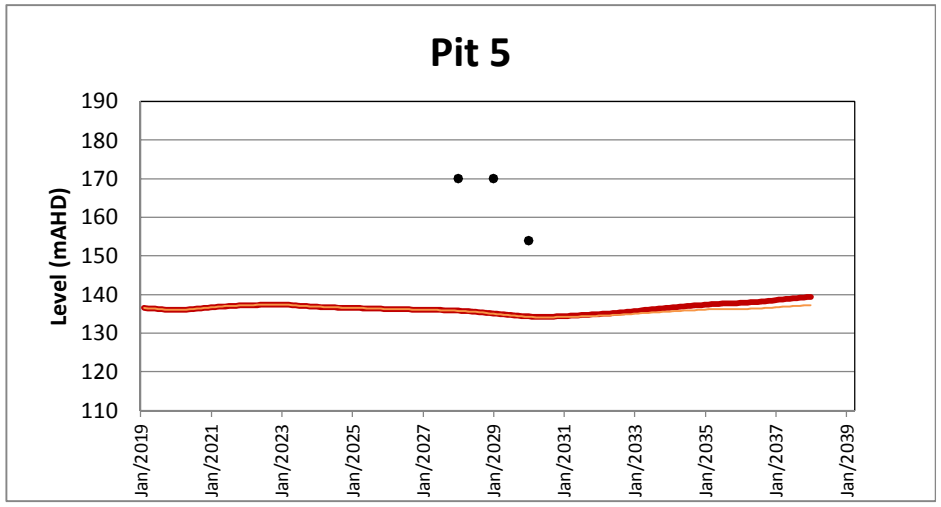

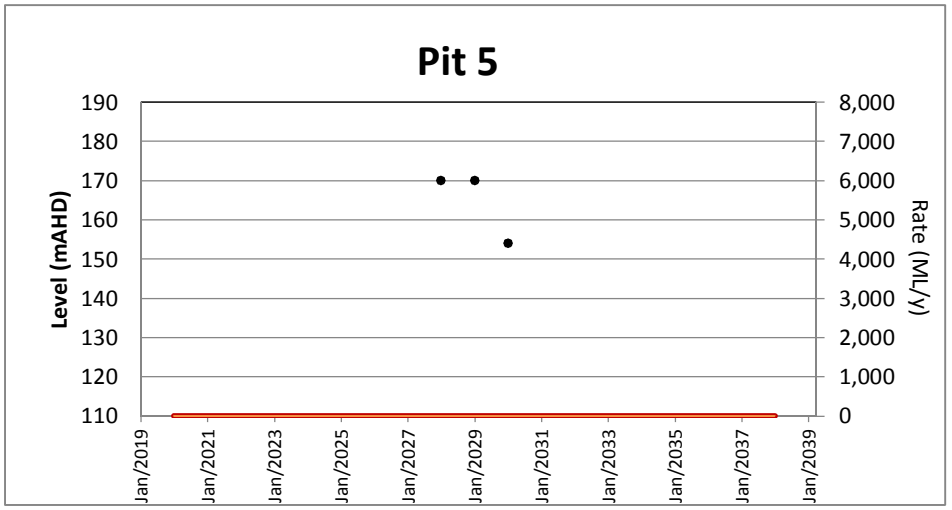

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PREDICTION RESULTS - MESA J - DEWATERING PREDICTIONS FIGURE B5

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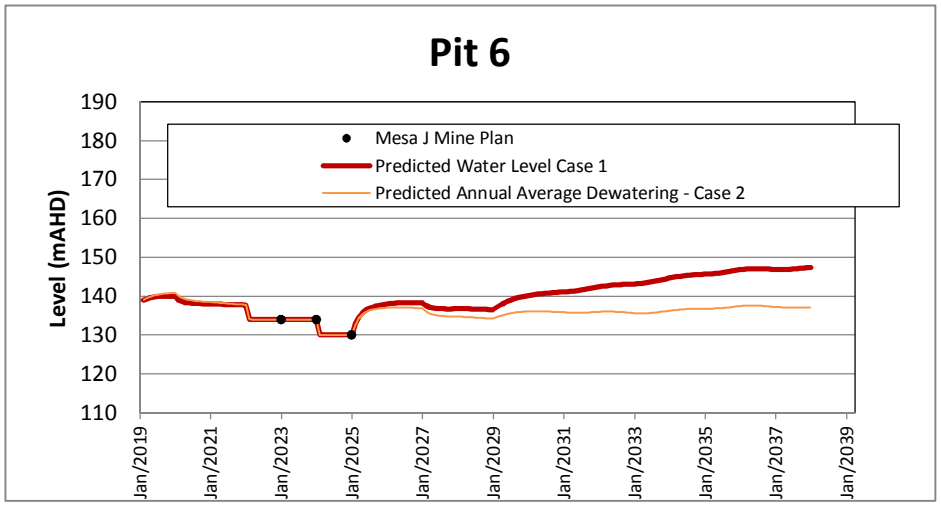

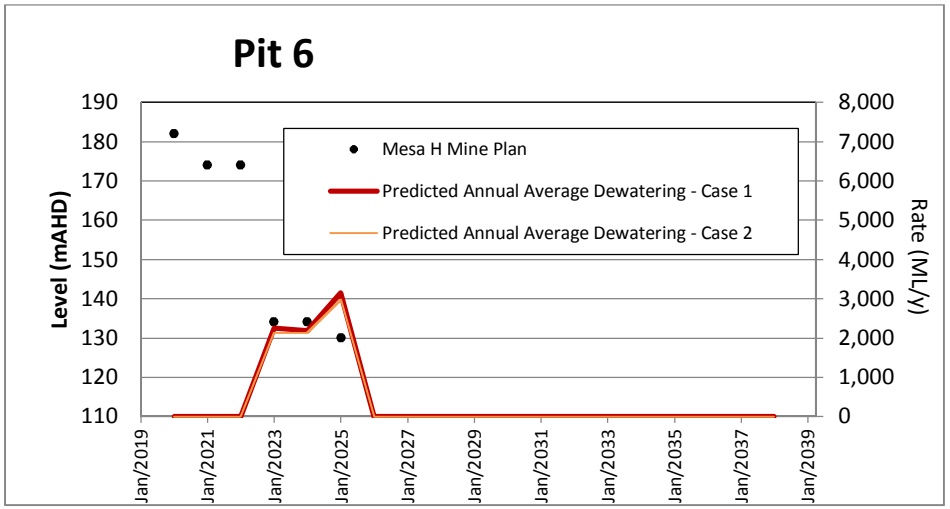

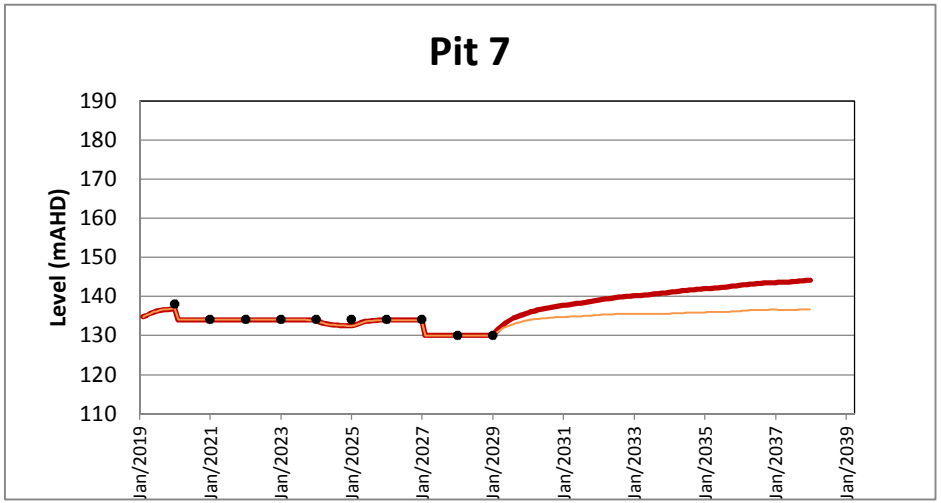

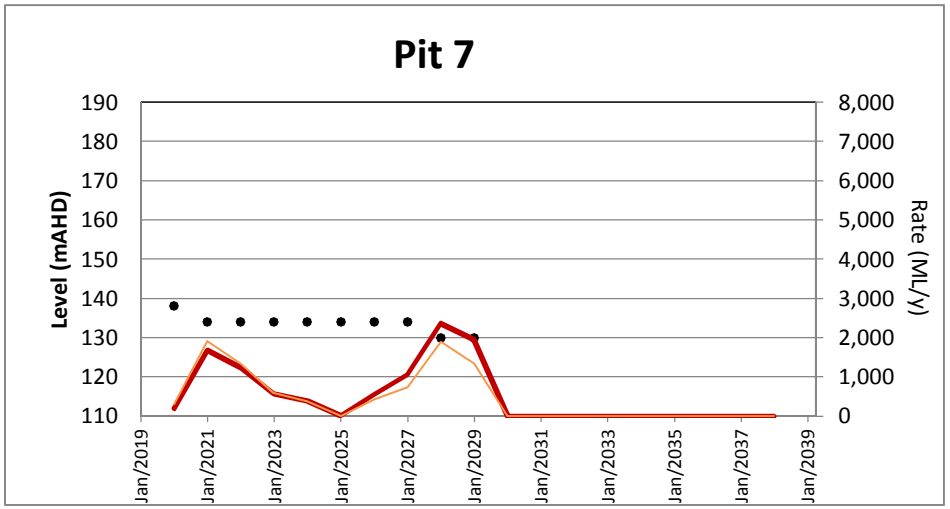

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PREDICTION RESULTS - MESA J - DEWATERING PREDICTIONS FIGURE B6

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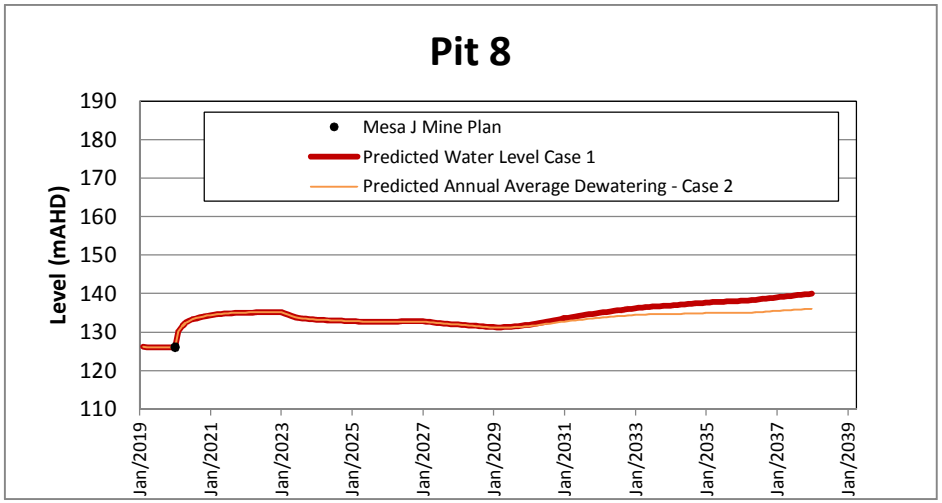

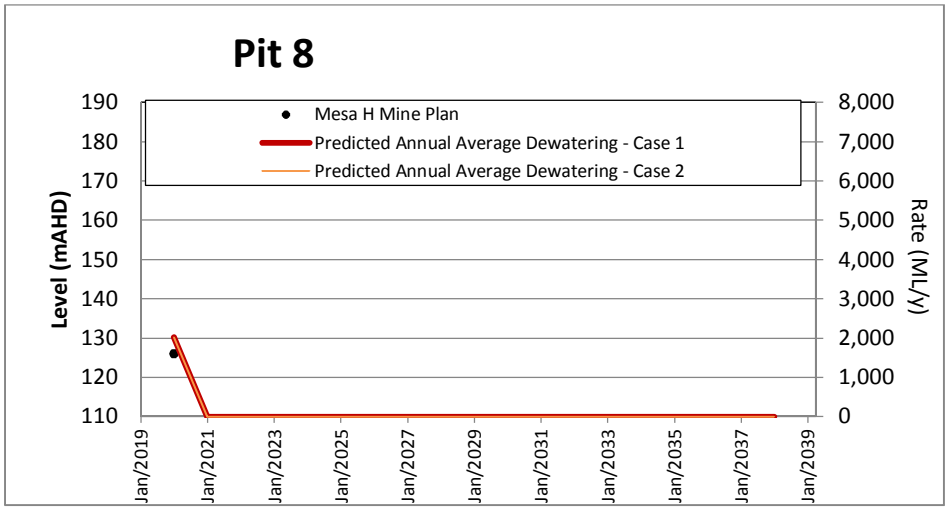

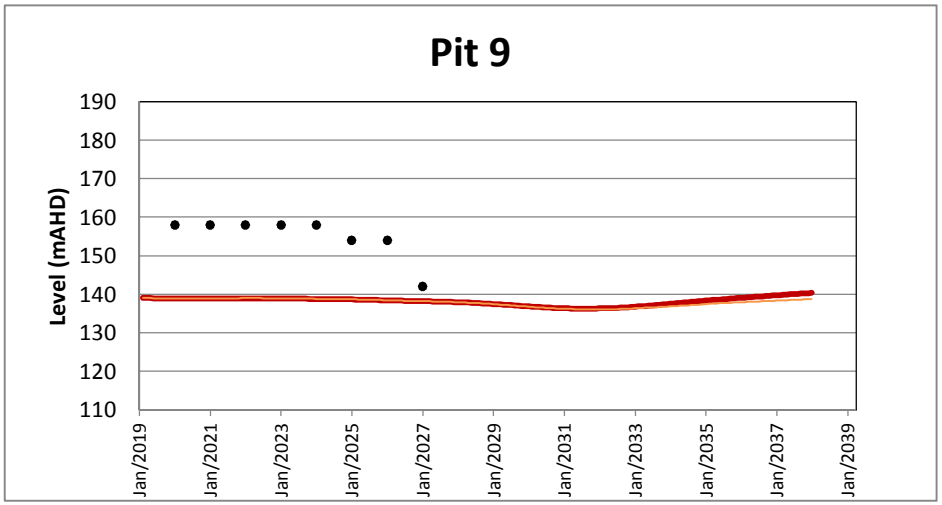

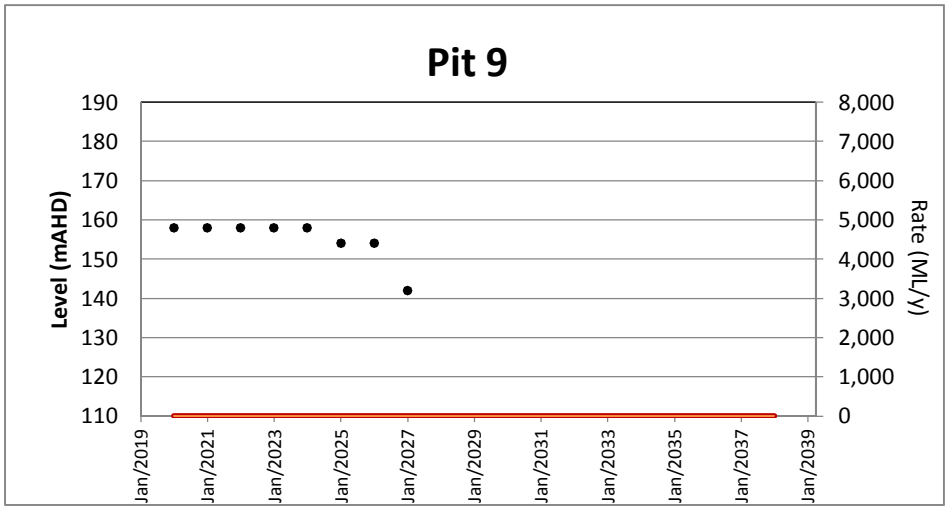

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PREDICTION RESULTS - MESA J - DEWATERING PREDICTIONS FIGURE B7

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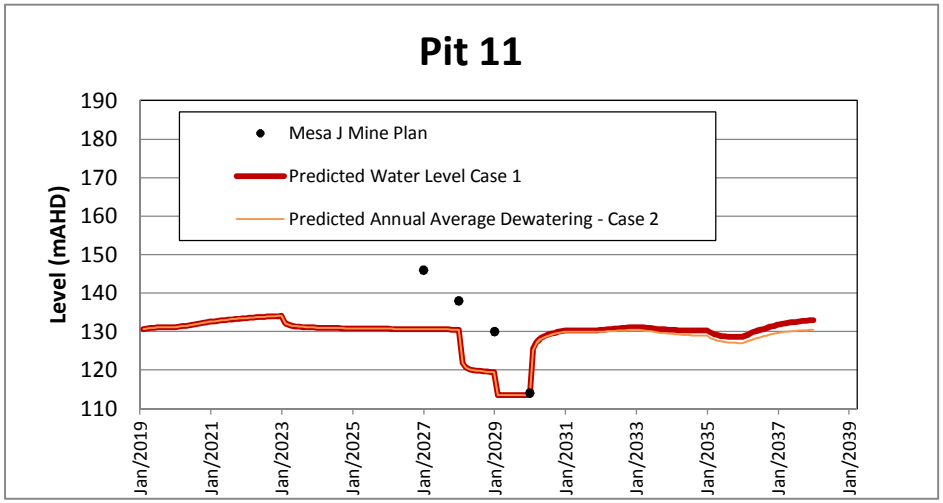

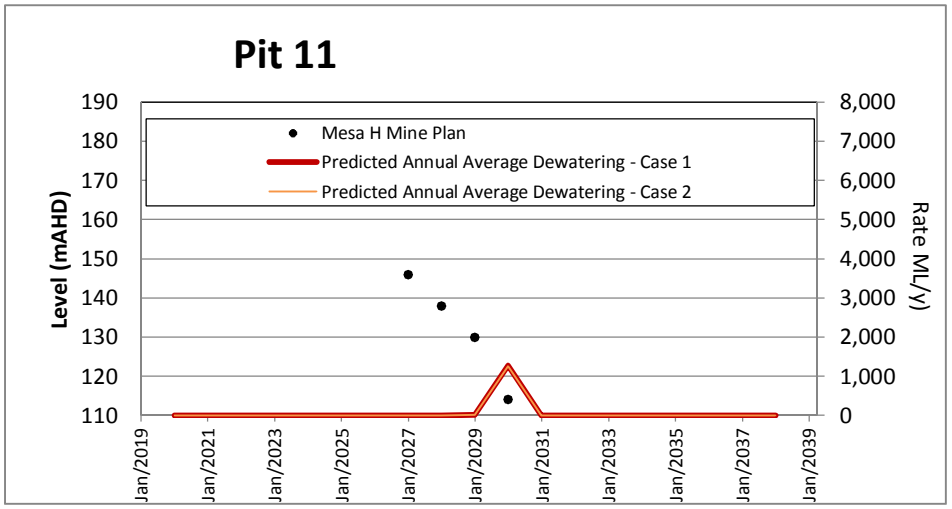

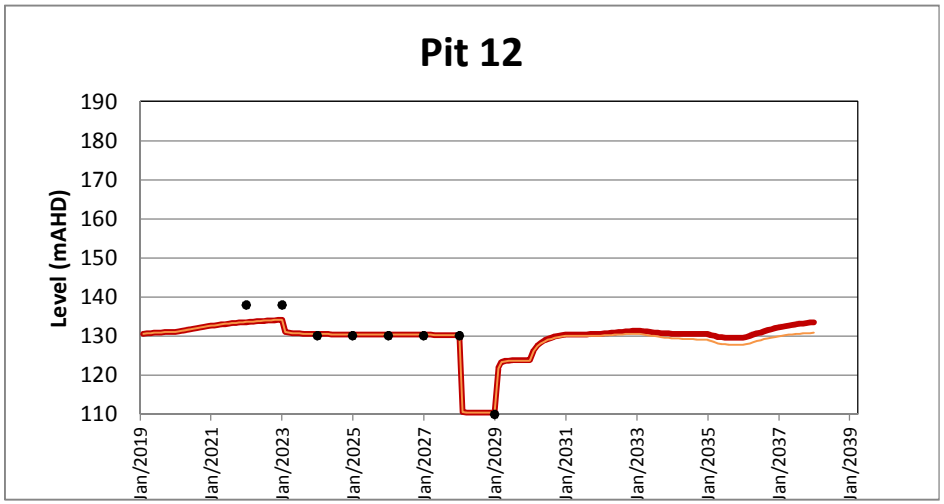

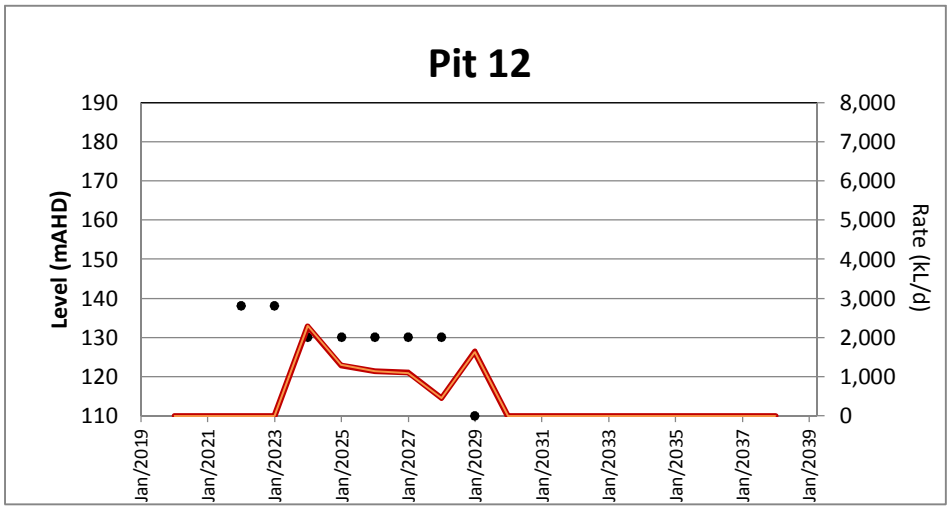

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PREDICTION RESULTS - MESA J - DEWATERING PREDICTIONS FIGURE B8

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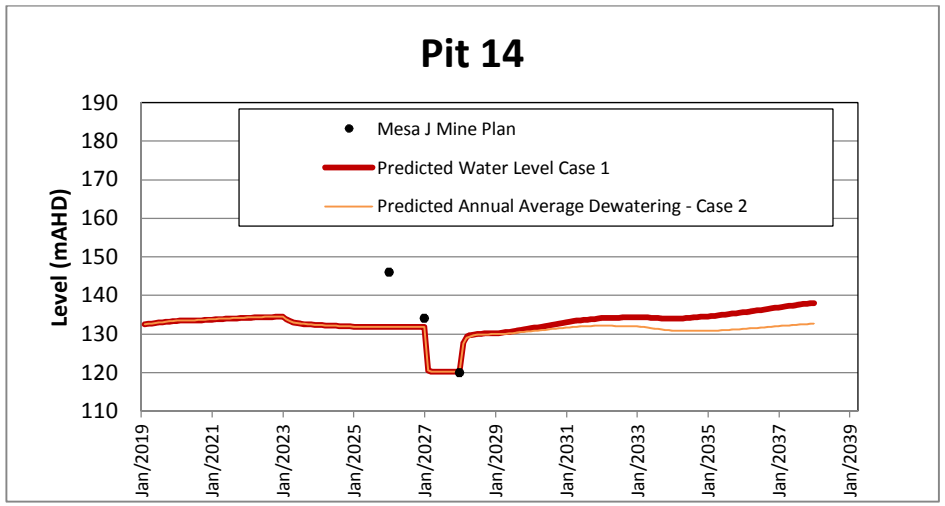

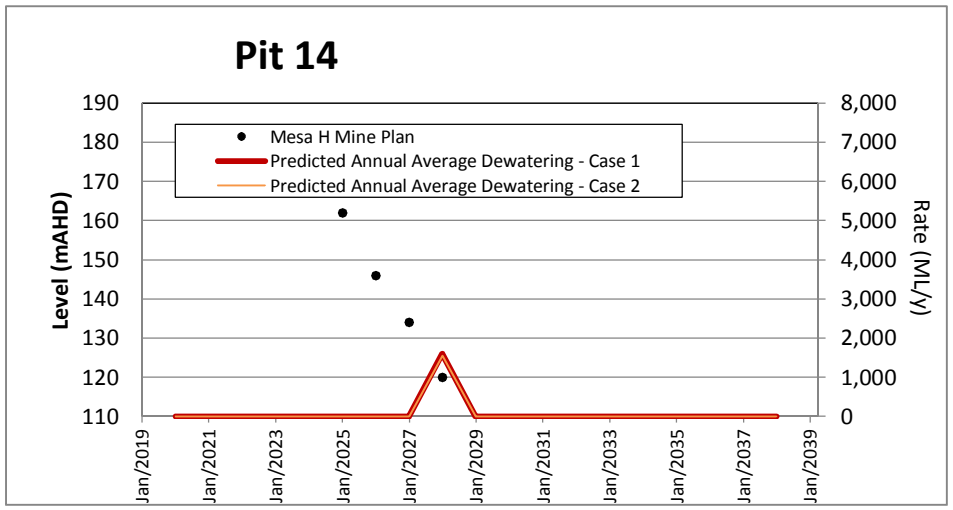

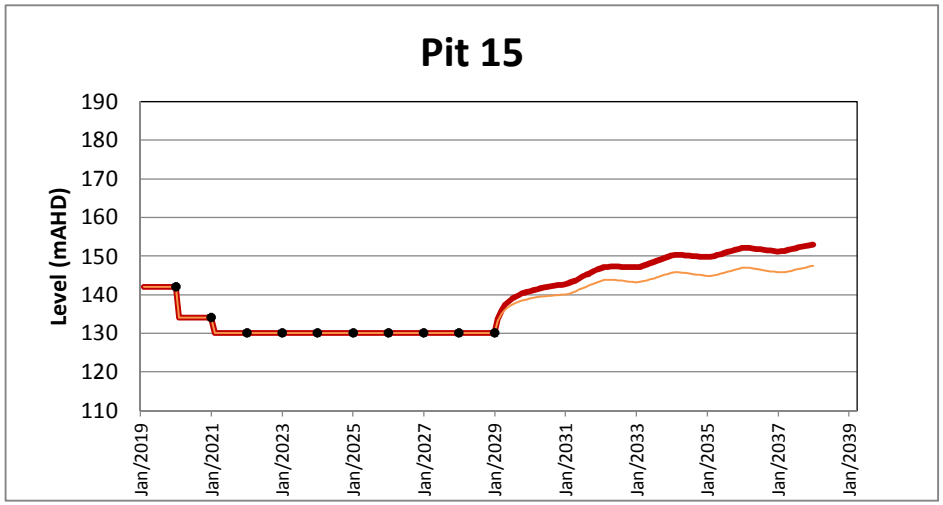

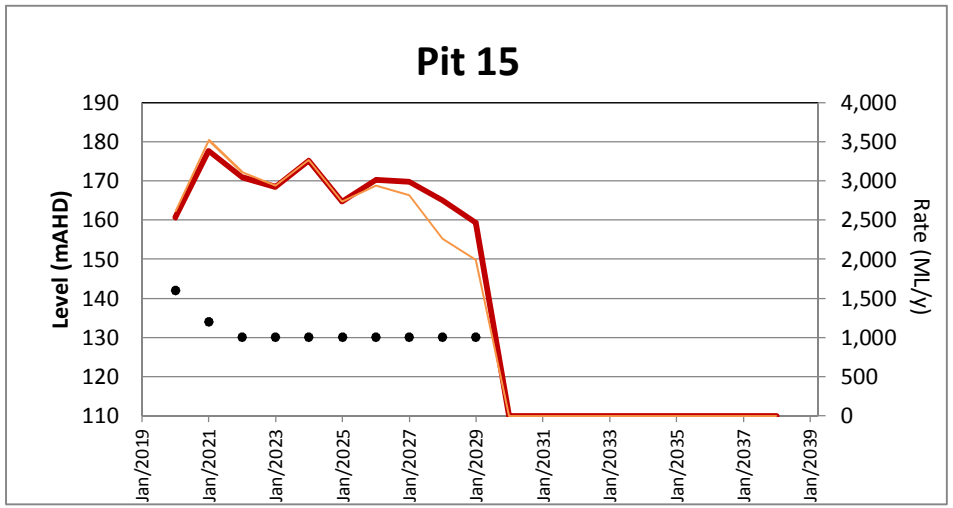

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PREDICTION RESULTS - MESA J - DEWATERING PREDICTIONS FIGURE B9

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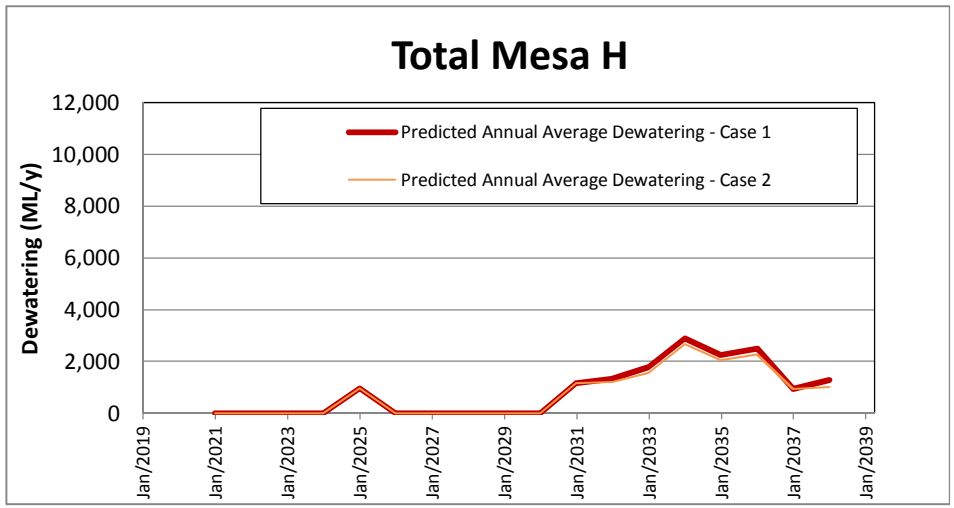

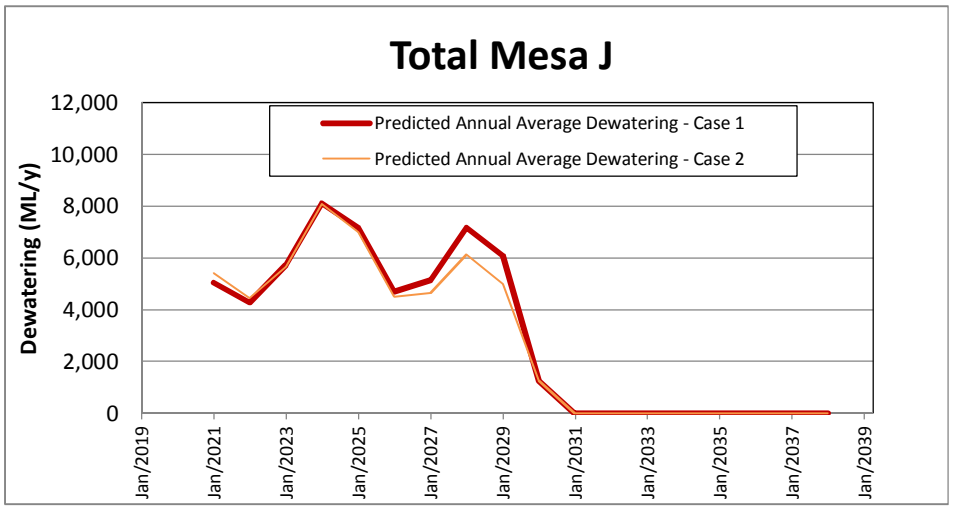

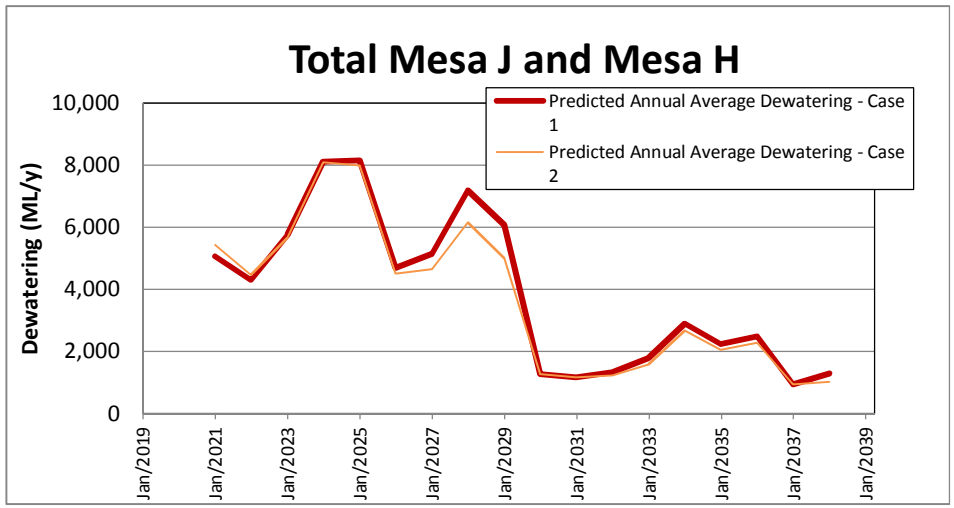

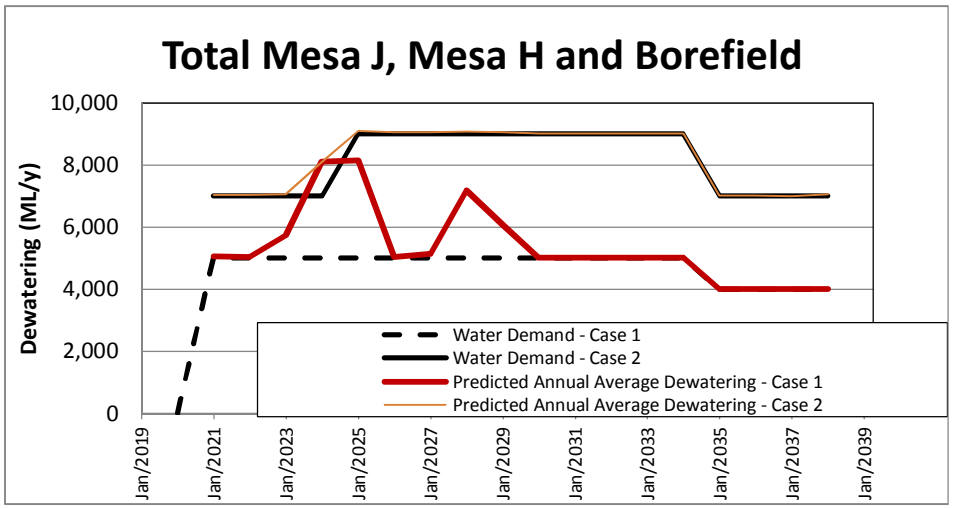

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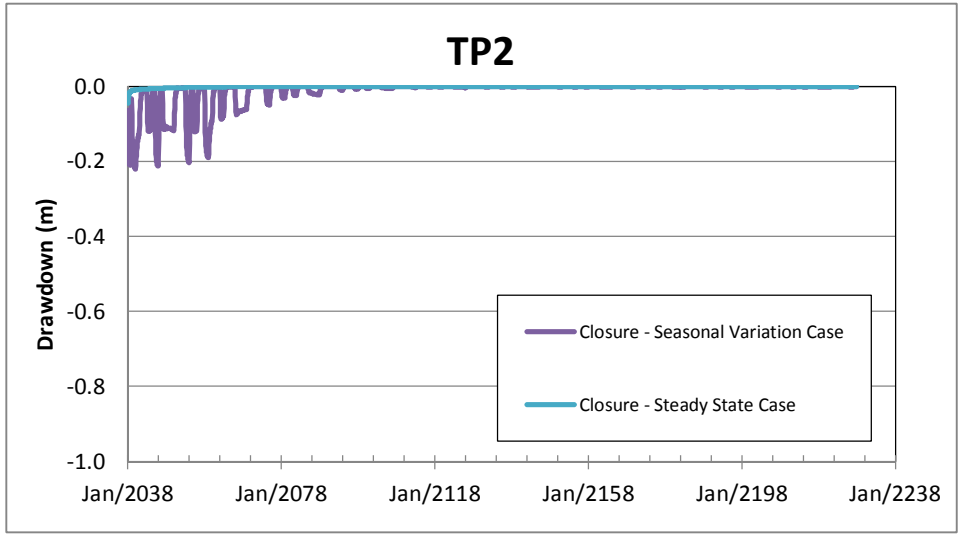
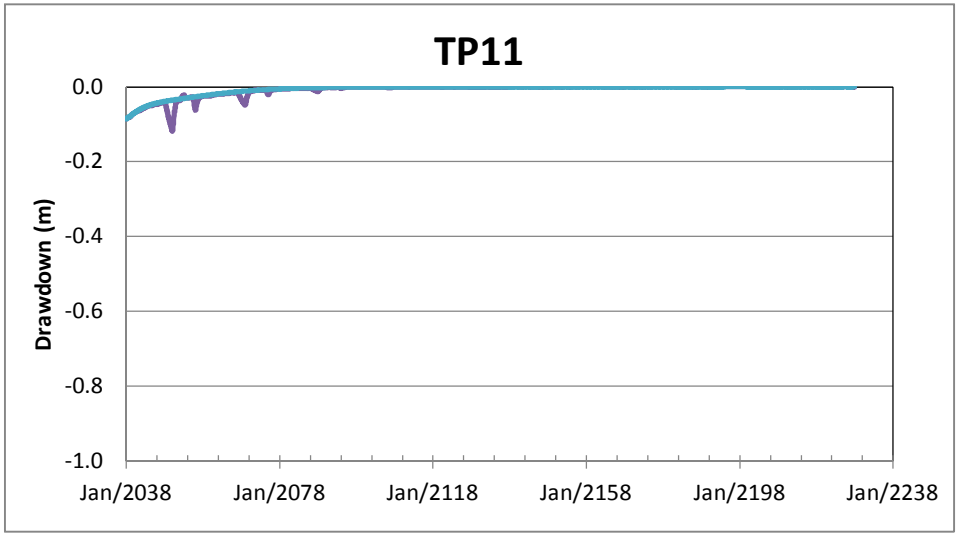
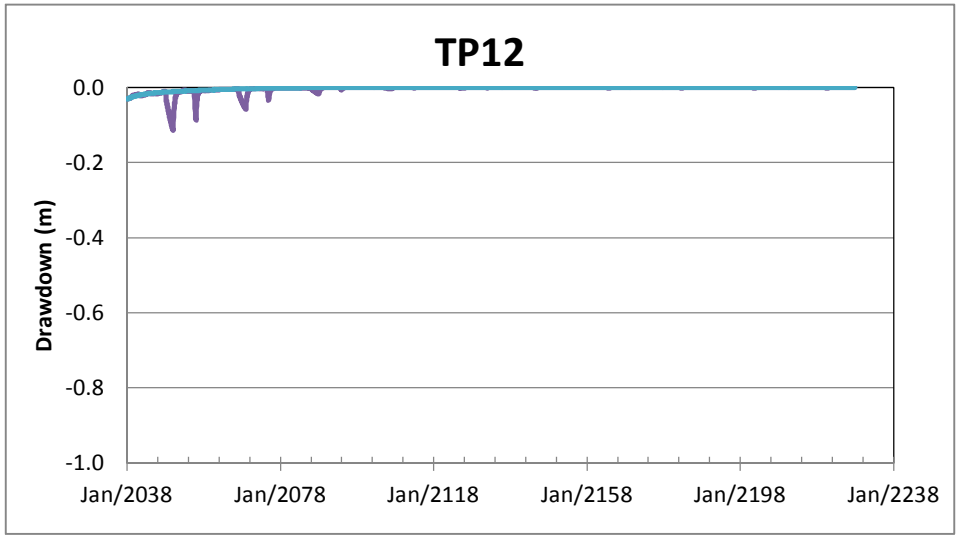
PREDICTION RESULTS - DEWATERING PREDICTIONS FIGURE B10

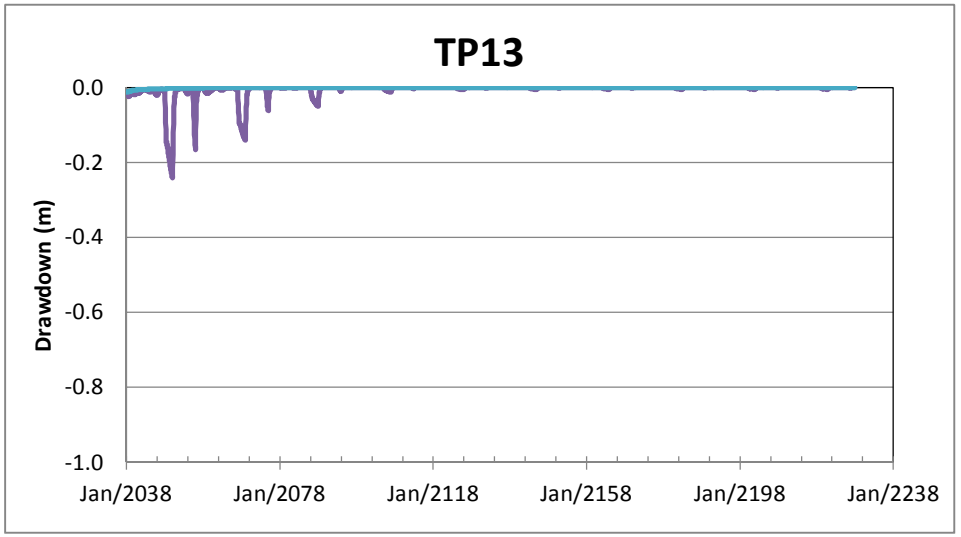
K:\08_WRE&S\09_Groundwater Modelling\02_Projects\Mesa_H\2018\Groundwater Model\Modelling\Model Results\prediction\[Case 1 & 2 Dewatering.xlsx]10a

APPENDIX C
CLOSURE RESULTS









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PREDICTED GROUNDWATER LEVEL RECOVERY AT TRACKING POINTS ALONG THE ROBE RIVER (CASE 1 MODEL) FIGURE C1

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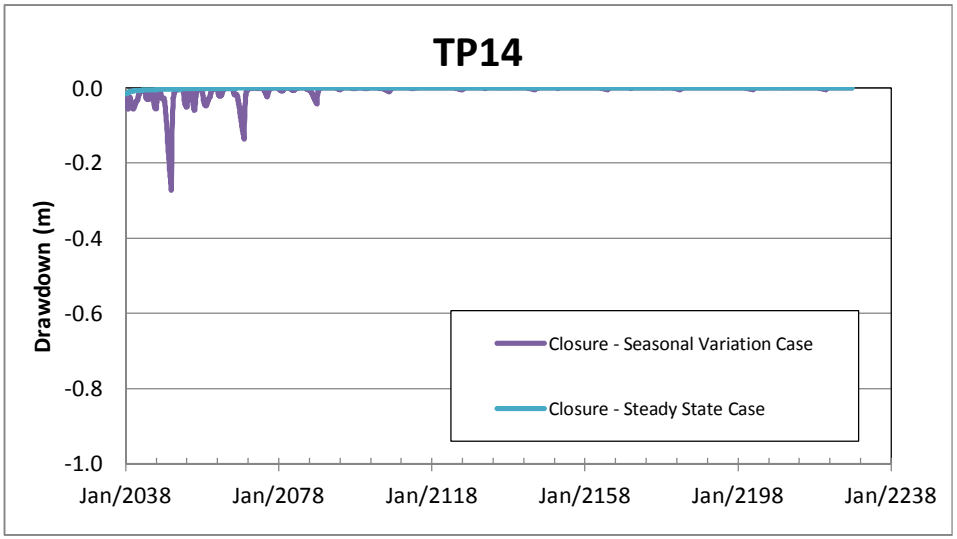

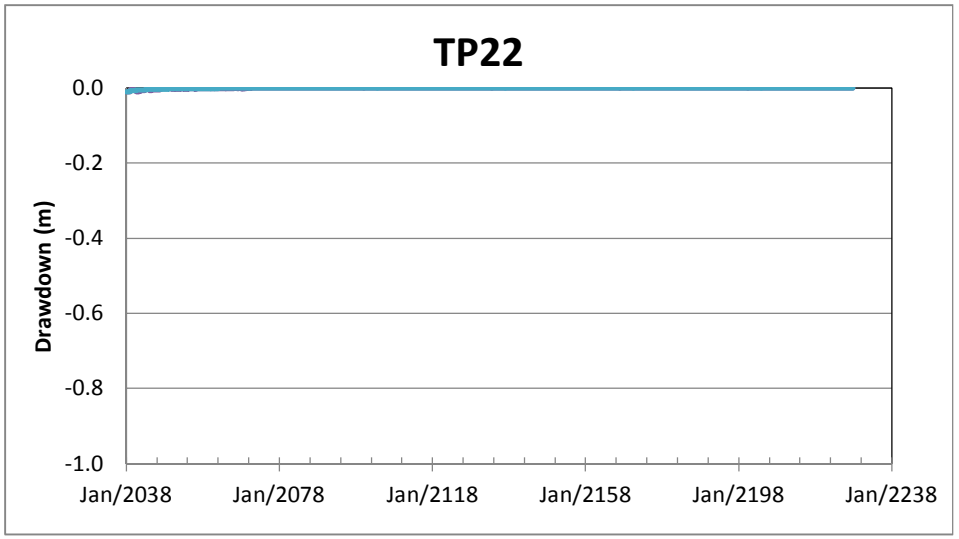

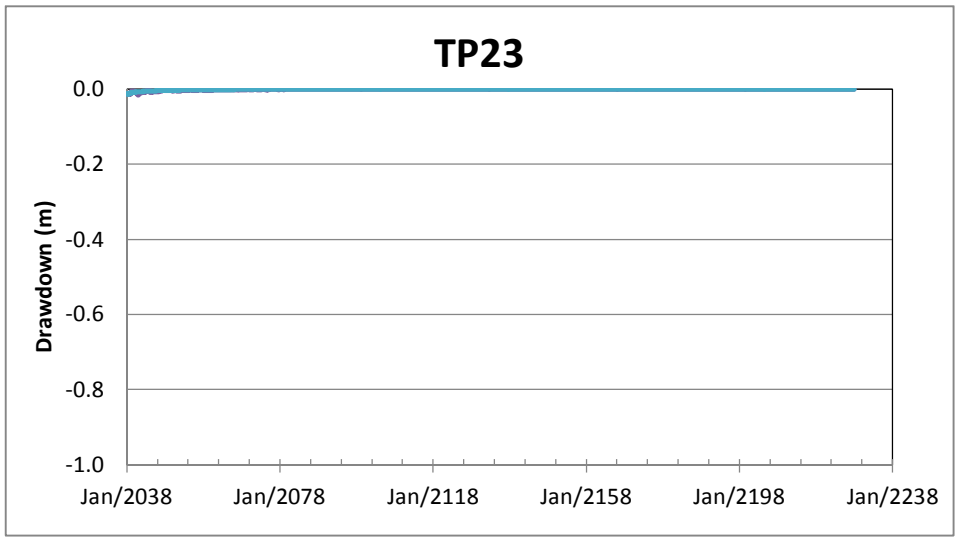

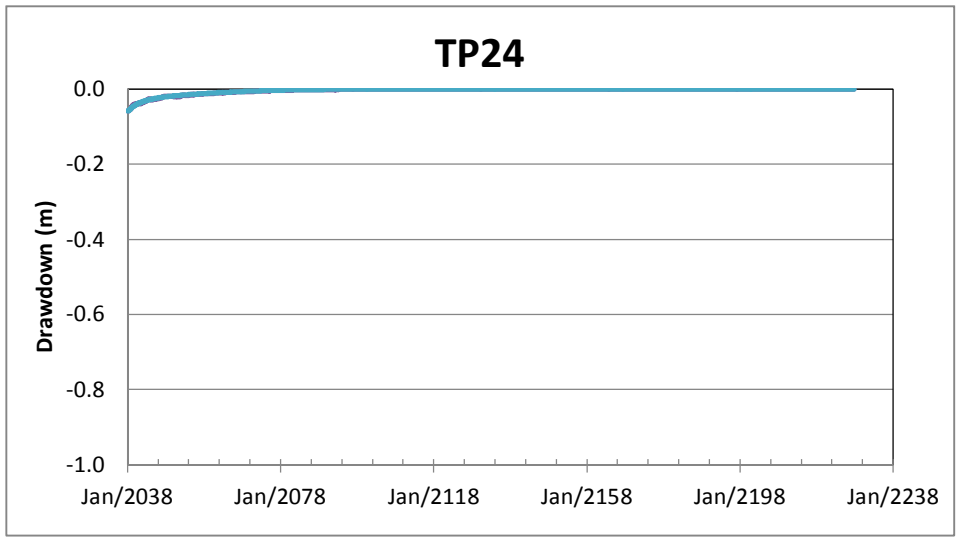

RioTinto

PREDICTED GROUNDWATER LEVEL RECOVERY AT TRACKING POINTS ALONG THE ROBE RIVER (CASE 1 MODEL) FIGURE C2

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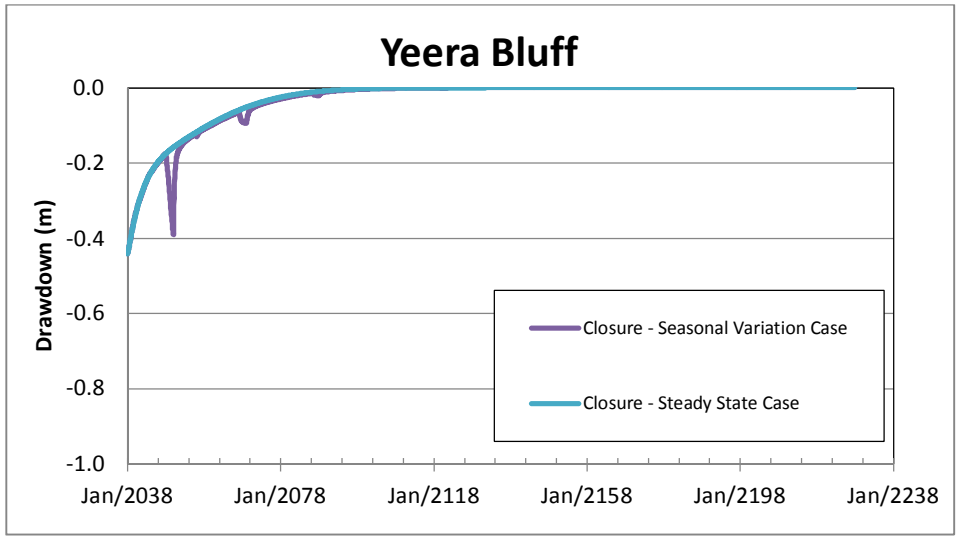

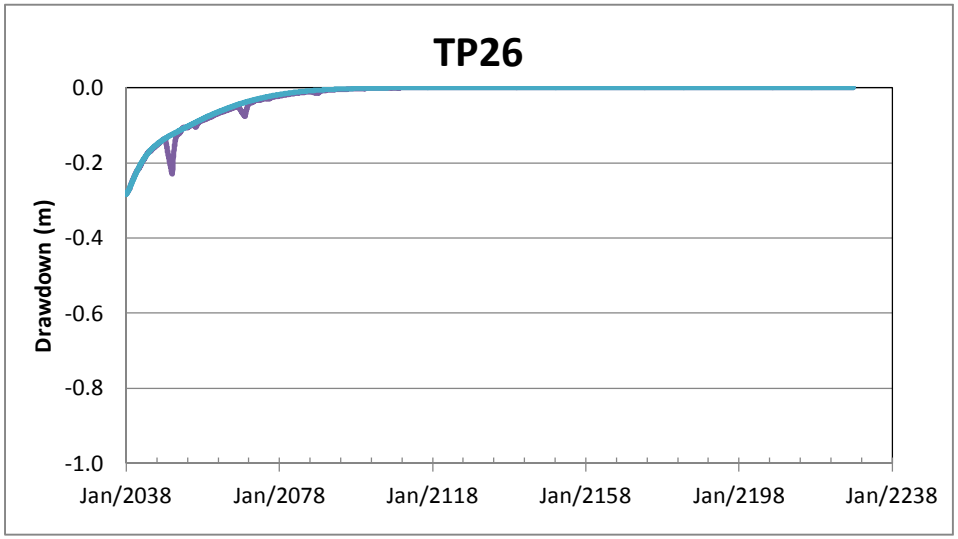

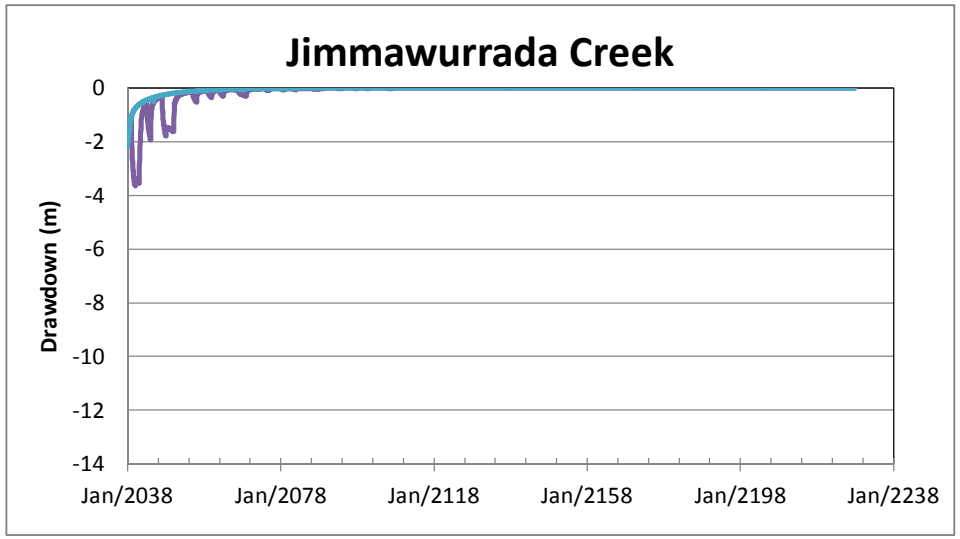

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PREDICTED GROUNDWATER LEVEL RECOVERY AT TRACKING POINTS ALONG THE ROBE RIVER (CASE 1 MODEL) FIGURE C3

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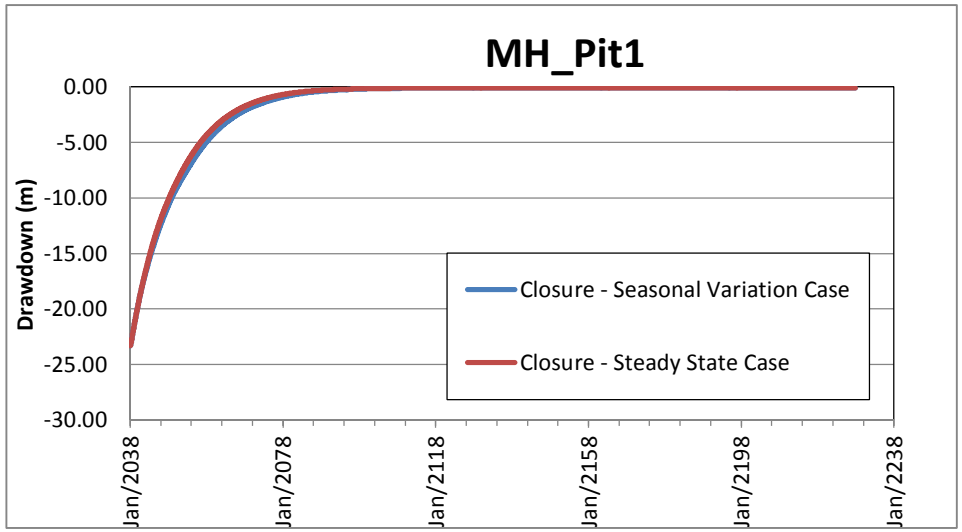

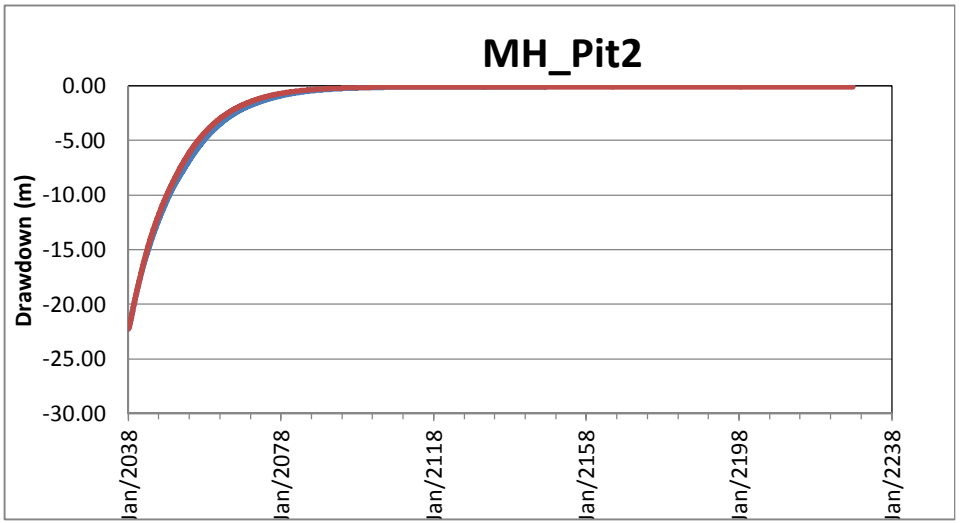

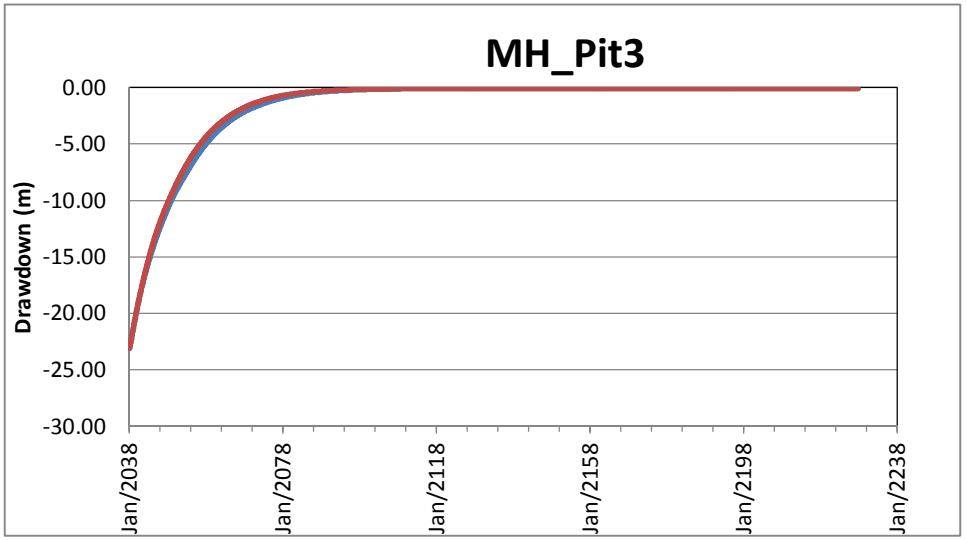

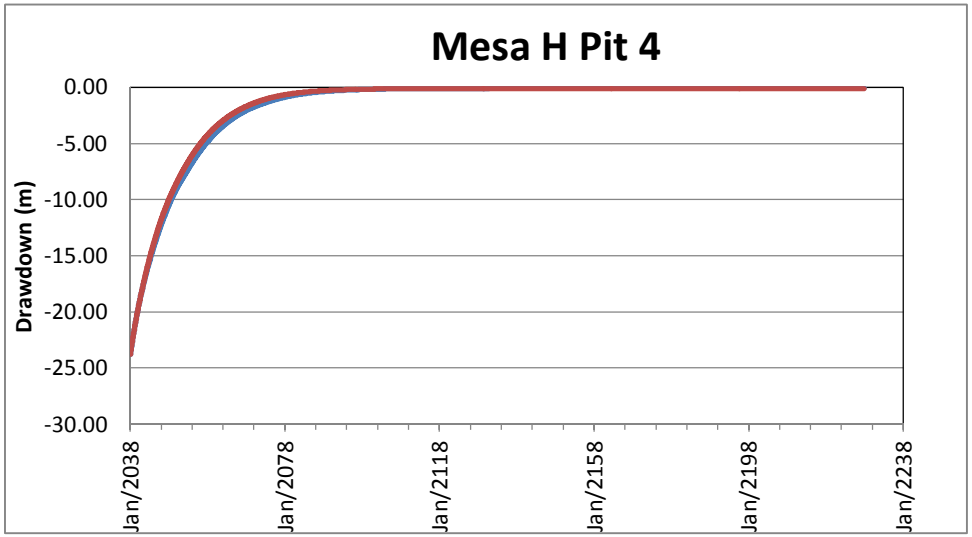

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PREDICTED GROUNDWATER LEVEL RECOVERY AT MESA H (CASE 1) FIGURE C4

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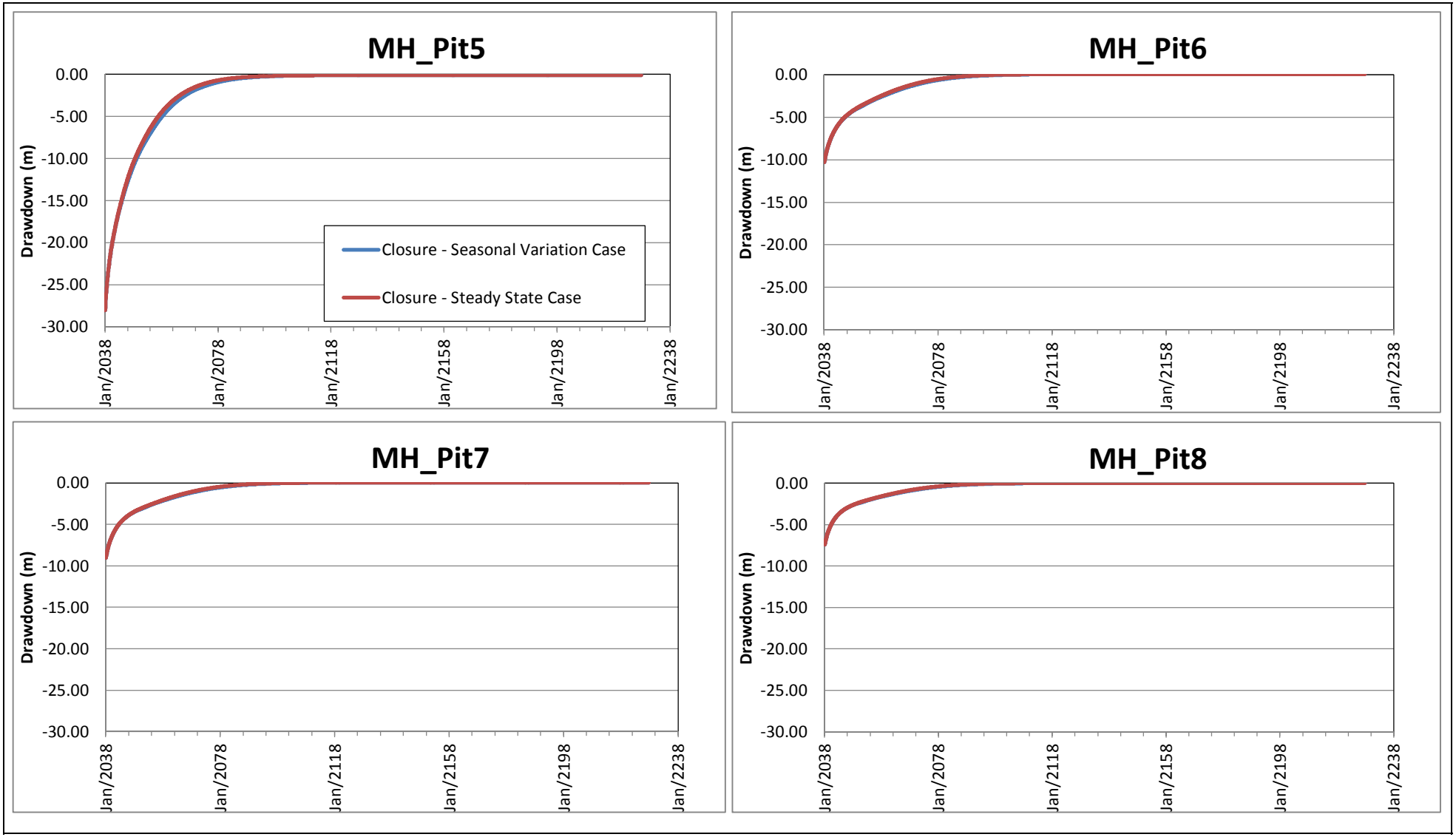

RioTinto

PREDICTED GROUNDWATER LEVEL RECOVERY AT MESA H (CASE 1) FIGURE C5

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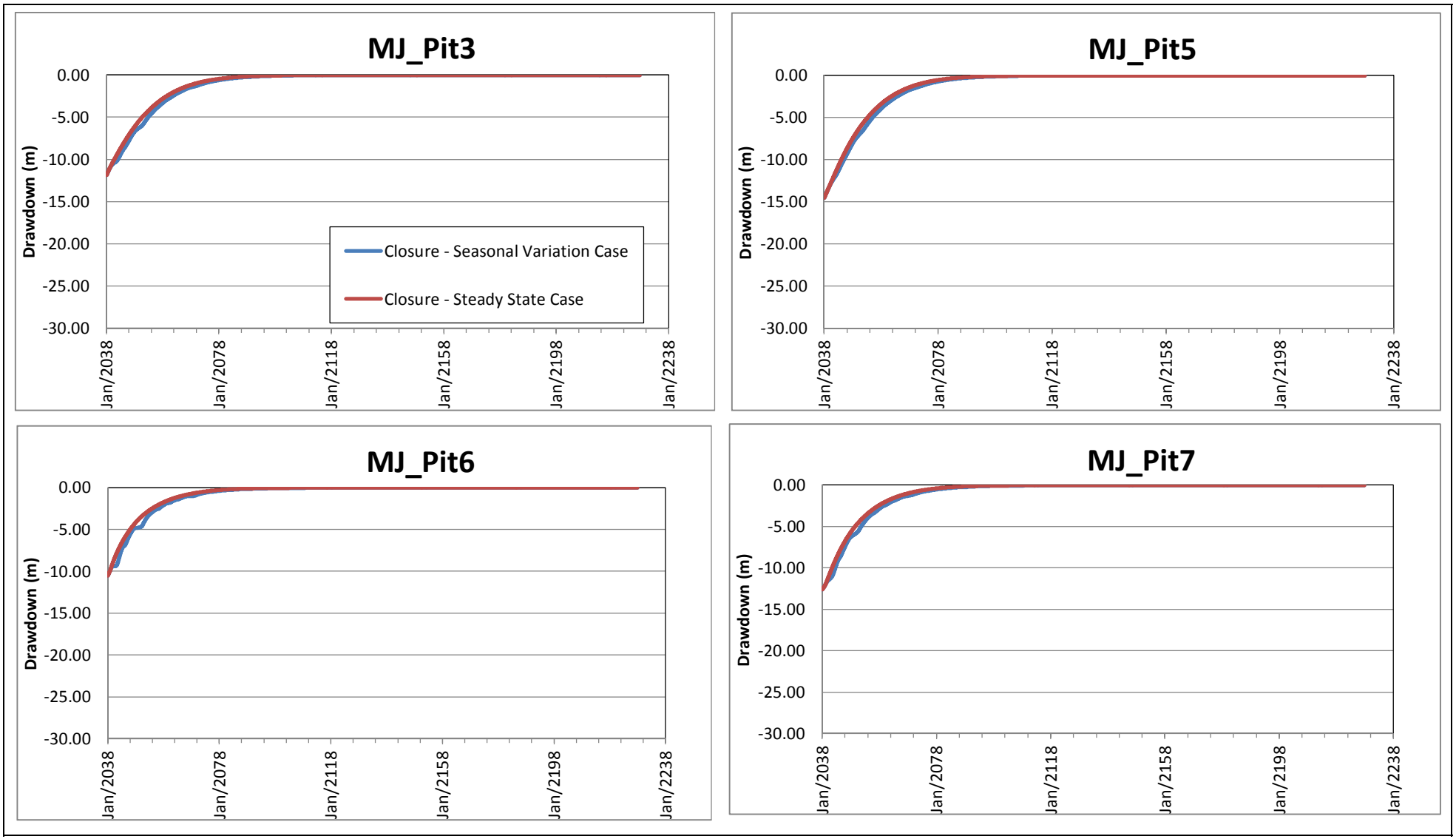

RioTinto

PREDICTED GROUNDWATER LEVEL RECOVERY AT MESA J (CASE 1) FIGURE C6

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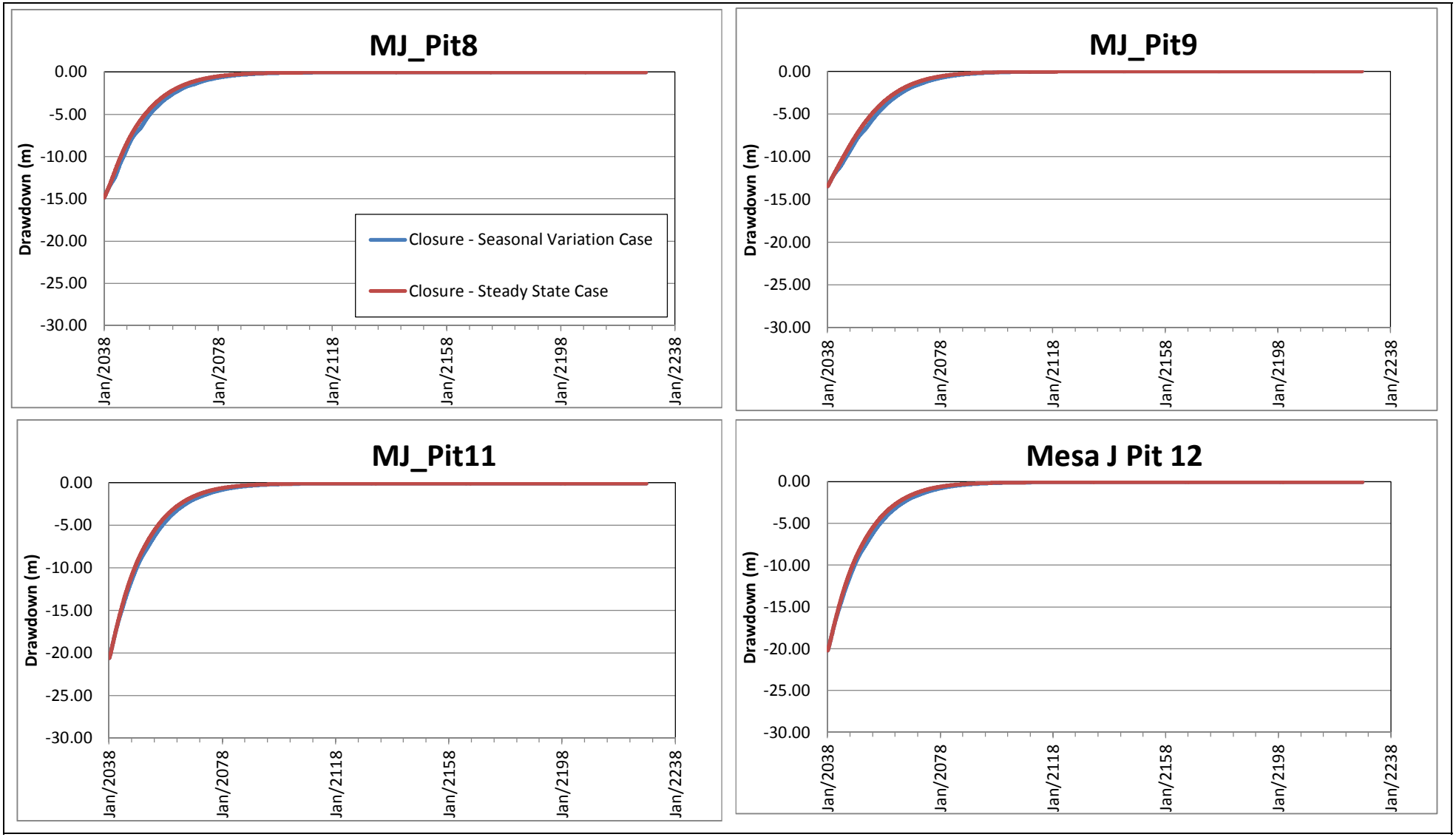

RioTinto

PREDICTED GROUNDWATER LEVEL RECOVERY AT MESA J (CASE 1) FIGURE C7

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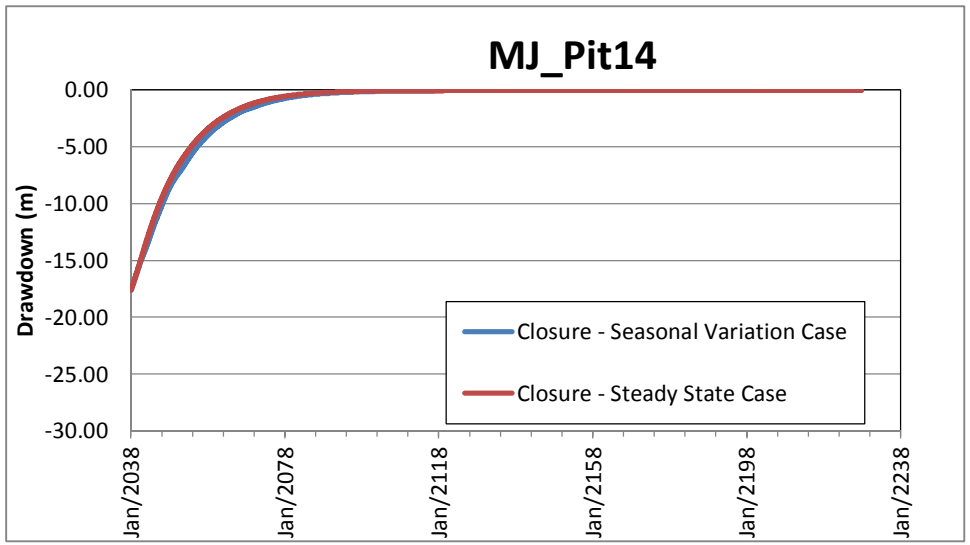

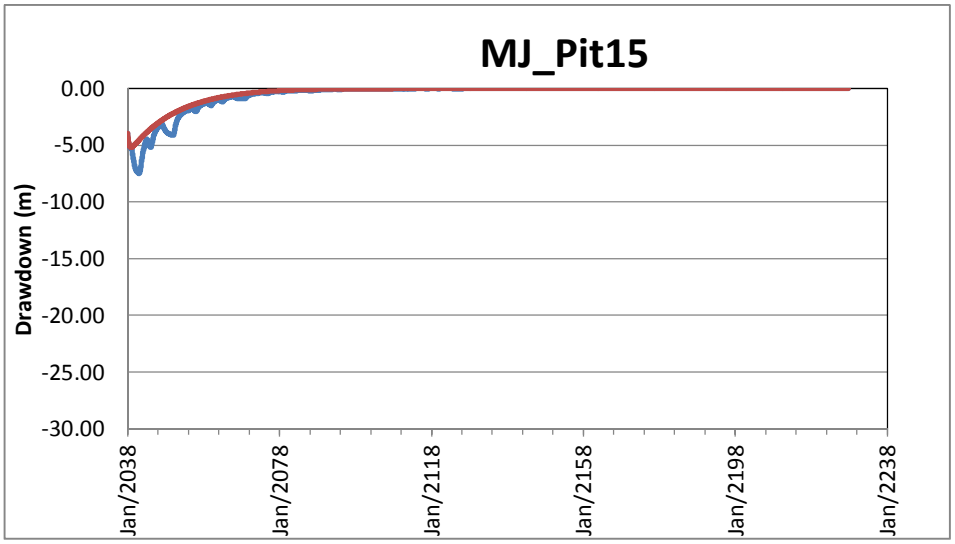

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PREDICTED GROUNDWATER LEVEL RECOVERY AT MESA J (CASE 1) FIGURE C8

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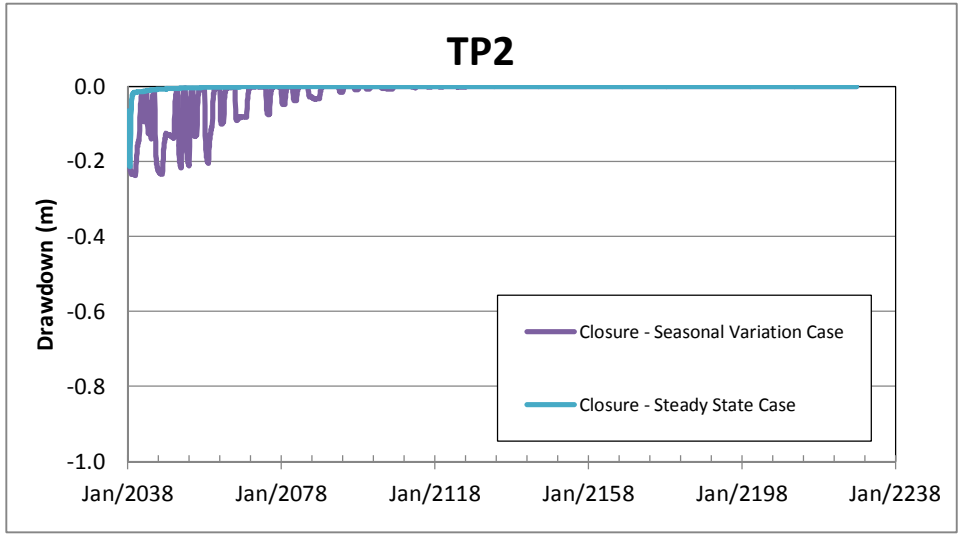

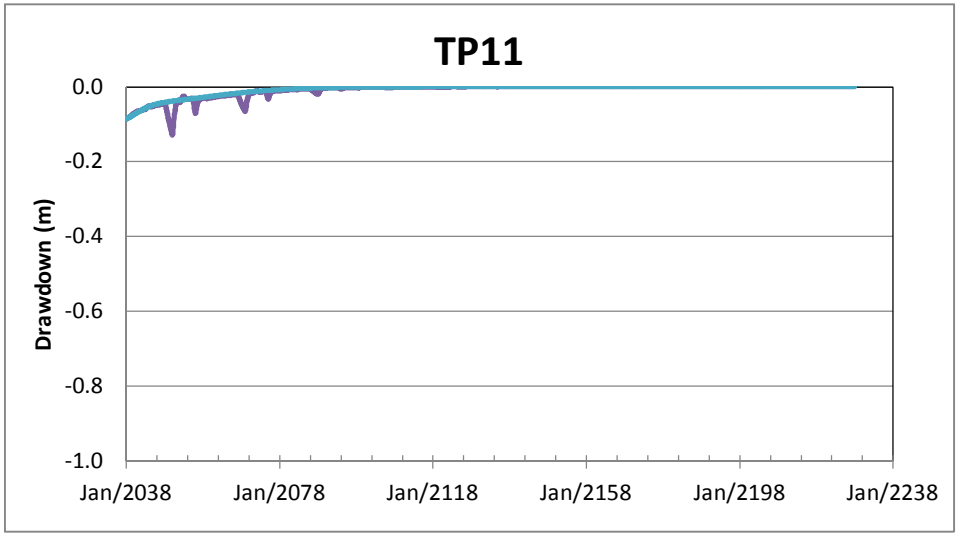

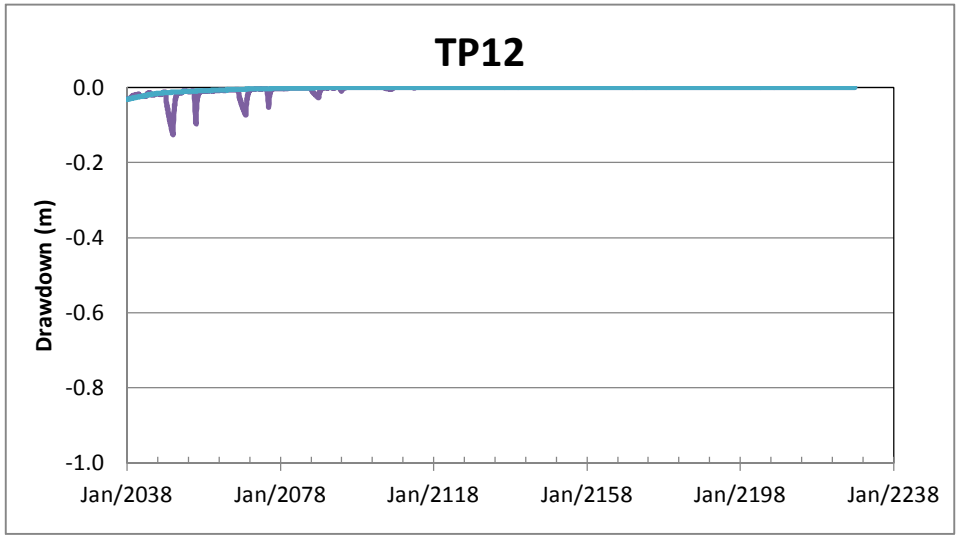

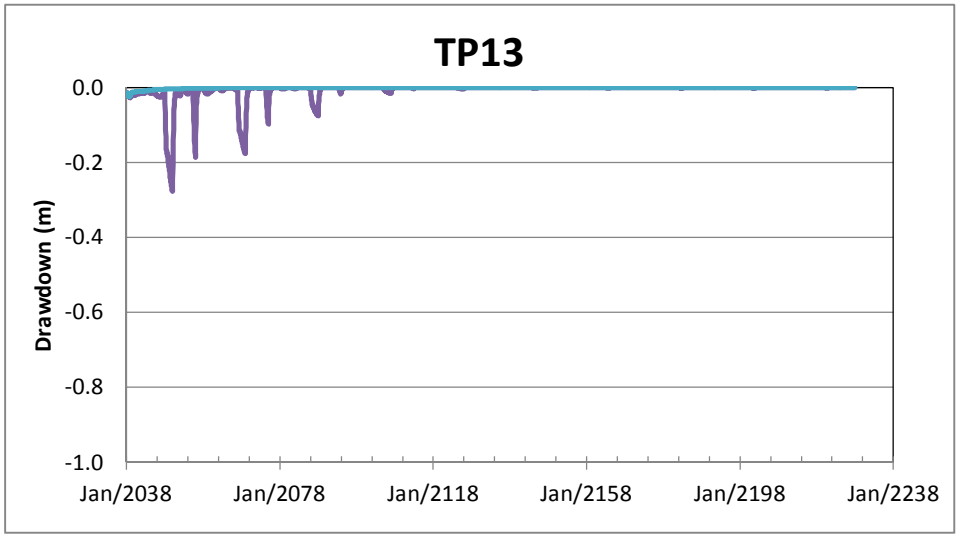

PREDICTED GROUNDWATER LEVEL RECOVERY AT TRACKING POINTS ALONG THE ROBE RIVER (DEWATERING CASE 2) FIGURE C9

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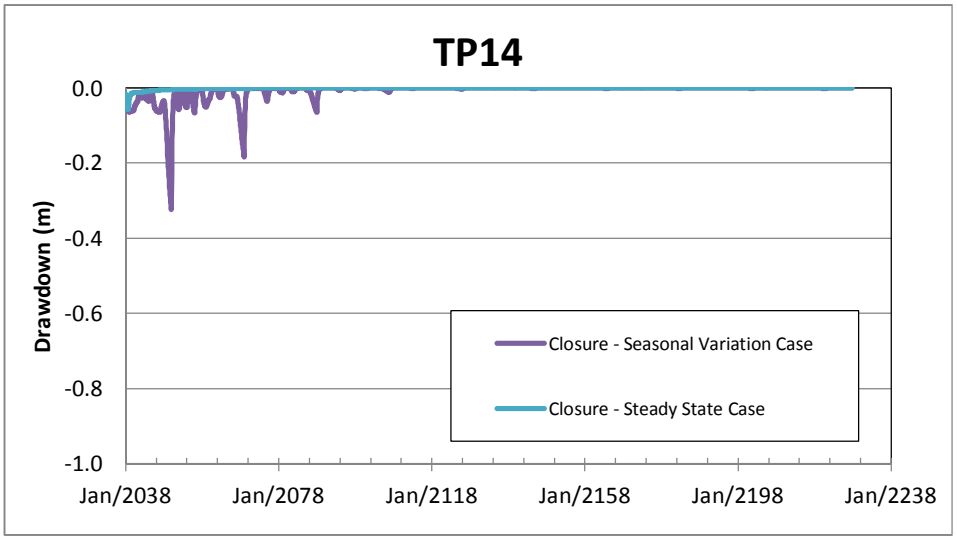

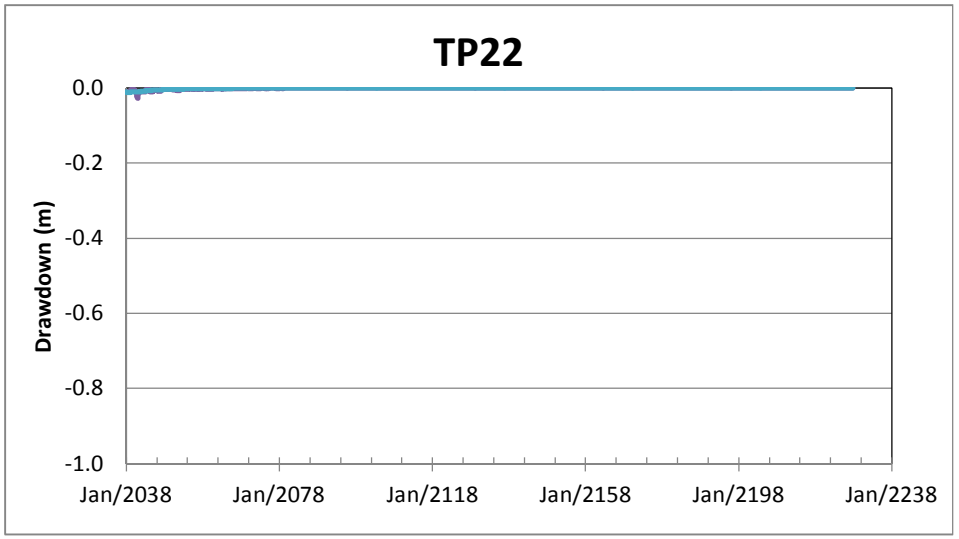

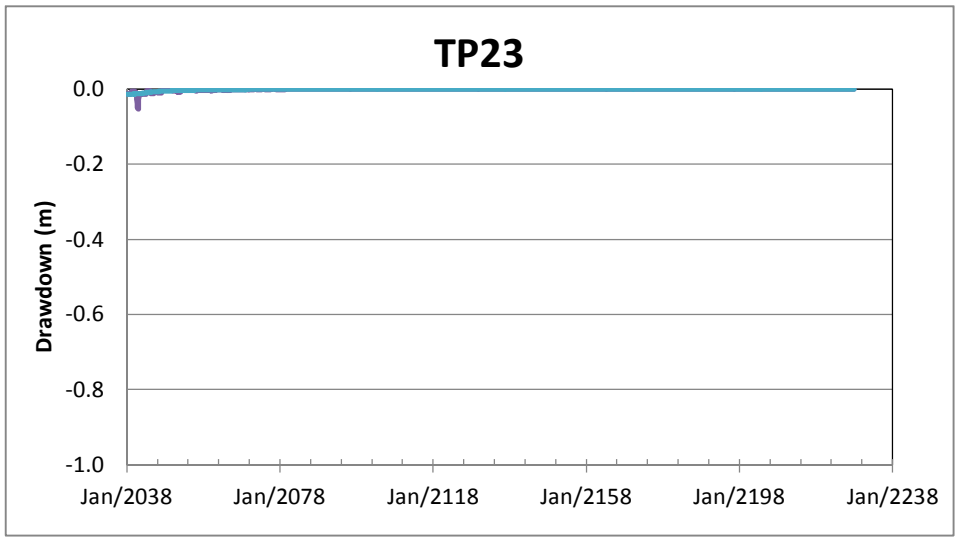

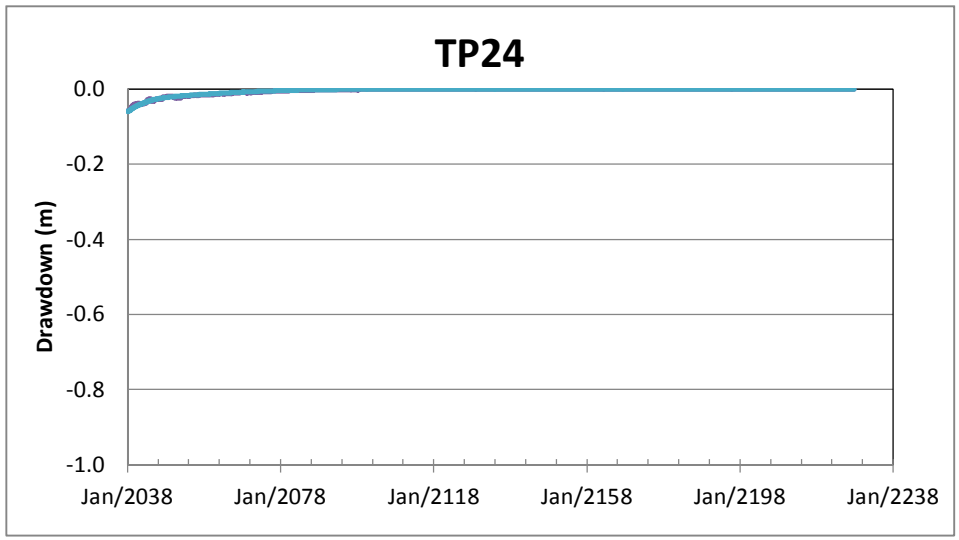

PREDICTED GROUNDWATER LEVEL RECOVERY AT TRACKING POINTS ALONG THE ROBE RIVER (DEWATERING CASE 2 MODEL) FIGURE C10

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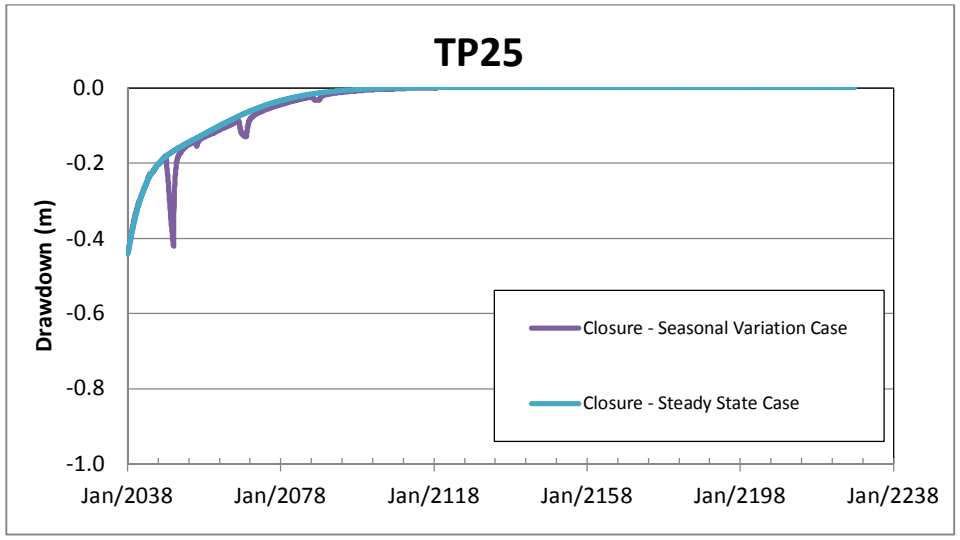

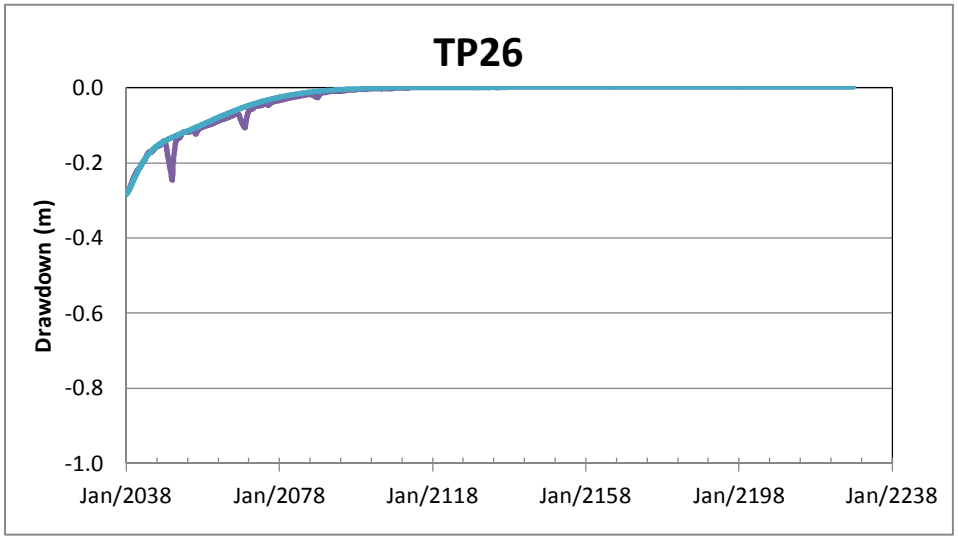

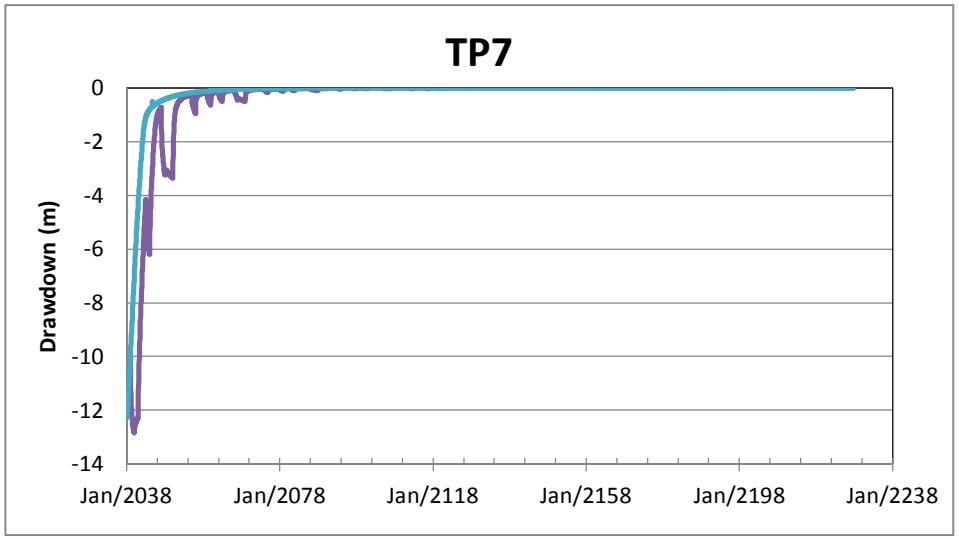

Note: Different vertical scales

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PREDICTED GROUNDWATER LEVEL RECOVERY AT TRACKING POINTS ALONG THE ROBE RIVER (DEWATERING CASE 2 MODEL) FIGURE C11

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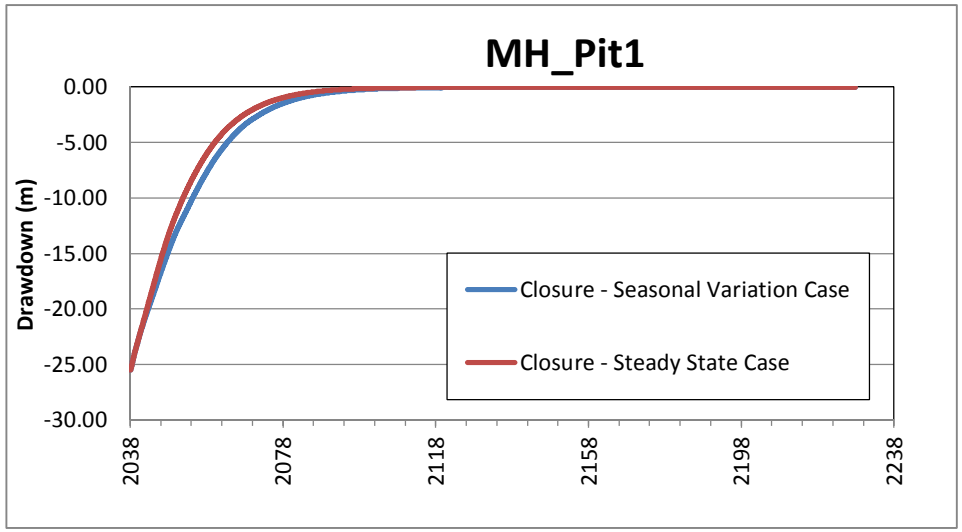

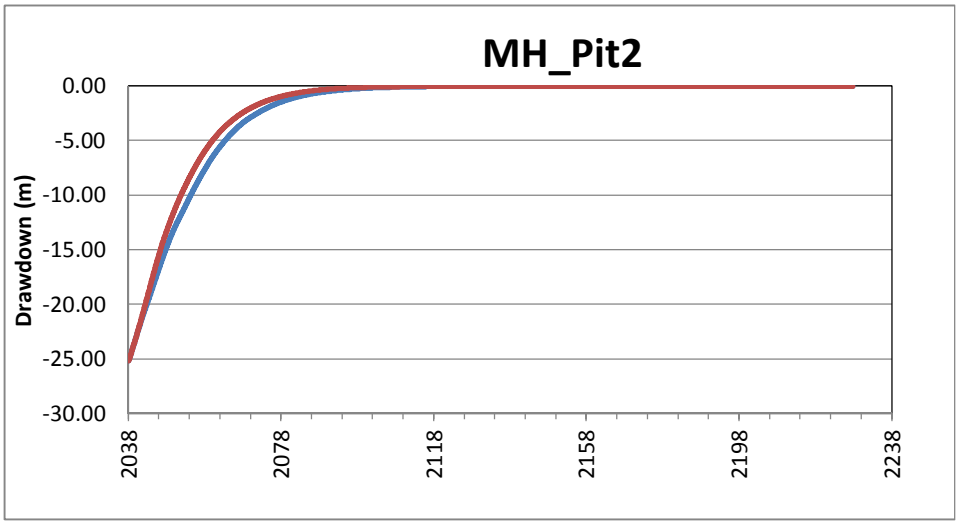

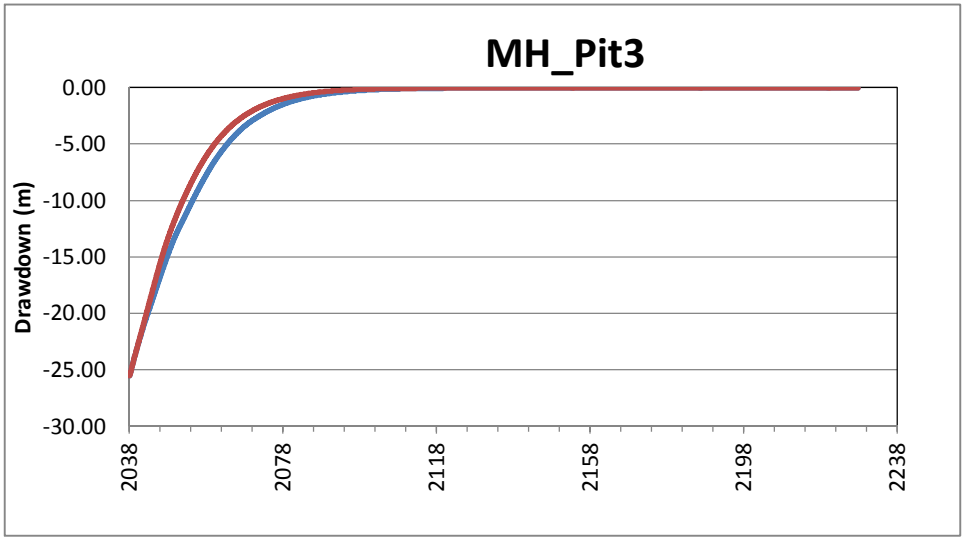

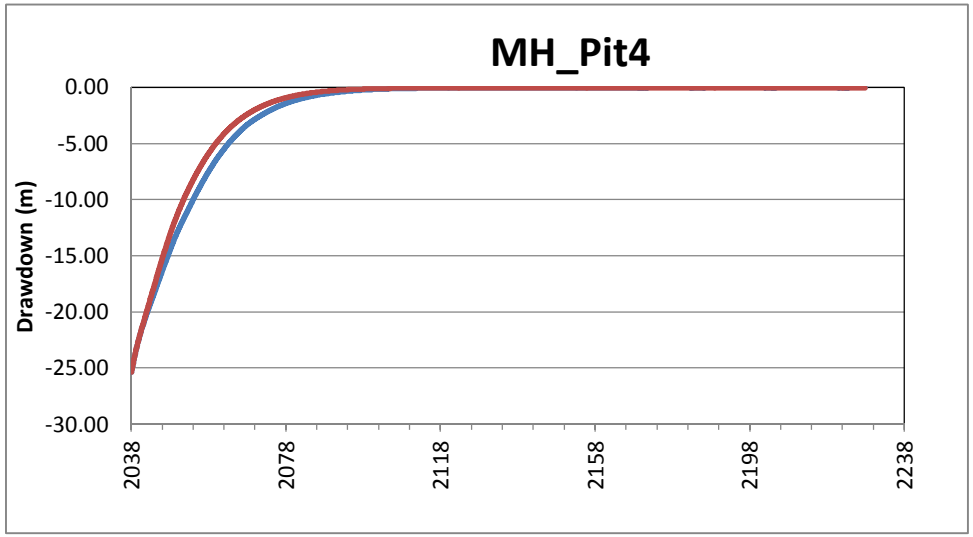

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PREDICTED GROUNDWATER LEVEL RECOVERY AT MESA H (CASE 2) FIGURE C12

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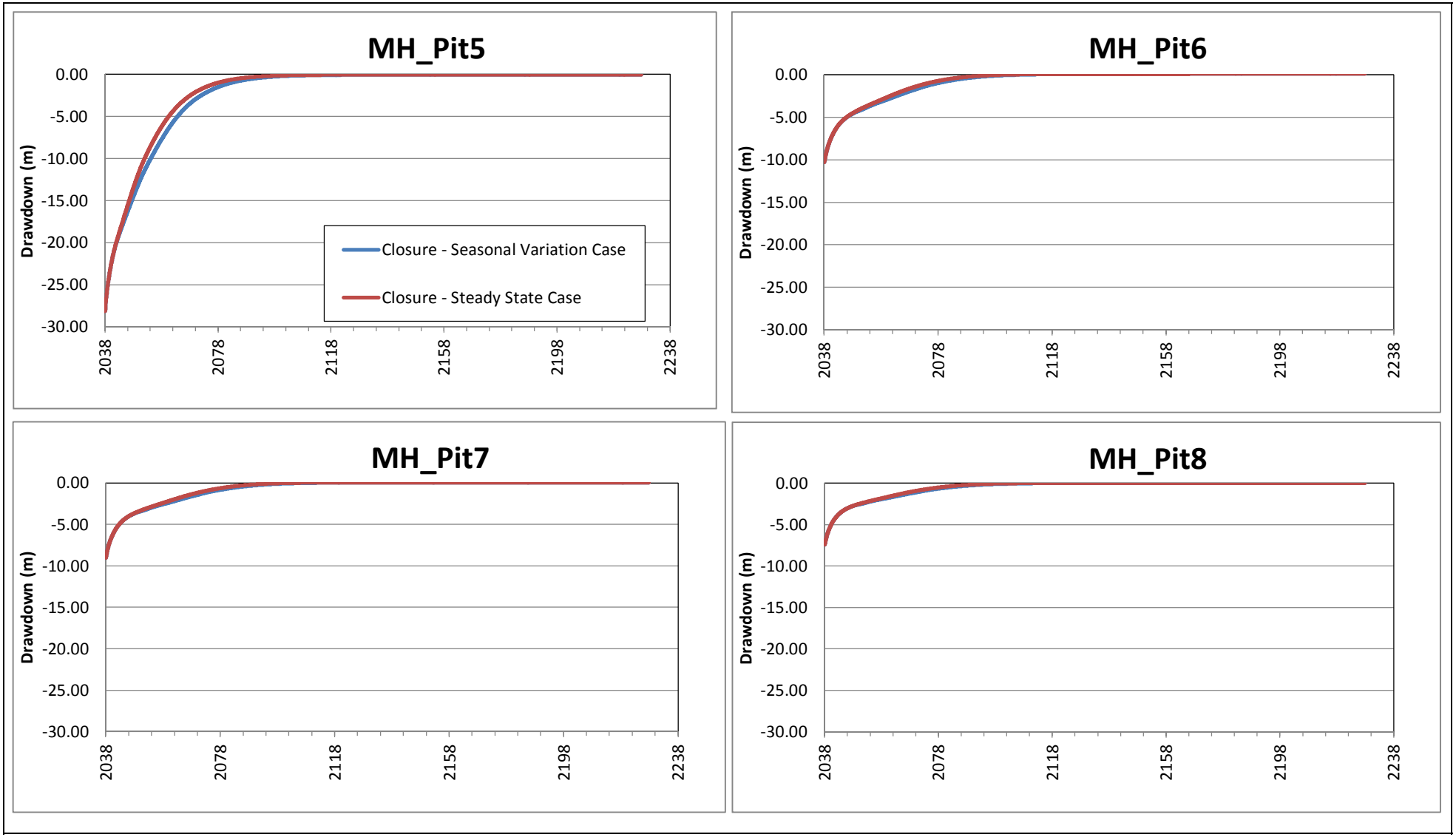

PREDICTED GROUNDWATER LEVEL RECOVERY AT MESA H (CASE 2) FIGURE C13

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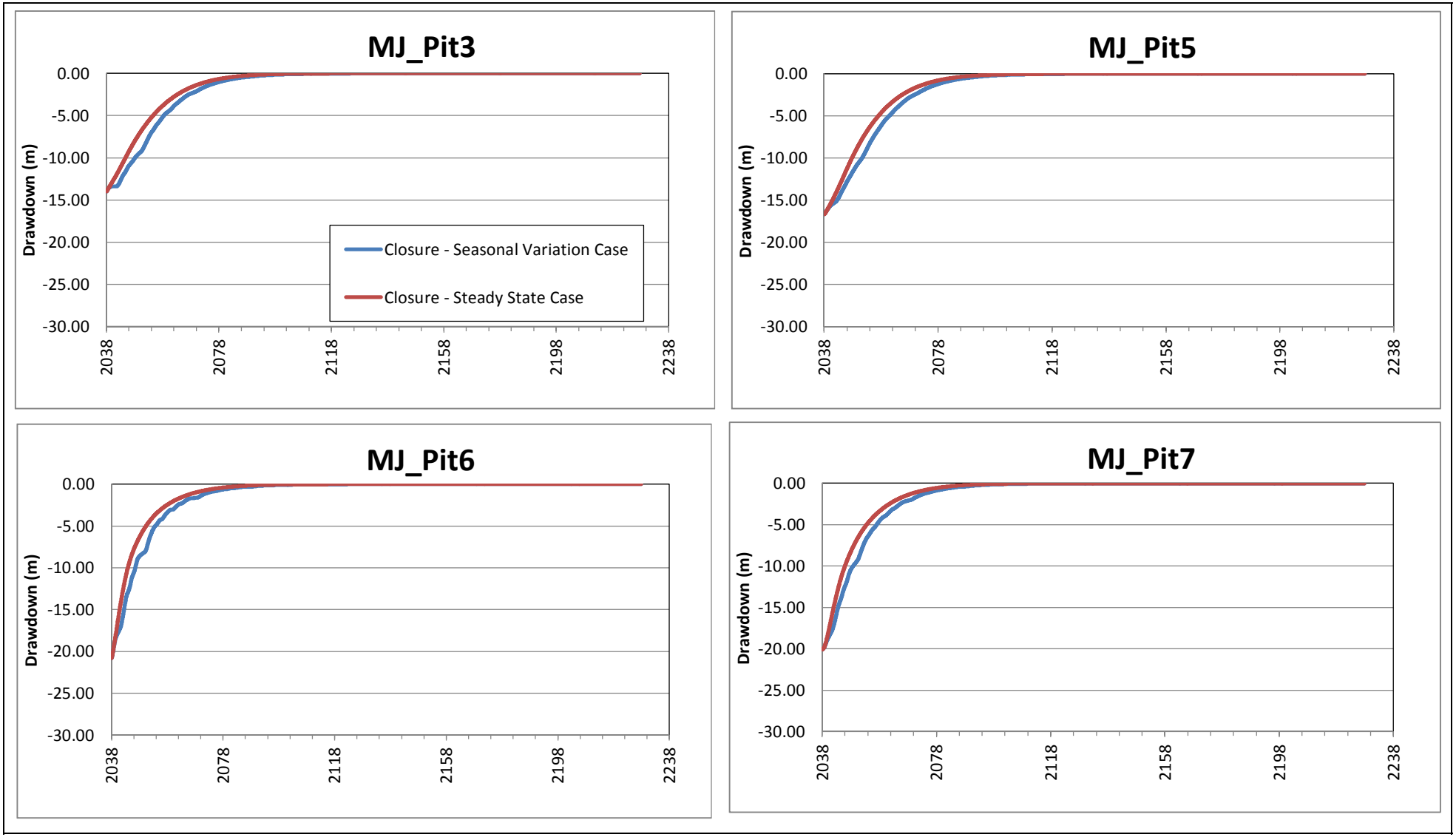

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PREDICTED GROUNDWATER LEVEL RECOVERY AT MESA J (CASE 2) FIGURE C14

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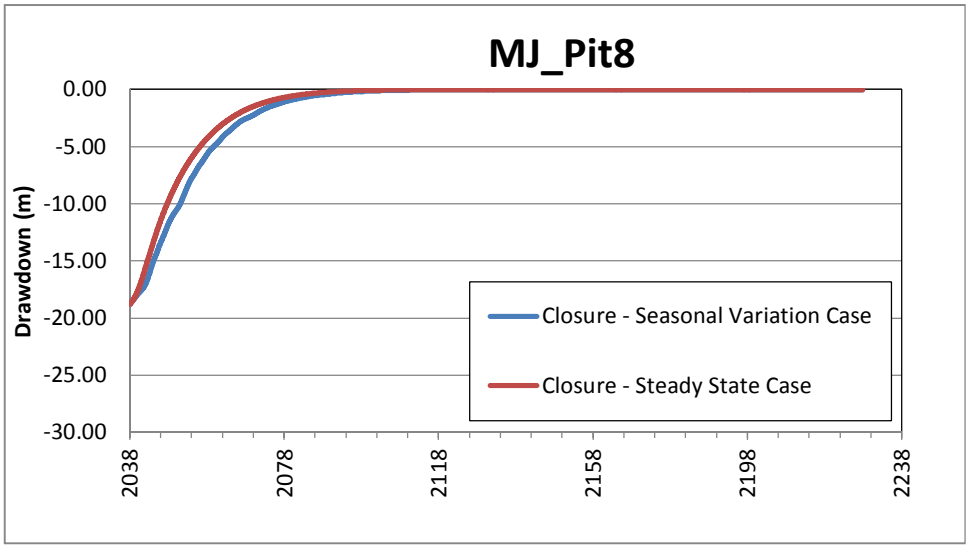

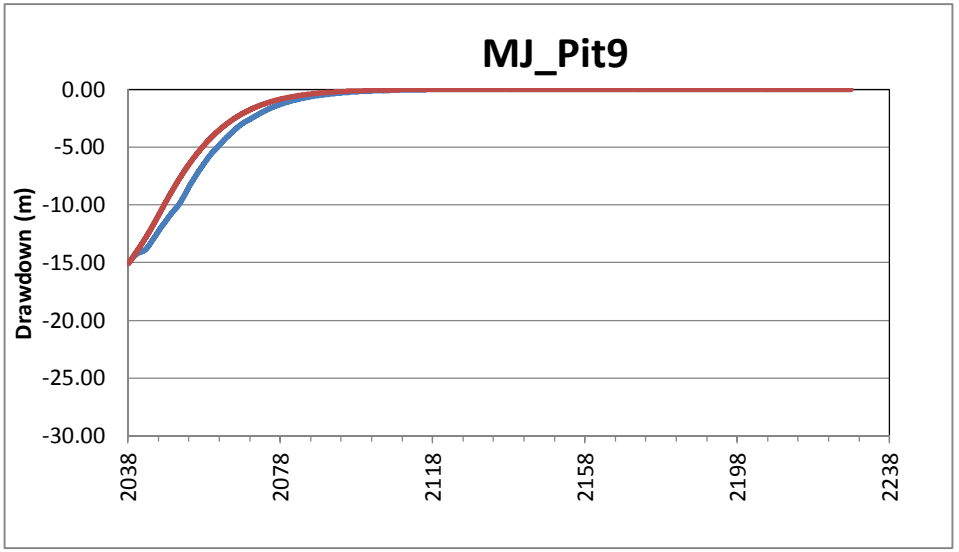

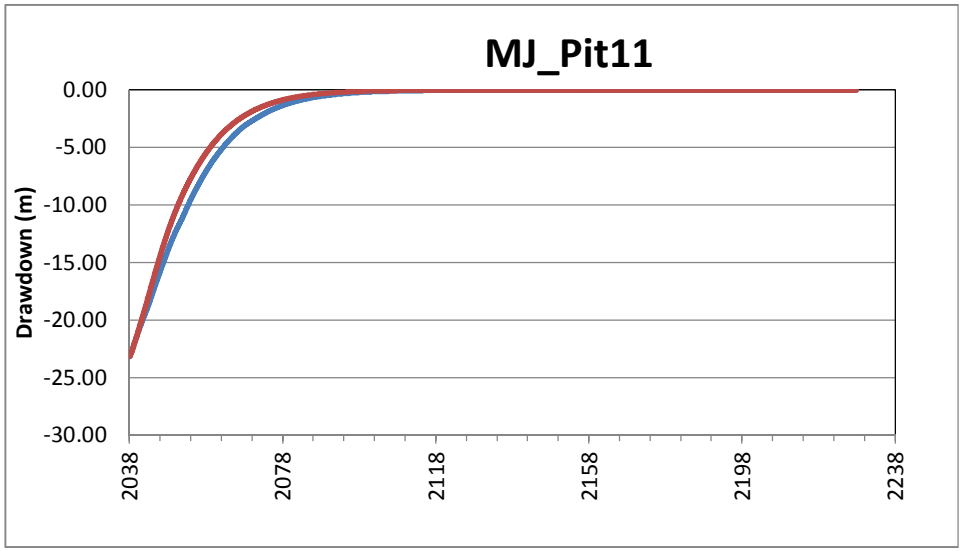

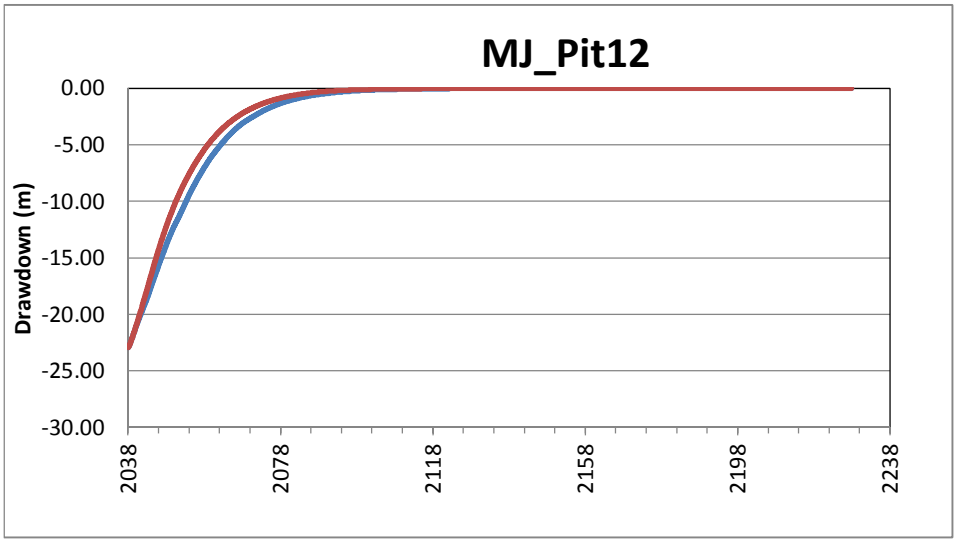

PREDICTED GROUNDWATER LEVEL RECOVERY AT MESA J (CASE 2) FIGURE C15

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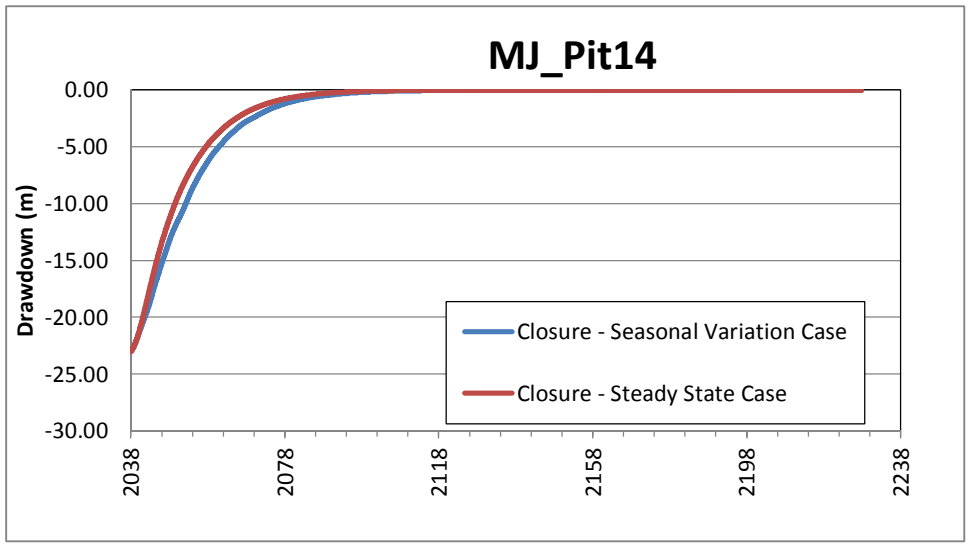

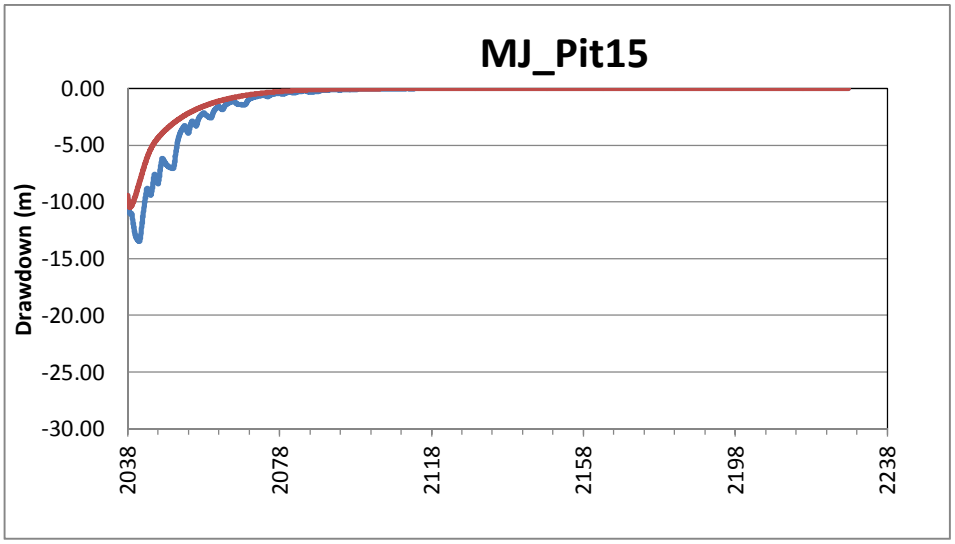

RioTinto

PREDICTED GROUNDWATER LEVEL RECOVERY AT MESA J (CASE 2) FIGURE C16

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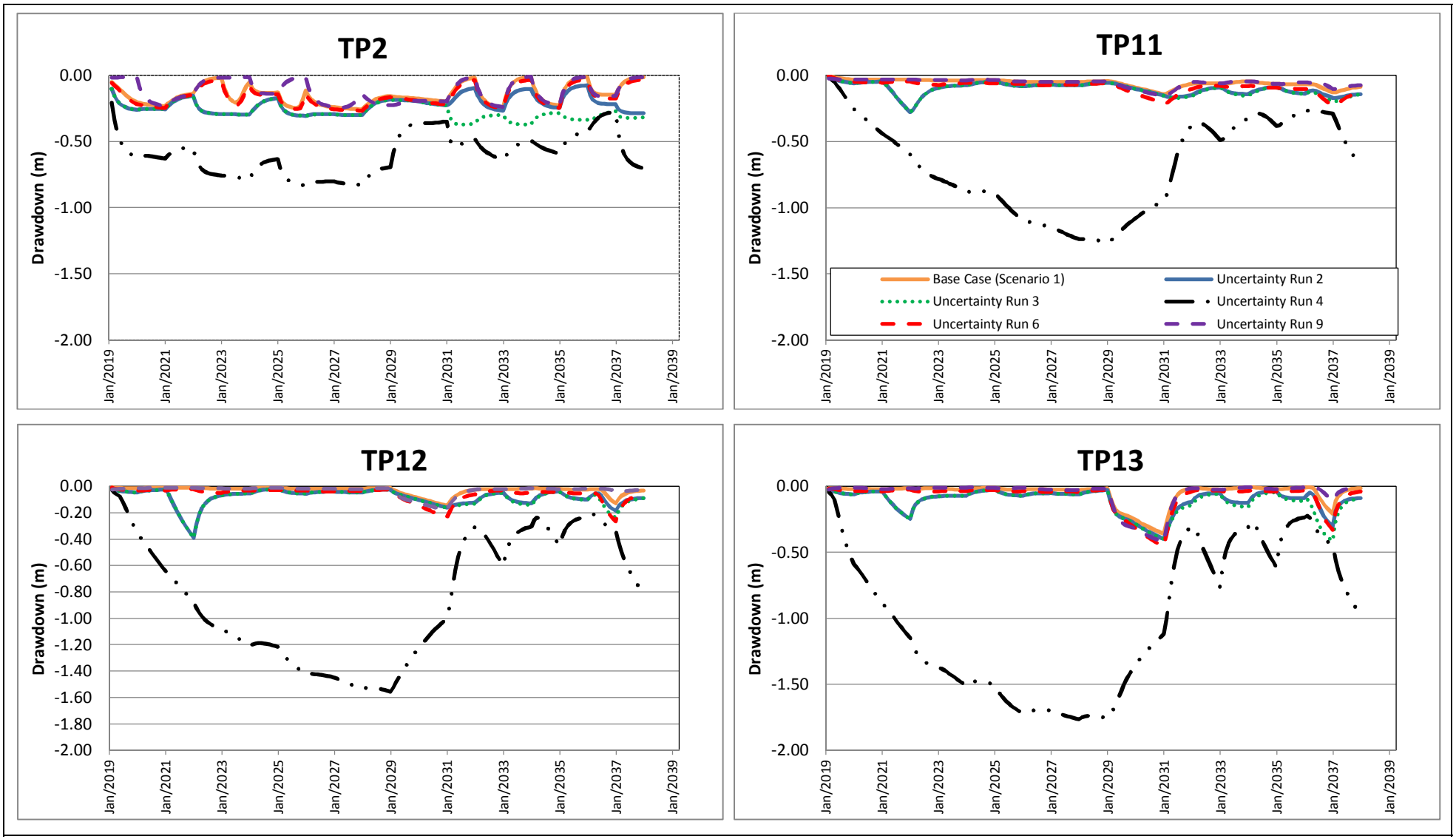
APPENDIX D
UNCERTAINTY RESULTS



RioTinto

PREDICTED DRAWDOWN AT TRACKING POINTS ALONG THE ROBE RIVER (UNCERTAINTY RUNS 2, 3, 4, 6 & 9 CLIMATE) CASE 1 FIGURE D1

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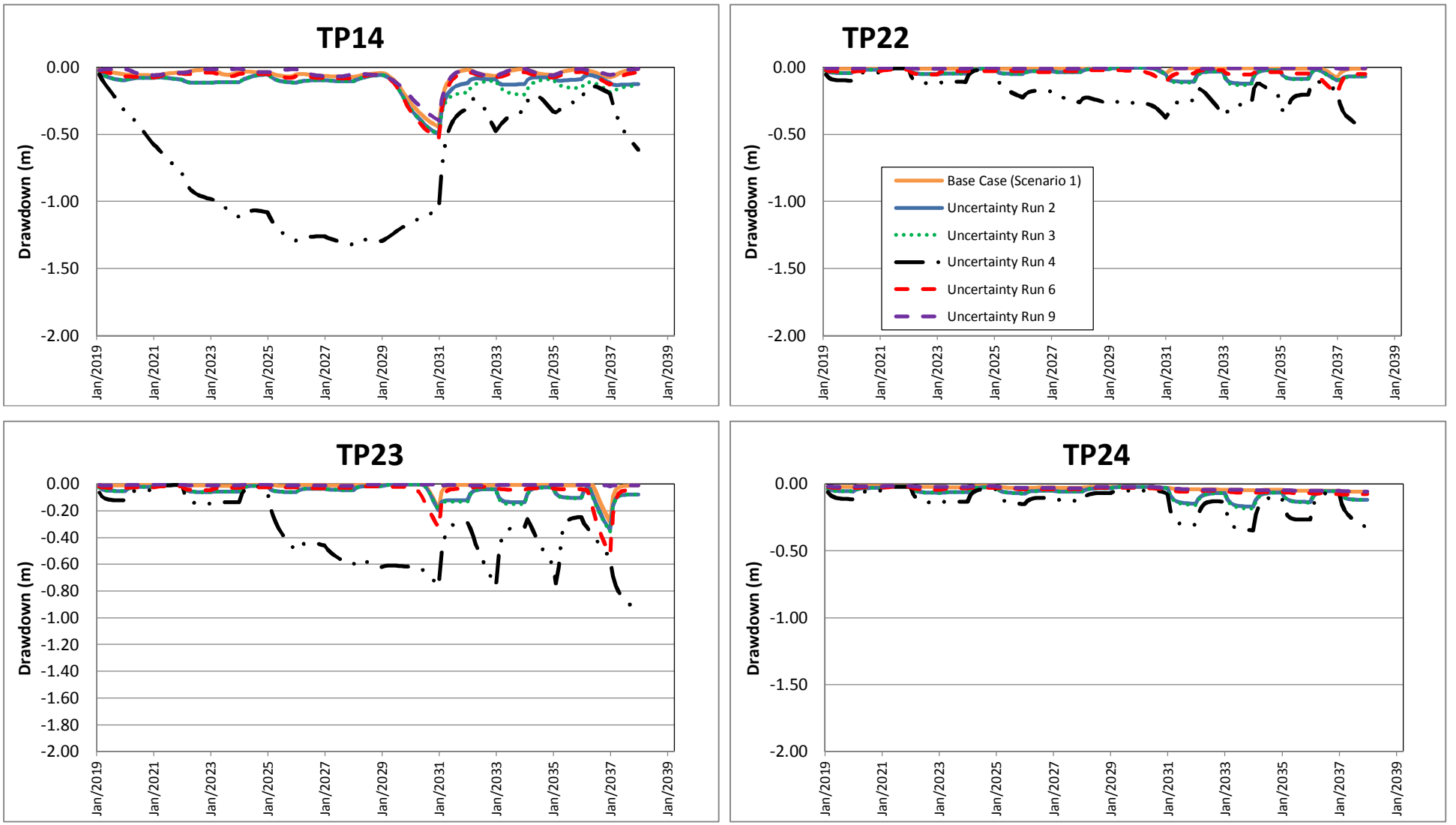

RioTinto

PREDICTED DRAWDOWN AT TRACKING POINTS ALONG THE ROBE RIVER (UNCERTAINTY RUNS 2, 3, 4, 6 & 9 CLIMATE) CASE 1 FIGURE D2

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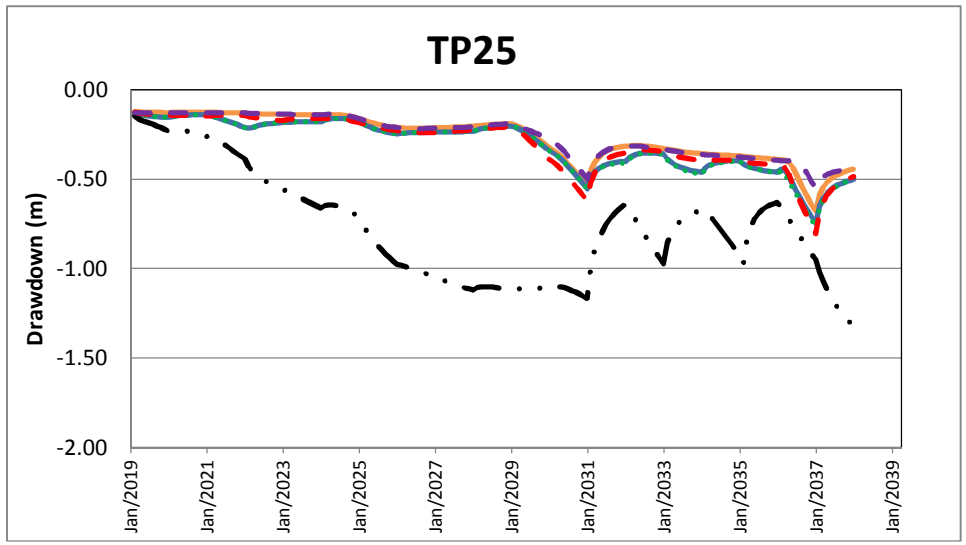

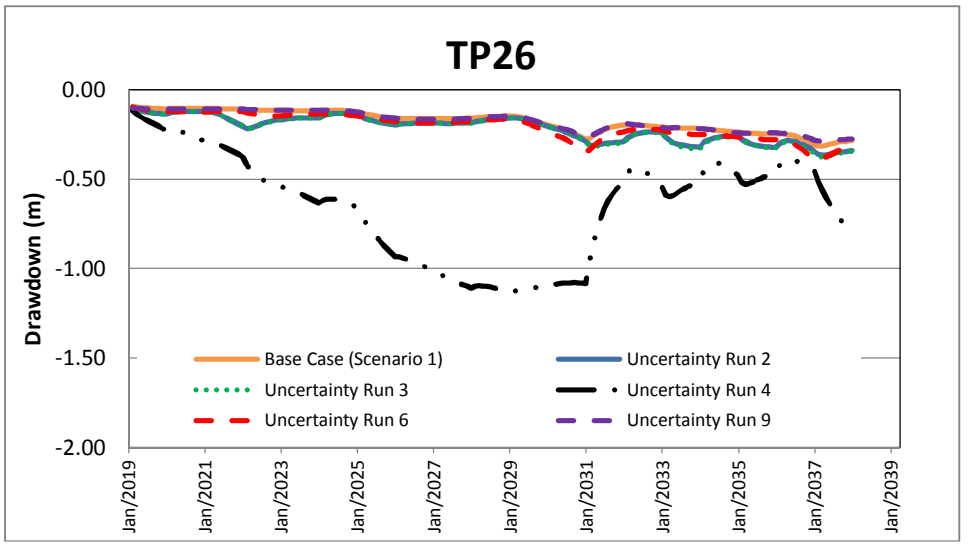

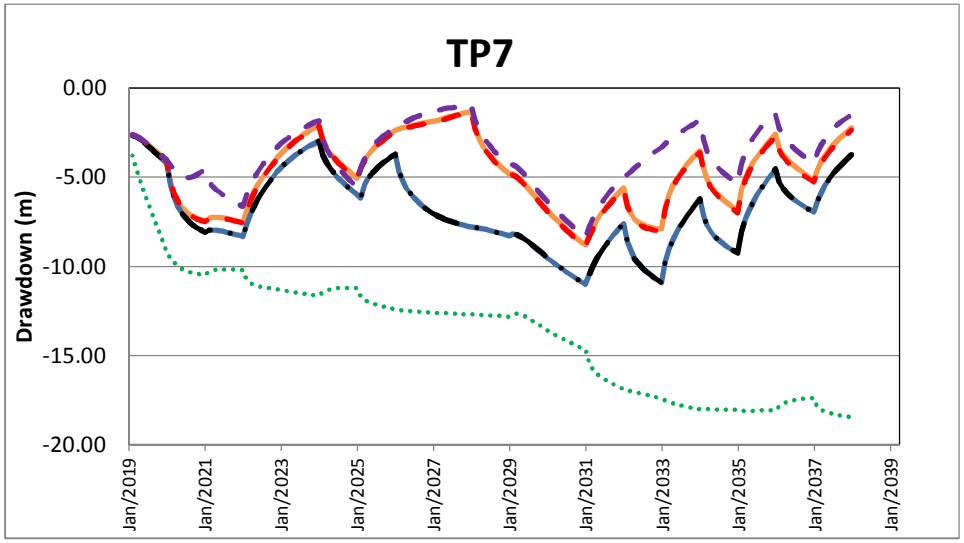

Note: Different vertical scale

RioTinto

PREDICTED DRAWDOWN AT TRACKING POINTS ALONG THE ROBE RIVER (UNCERTAINTY RUNS 2, 3, 4, 6 & 9 CLIMATE) CASE 1 FIGURE D3

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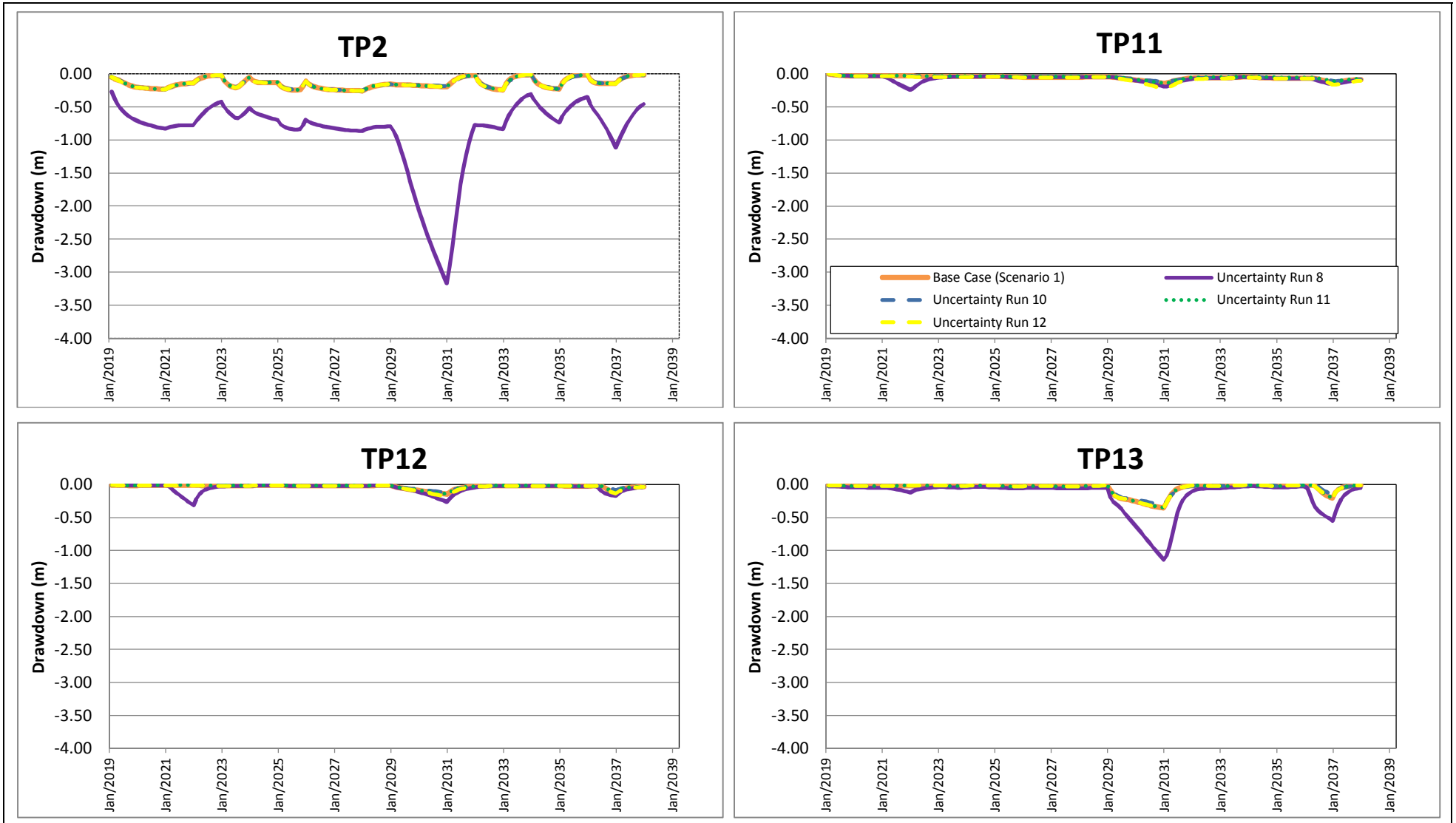

RioTinto

PREDICTED DRAWDOWN AT TRACKING POINTS ALONG THE ROBE RIVER (UNCERTAINTY RUNS 8, 10, 11 & 12 CONCEPTUAL) CASE 1 FIGURE D4

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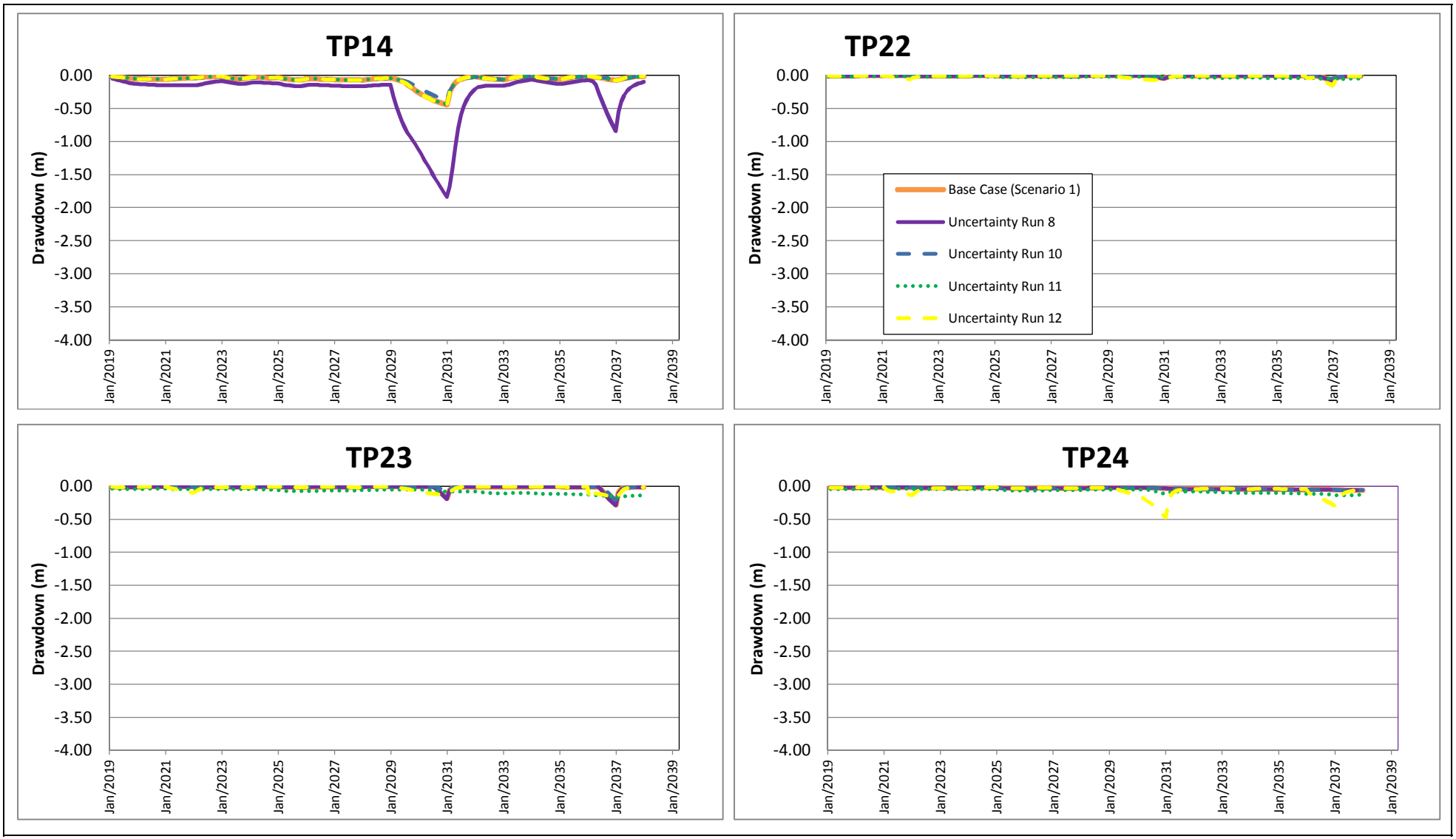

RioTinto

PREDICTED DRAWDOWN AT TRACKING POINTS ALONG THE ROBE RIVER (UNCERTAINTY RUNS 8, 10, 11 & 12 CONCEPTUAL) CASE 1 FIGURE D5

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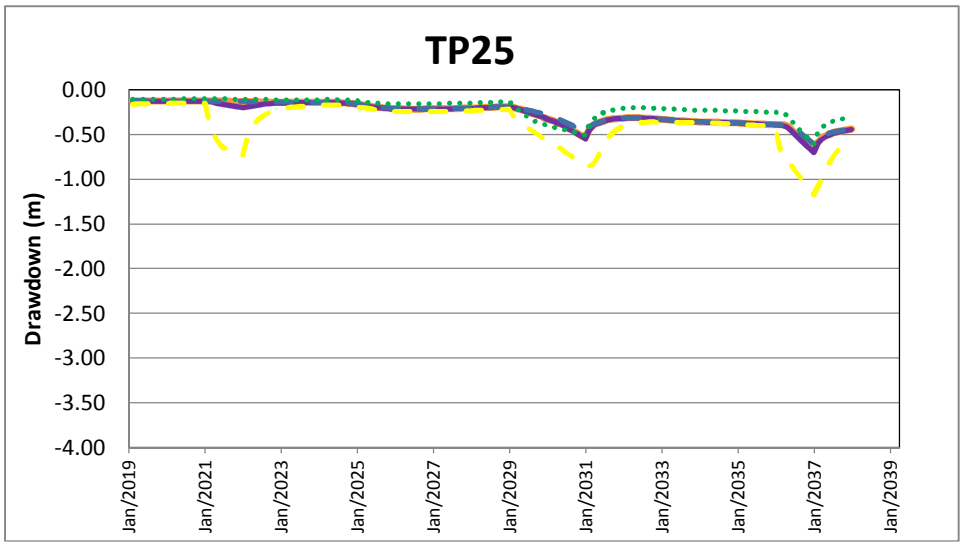

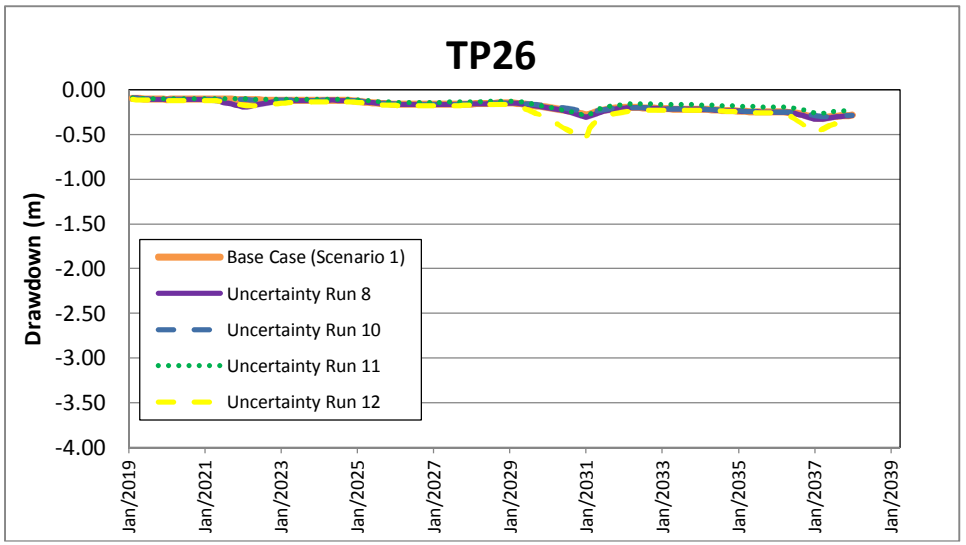

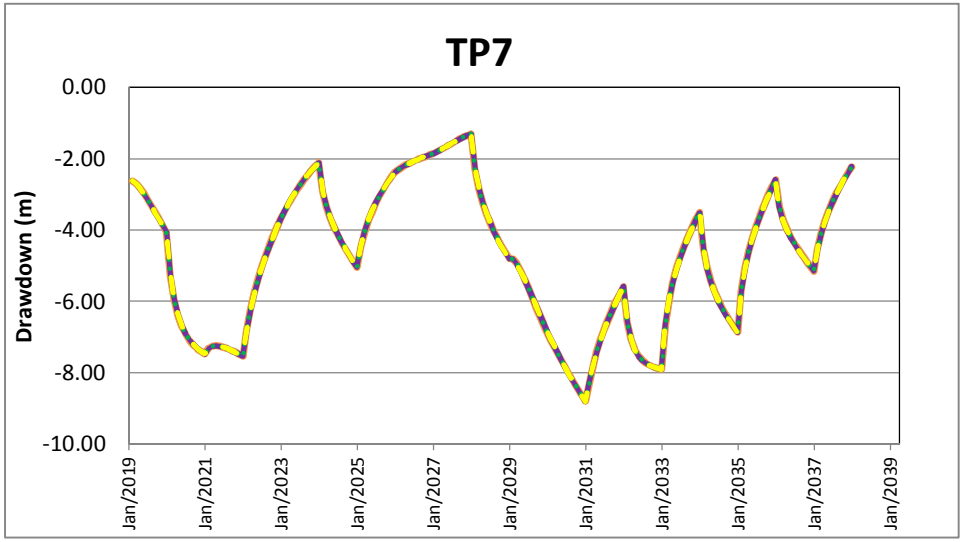

Note: Different vertical scales

RioTinto

PREDICTED DRAWDOWN AT TRACKING POINTS ALONG THE ROBE RIVER (UNCERTAINTY RUNS 8, 10, 11 & 12 CONCEPTUAL) CASE 1 FIGURE D6

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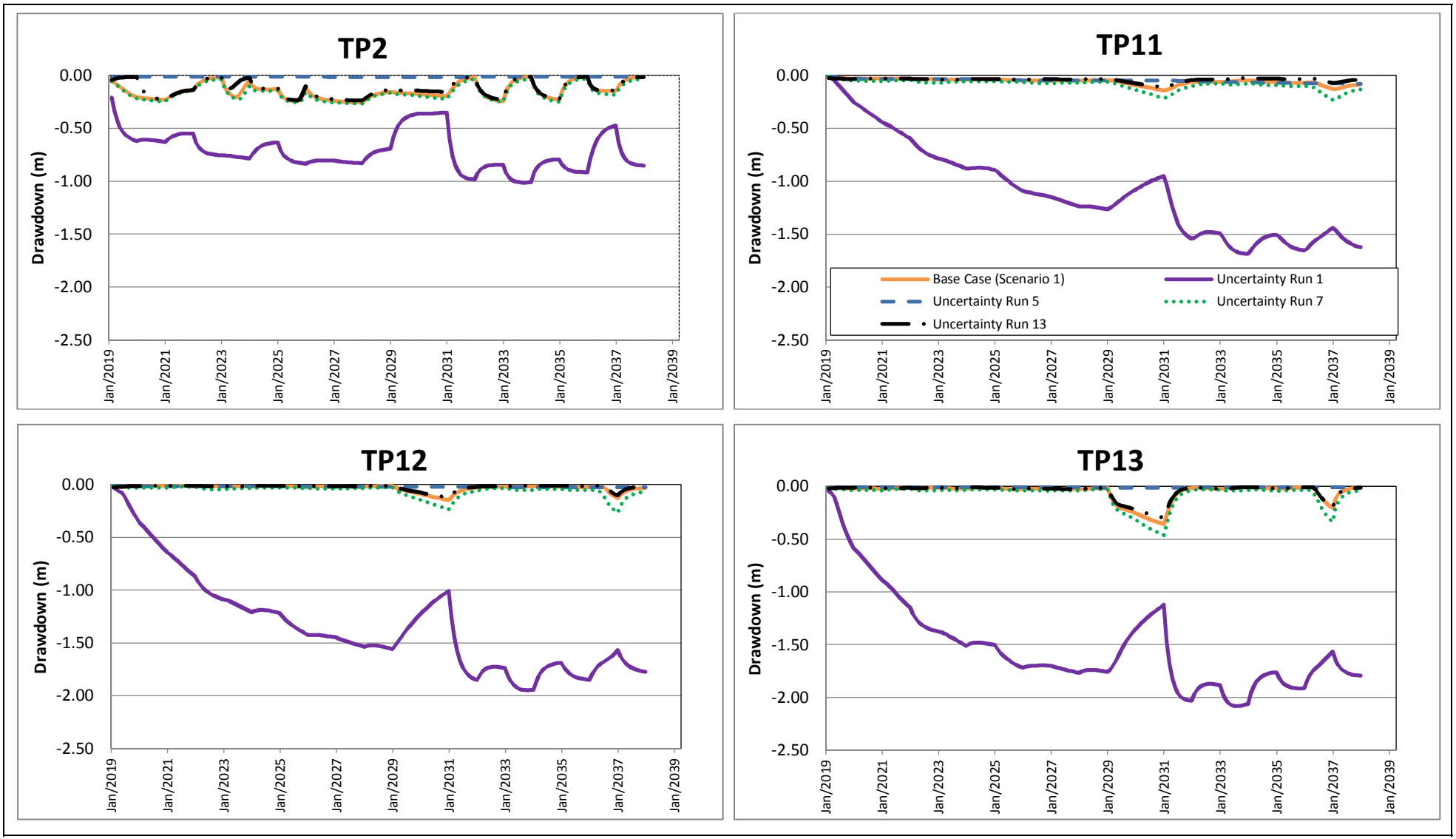

RioTinto

PREDICTED DRAWDOWN AT TRACKING POINTS ALONG THE ROBE RIVER (UNCERTAINTY RUNS 1,5,7 &13 STRESS) CASE 1 FIGURE D7

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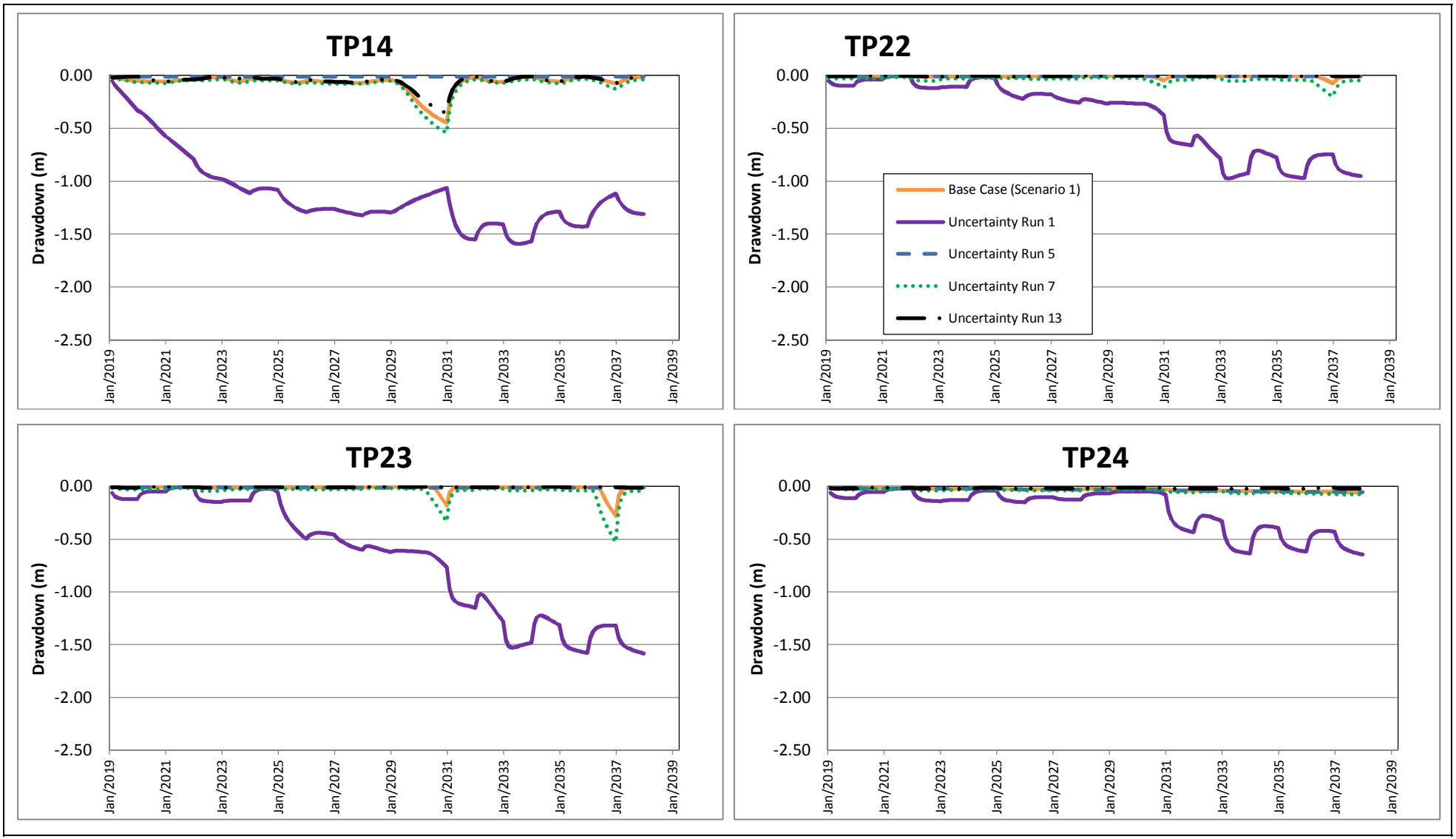

RioTinto

PREDICTED DRAWDOWN AT TRACKING POINTS ALONG THE ROBE RIVER (UNCERTAINTY RUNS 1,5,7 &13 STRESS) CASE 1 FIGURE D8

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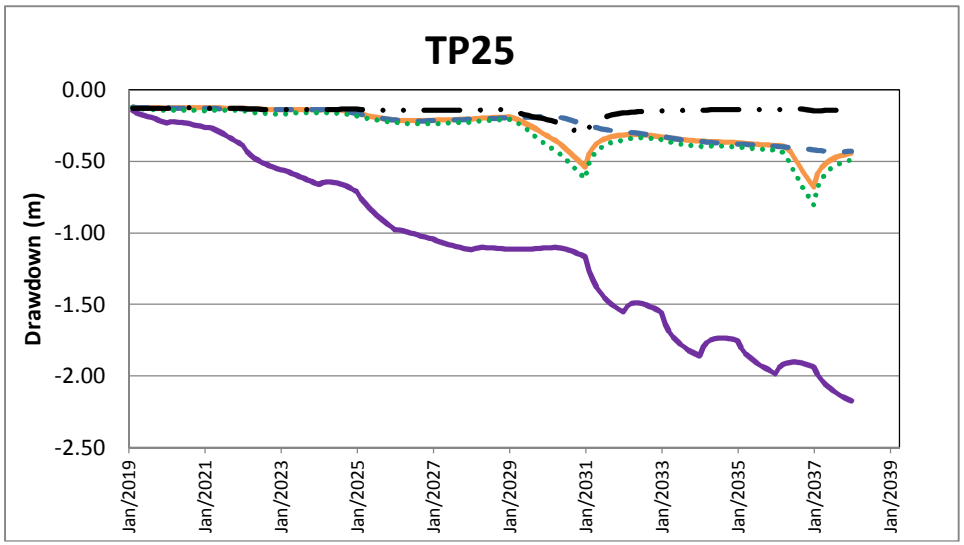

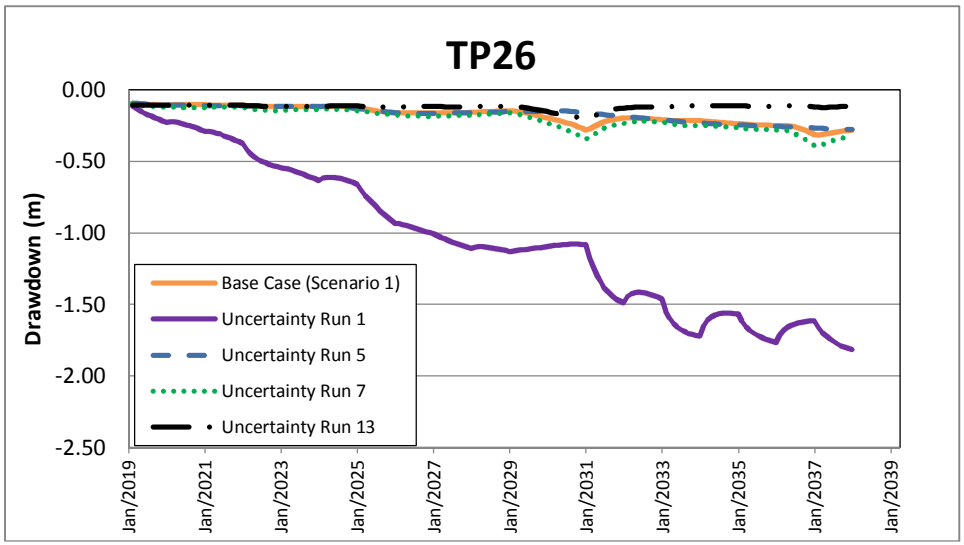

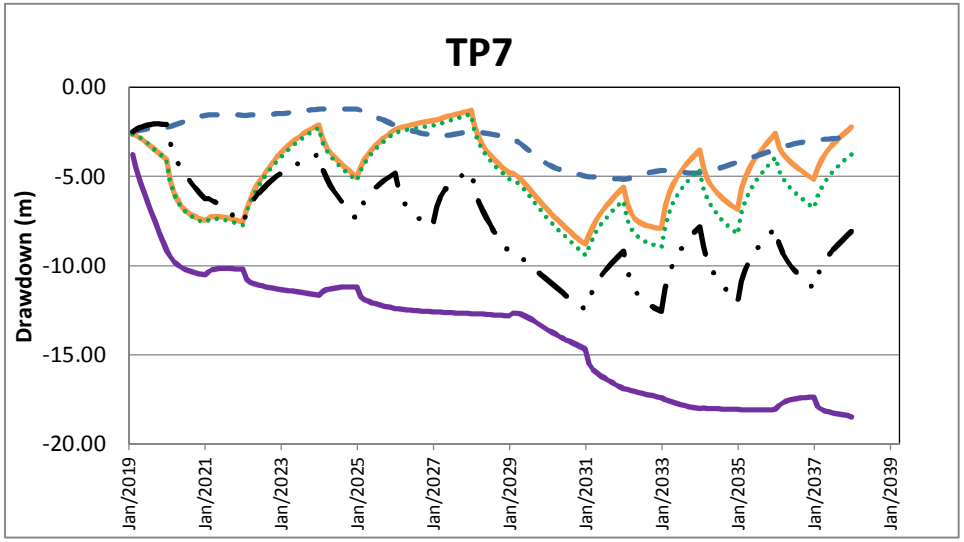

Note: Different vertical scale

RioTinto

PREDICTED DRAWDOWN AT TRACKING POINTS ALONG THE ROBE RIVER (UNCERTAINTY RUNS 1,5,7 &13 STRESS) CASE 1 FIGURE D9

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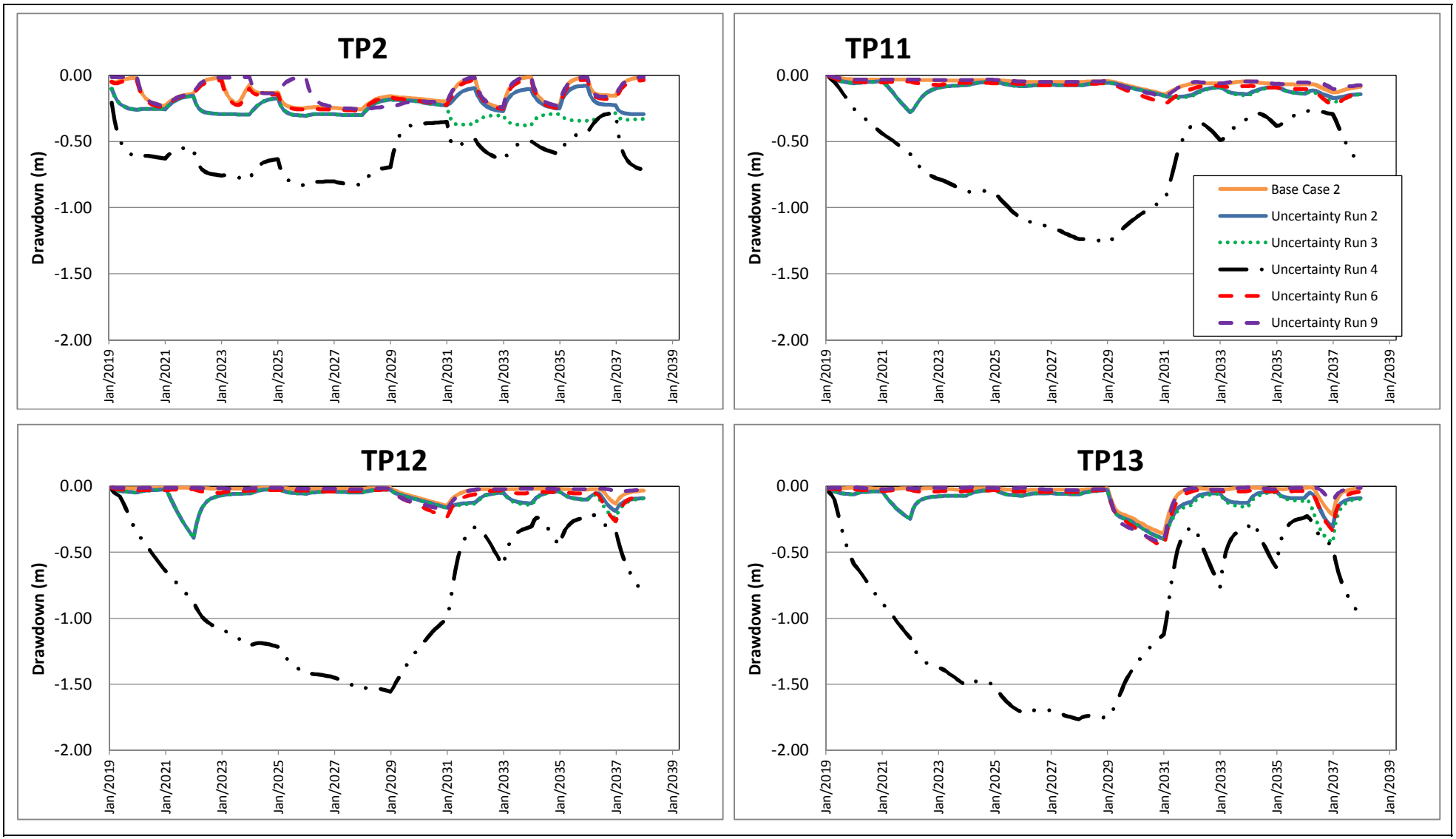

RioTinto

PREDICTED DRAWDOWN AT TRACKING POINTS ALONG THE ROBE RIVER (UNCERTAINTY RUNS 2, 3, 4, 6 & 9 CLIMATE) CASE 2 FIGURE D10

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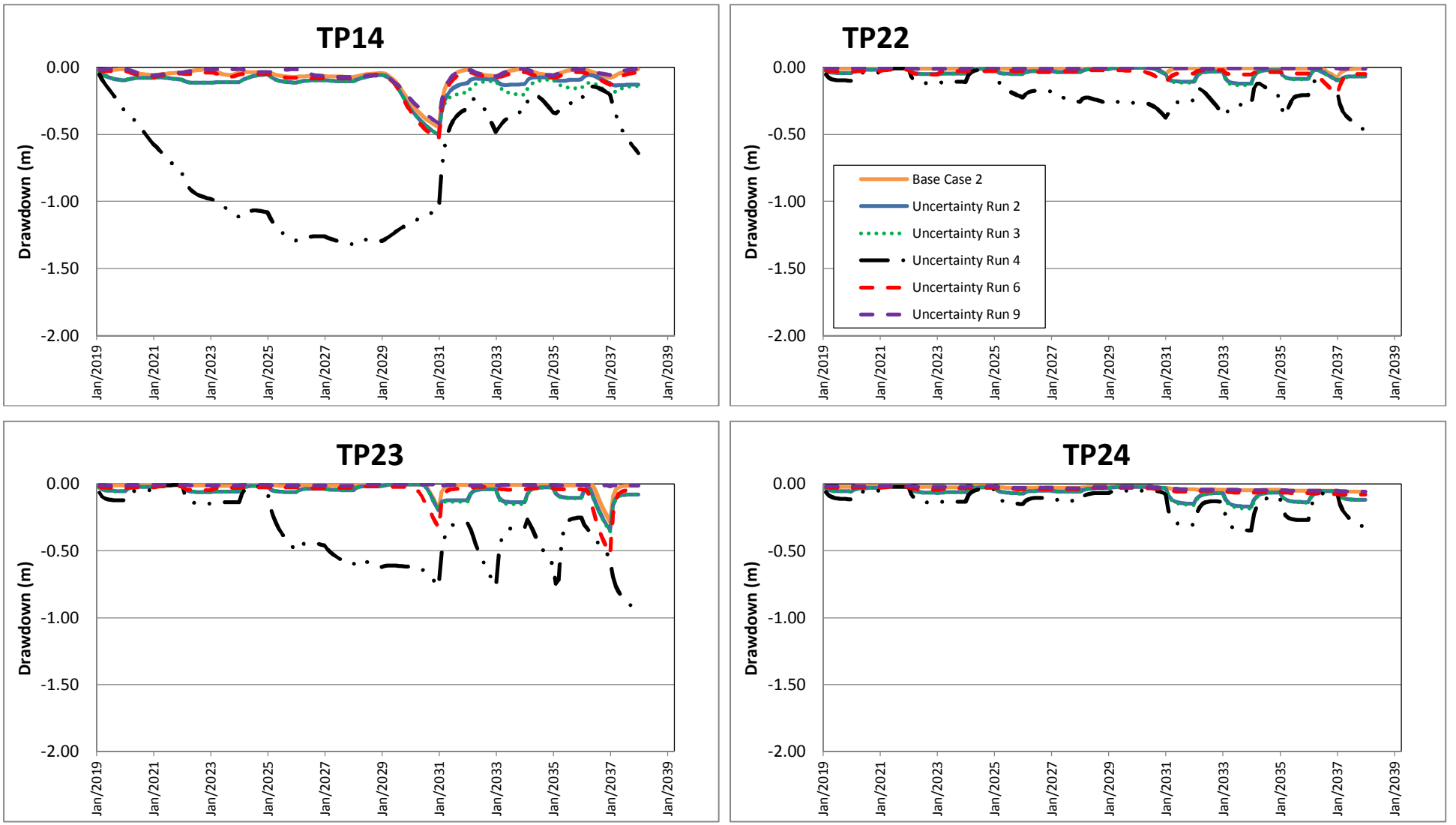

RioTinto

PREDICTED DRAWDOWN AT TRACKING POINTS ALONG THE ROBE RIVER (UNCERTAINTY RUNS 2, 3, 4, 6 & 9 CLIMATE) CASE 2 FIGURE D11

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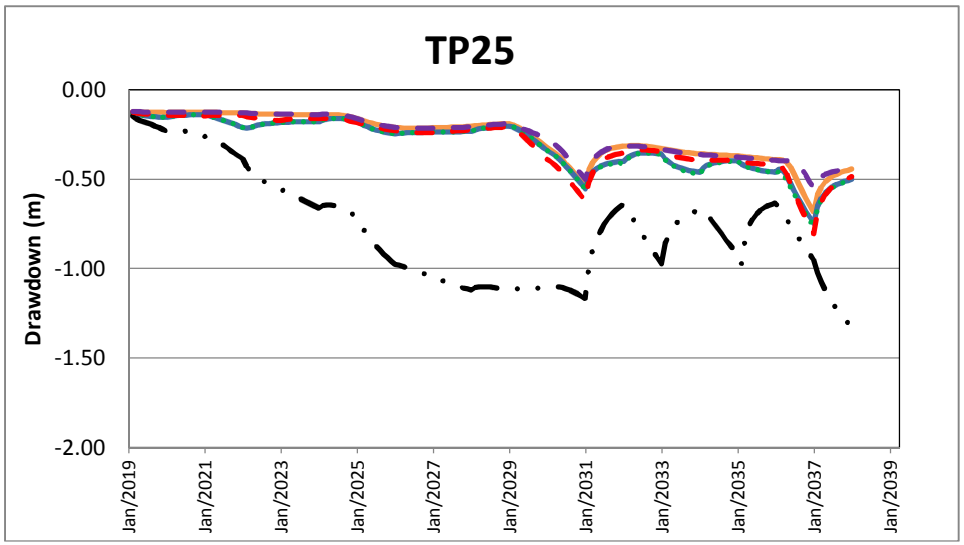

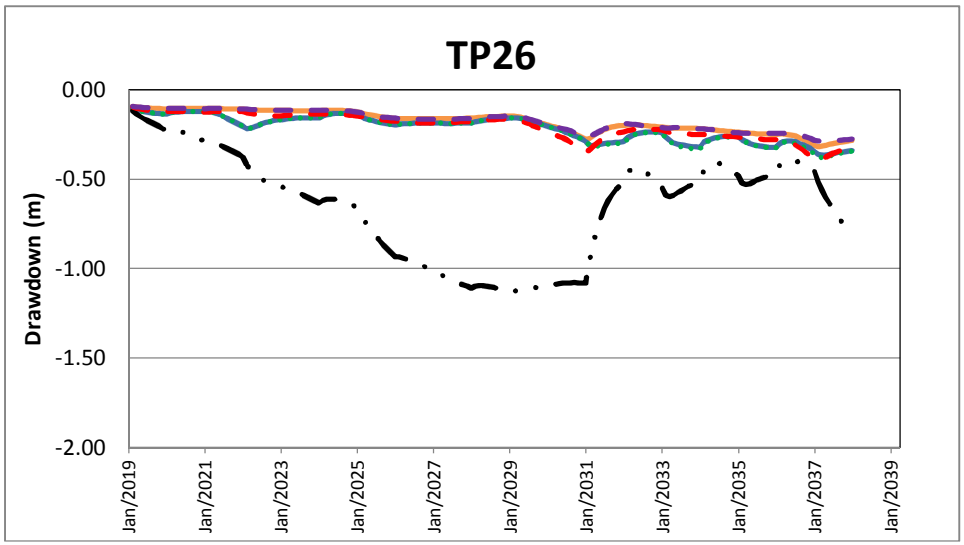

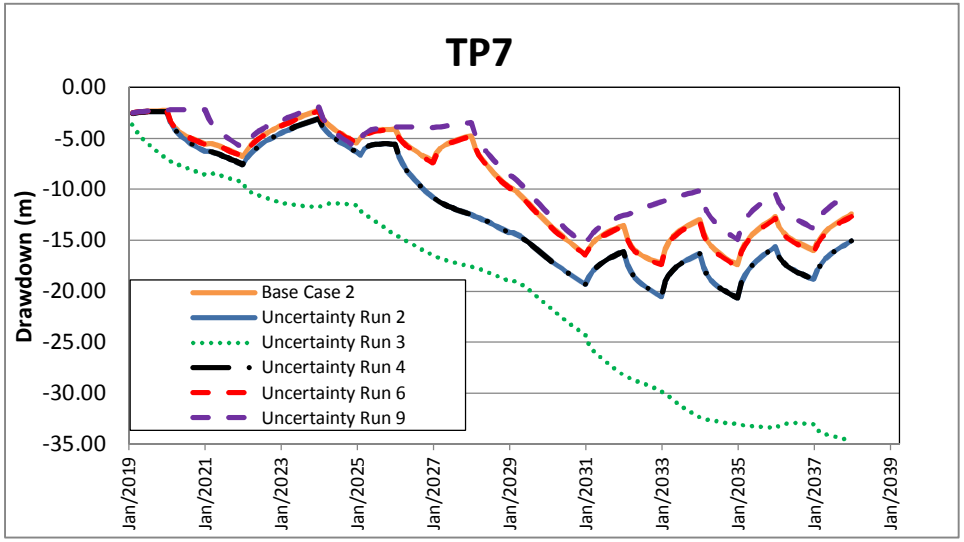

Note: Different vertical scales

RioTinto

PREDICTED DRAWDOWN AT TRACKING POINTS ALONG THE ROBE RIVER (UNCERTAINTY RUNS 2, 3, 4, 6 & 9 CLIMATE) CASE 2 FIGURE D12

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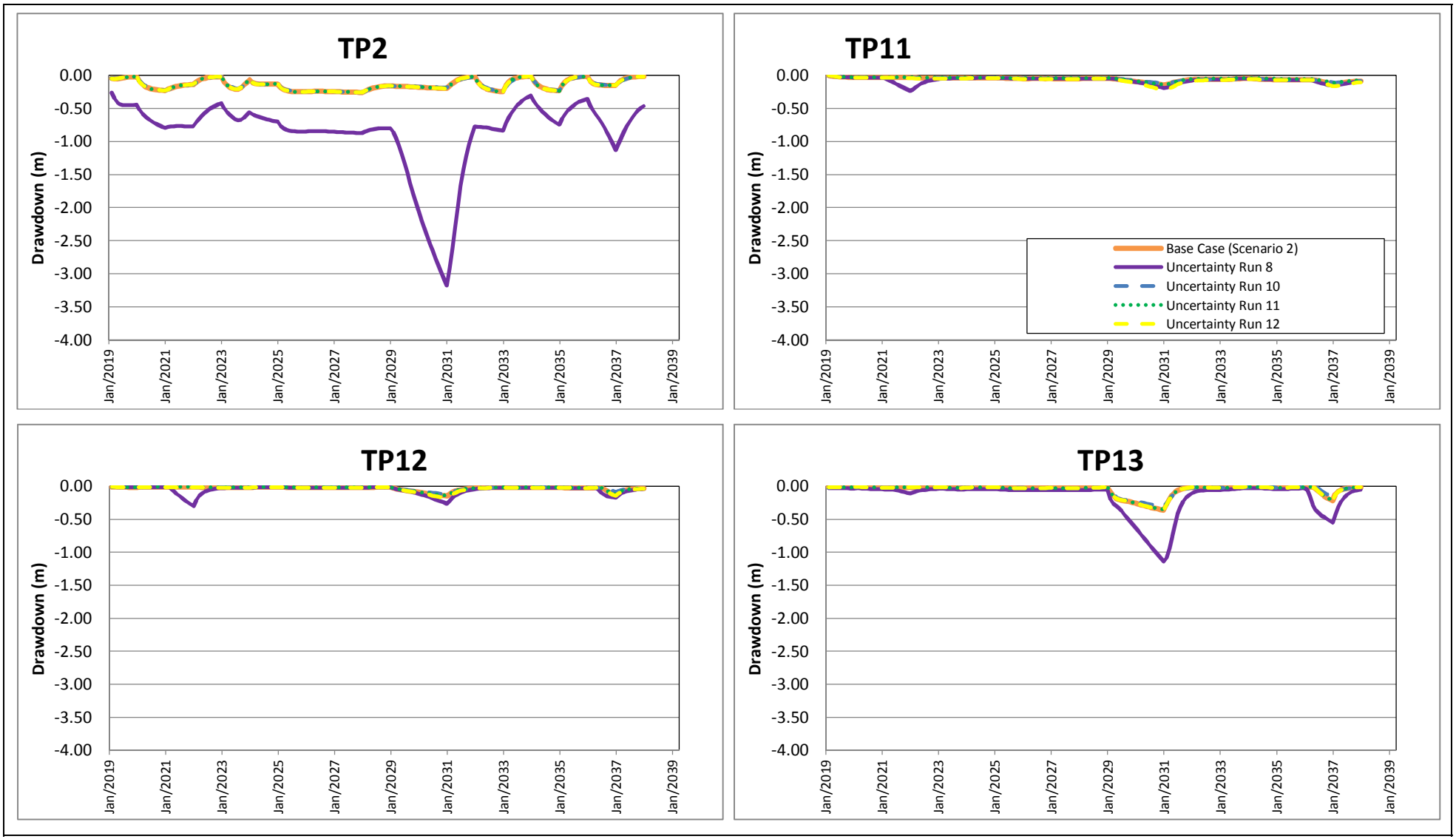

RioTinto

PREDICTED DRAWDOWN AT TRACKING POINTS ALONG THE ROBE RIVER (UNCERTAINTY RUNS 8, 10, 11 & 12 CONCEPTUAL) CASE 2 FIGURE D13

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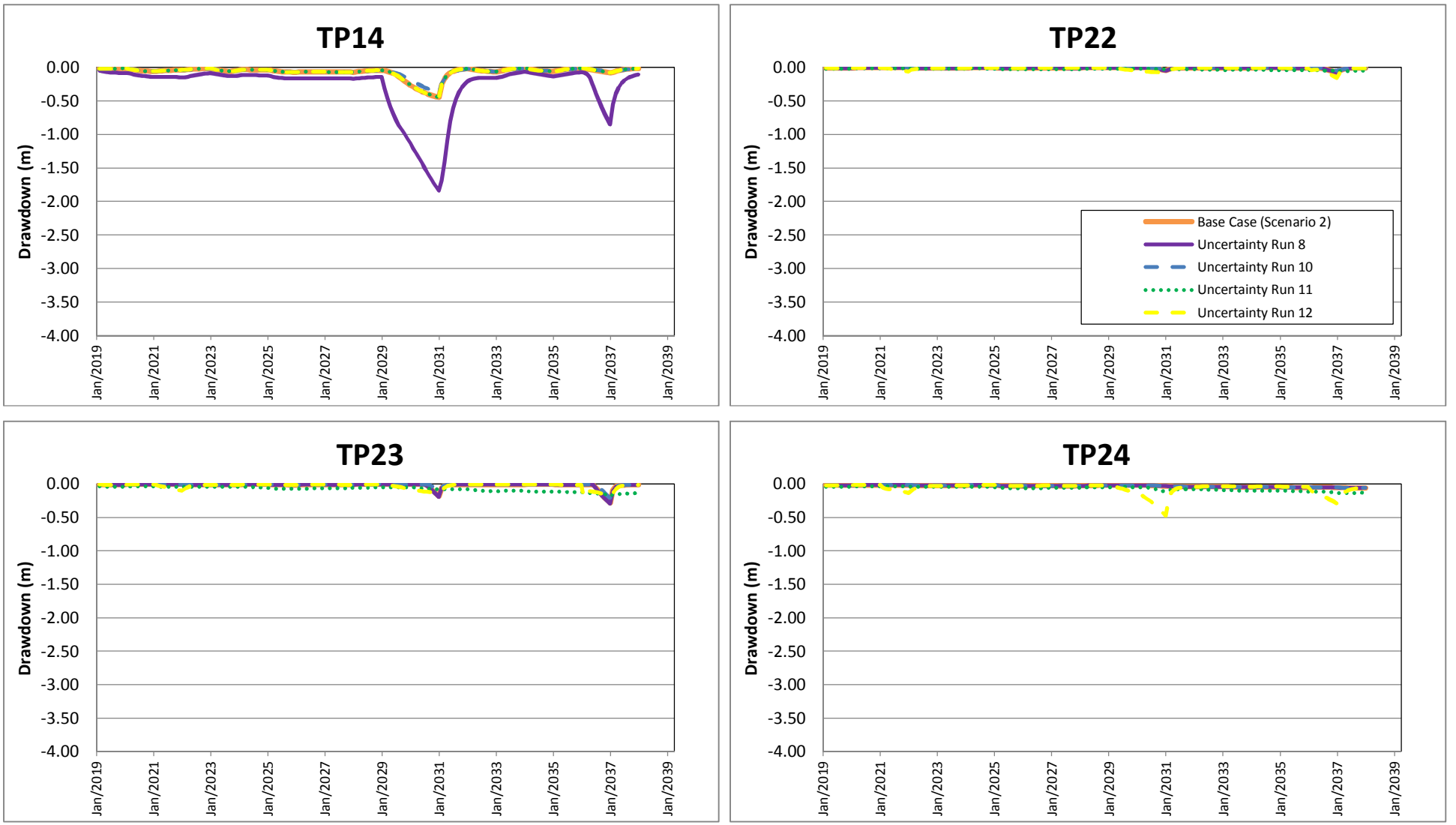

RioTinto

PREDICTED DRAWDOWN AT TRACKING POINTS ALONG THE ROBE RIVER (UNCERTAINTY RUNS 8, 10, 11 & 12 CONCEPTUAL) CASE 2 FIGURE D14

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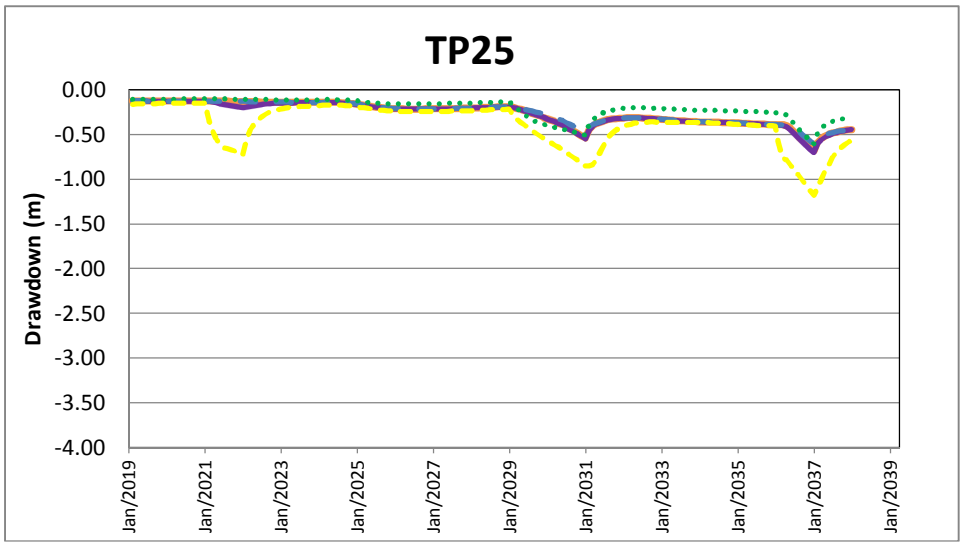

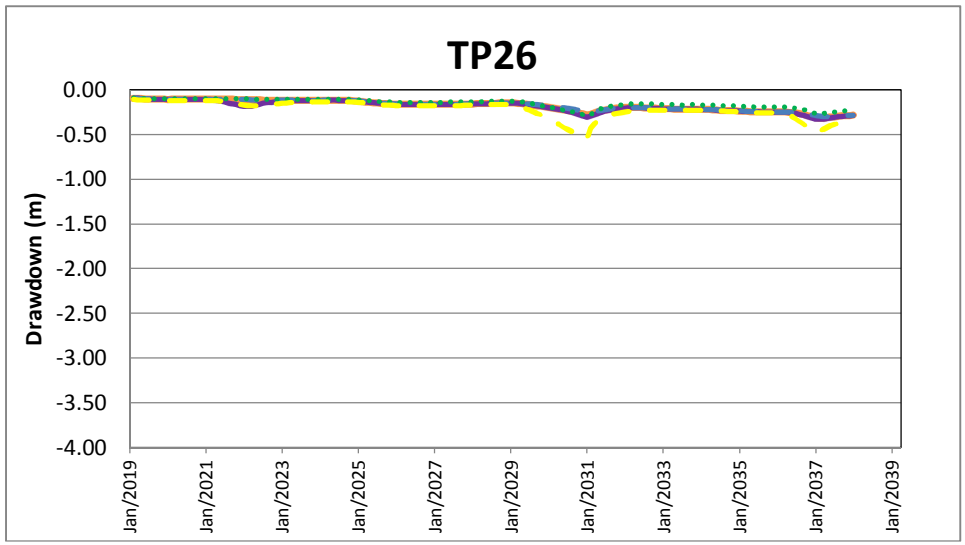

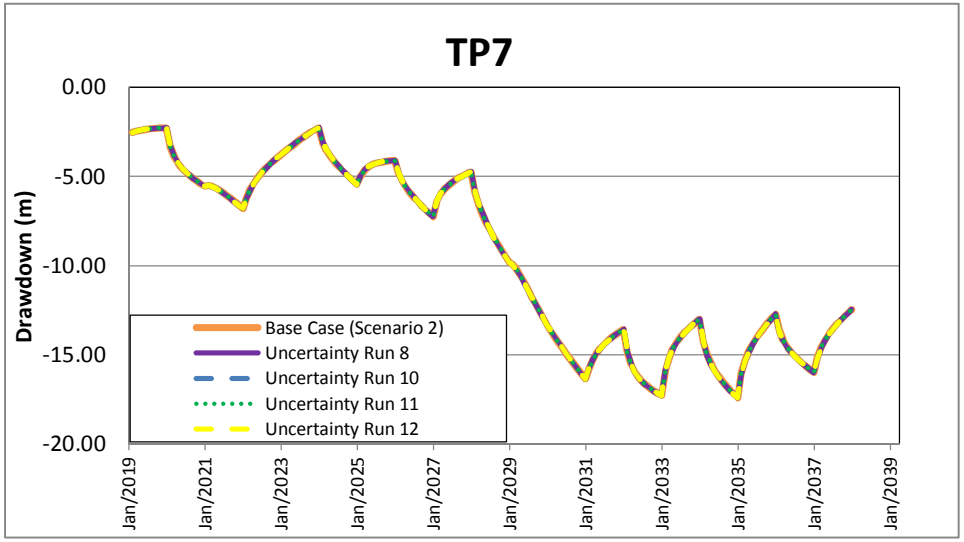

Note: Different vertical scales

RioTinto

PREDICTED DRAWDOWN AT TRACKING POINTS ALONG THE ROBE RIVER (UNCERTAINTY RUNS 8, 10, 11 & 12 CONCEPTUAL) CASE 2 FIGURE D15

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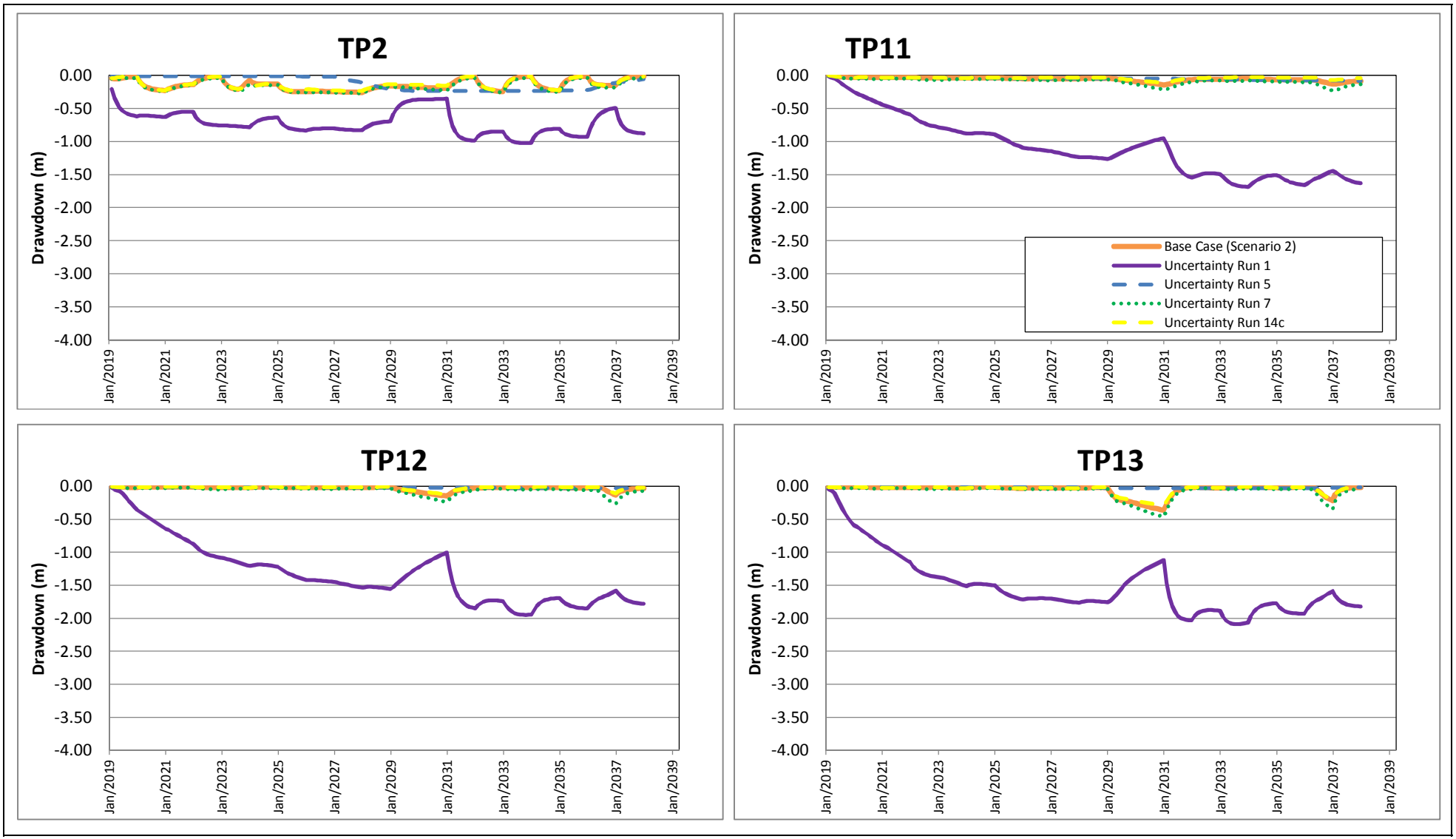

RioTinto

PREDICTED DRAWDOWN AT TRACKING POINTS ALONG THE ROBE RIVER (UNCERTAINTY RUNS 1,5,7 &13 STRESS) CASE 2 FIGURE D16

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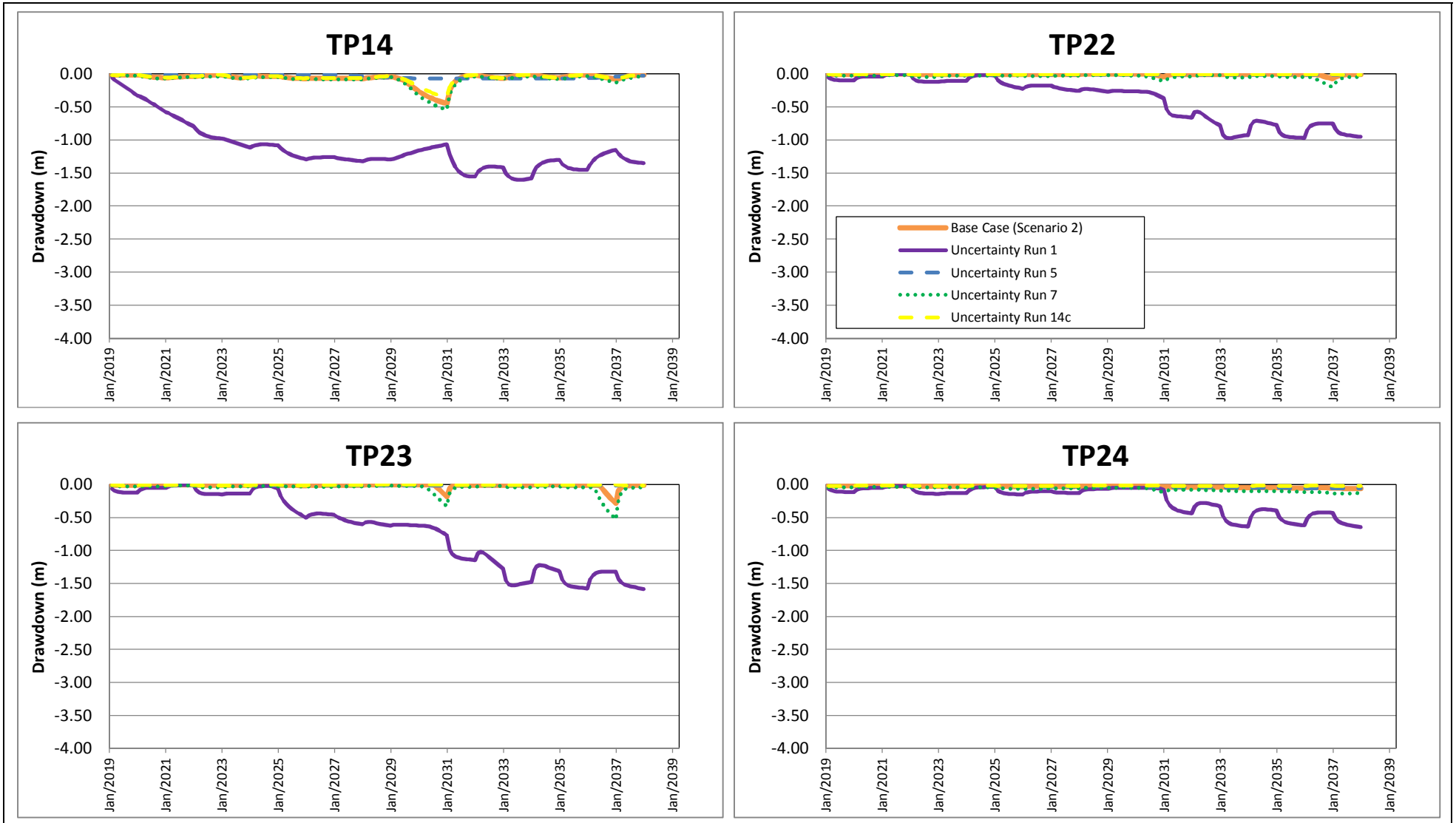

RioTinto

PREDICTED DRAWDOWN AT TRACKING POINTS ALONG THE ROBE RIVER (UNCERTAINTY RUNS 1,5,7 &13 STRESS) CASE 2 FIGURE D17

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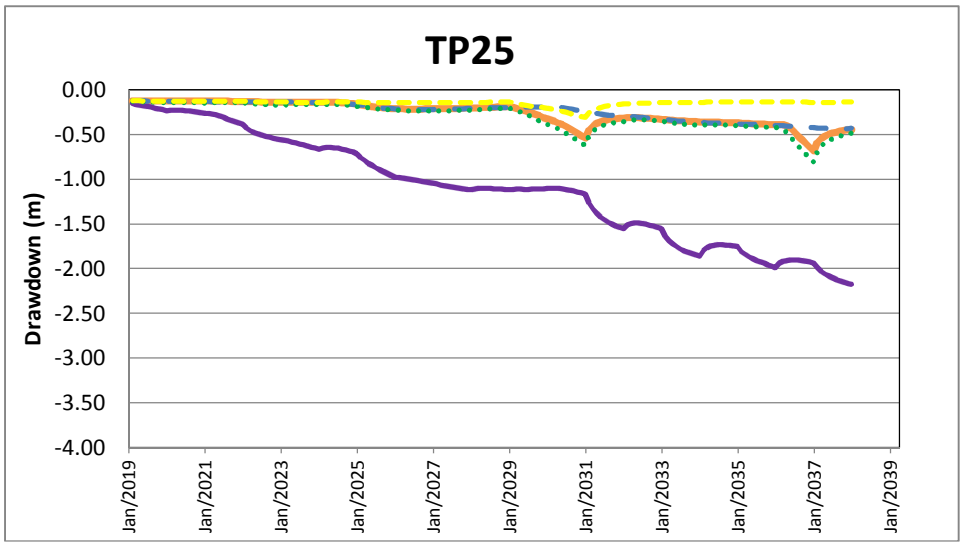

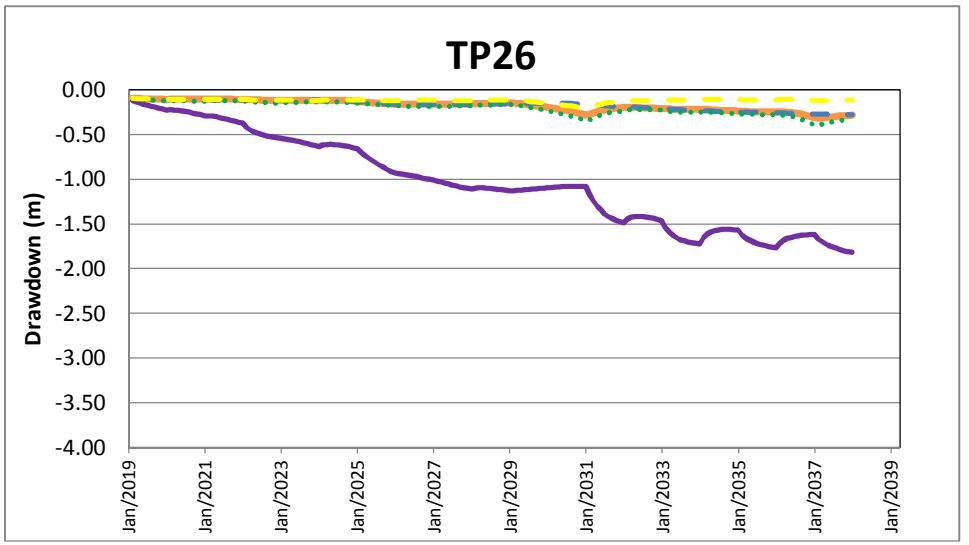

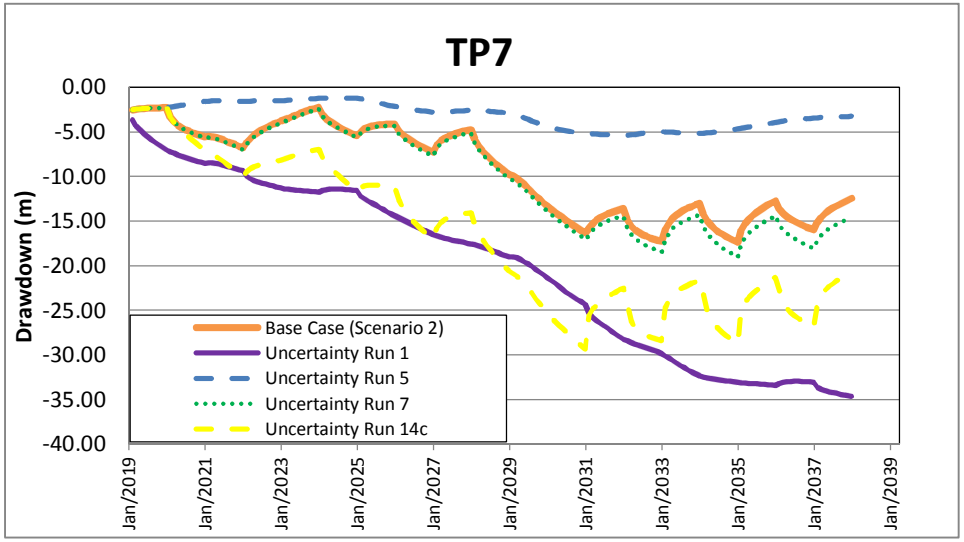

Note: Different vertical scales

RioTinto

PREDICTED DRAWDOWN AT TRACKING POINTS ALONG THE ROBE RIVER (UNCERTAINTY RUNS 1,5,7 &13 STRESS) CASE 2 FIGURE D18

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APPENDIX C: SURPLUS WATER DISCHARGE EXTENT ASSESSMENT

Iron Ore
152-158 St Georges Terrace
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Western Australia
T + 61 (8) 9327 2000

Memo

From	Darryn Knoesen
Department	Water Resource Evaluation
To	File
CC	Mark Pearcey; Jeremy English
Reference	RTIO-PDE-0149961
Date	12 March 2017
Number of pages	12

Surplus water discharge extent assessment: Mesa H

Overview

The Mesa H deposit is located approximately 11 km southwest of Pannawonica and adjacent to the Robe JV Mesa J mine, downstream of the confluence of the Robe River and Jimmawurrada Creek (Figure 1). Approximately 40% of the resource is below the current water table (which has been lowered by dewatering at Mesa J). Consequently, approval will be sought to commence mining below water table, which will require dewatering.

Management of water on Rio Tinto sites follows strict environmental and water use standards (refer to Rio Tinto Environmental Standards). These standards align with the "Pilbara Water in Mining Guideline" (DoW, 2009) which identifies options for use and/or release of dewatering discharge:

- Efficient on-site use, including mitigation of any impacts.
- Used for fit for purpose activities (such as processing and dust suppression). The proponent needs to demonstrate that the water is of suitable quality for the end use.
- Transferred to meet other demand including other proponents in the area and public water supply, as approved by the Department. Where it is proposed to use the water for public supply, a drinking water source protection plan should be developed and approved by the Department of Water and the Department of Health.
- Injection back into the aquifer at designated sites determined by the proponent and agreed by the Department.
- Controlled release to the environment where the dewater release is allowed to flow (either through a pipe or overland) into a designated water course or wetland and determined by the proponent and agreed by the Department.

Management of surplus water at Mesa H may include the controlled discharge of surplus water at existing discharge locations at Mesa J, namely Discharge point 5 (Jimmawurrada Creek) or Discharge Point B (Robe River tributary immediately west of Mesa J). Therefore, the objective of this study was to estimate the extent of impact of surplus water discharge along the respective watercourses. The methodology to achieve this objective is outlined below:

- Develop a 2D hydraulic model of the river system downstream of the proposed discharge location.
- Determine the hydraulic characteristics that are not inherently accounted for by the 2D hydraulic model, i.e. saturated hydraulic conductivity of the soils.
- Estimate the maximum possible extent that surplus water discharge will flow under steady-state conditions.
- Investigate multiple steady-state scenarios, namely a continuous discharge rate of 5, 10, 15, 20, 25 and 30 ML/day.

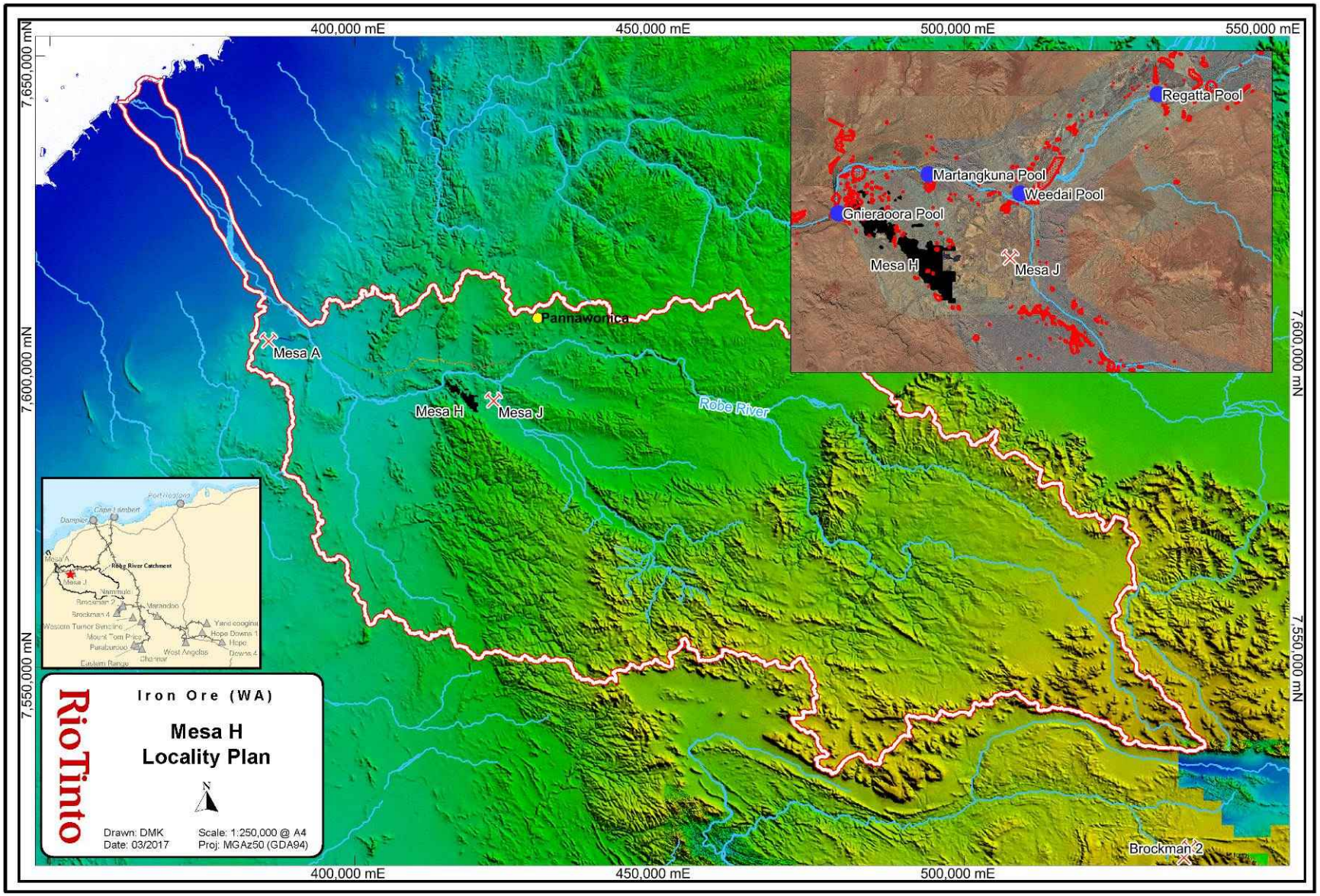

Figure 1: **Mesa H surplus water discharge study location plan**

Modelling Approach

Water flowing in a watercourse is removed from the surface via two mechanisms, namely: evaporation and infiltration. However, these hydrologic processes are inextricably intertwined with the flow characteristics, and hence the hydraulics, of the river system. The braided nature of typical Pilbara watercourses creates a complex hydrodynamic environment where the flow behaviour is essentially 2D in nature, which may be poorly represented using a 1D model.

Recent developments to the **T**wo-dimensional **U**nsteady **Flow** (TUFLOW) model have effectively transformed TUFLOW into a 2D coupled hydrologic-hydraulic modelling system, with the ability to model soil infiltration in both unsaturated and saturated conditions. This makes the TUFLOW model a useful tool for the estimation of surplus water discharge extent.

This section documents the process and assumptions made in developing the 2D hydraulic model for the Mesa H surplus water discharge.

TUFLOW hydraulic model

For this study, TUFLOW's GPU Module was adopted. This is a powerful new solver built into the TUFLOW software, which utilises the substantial parallel computing ability of modern Graphics Processor Units, or GPUs (TUFLOW, 2014). TUFLOW GPU is an explicit solver for the full 2D Shallow Water Equations, including a sub-grid scale eddy viscosity model. The scheme is both volume and momentum conserving. Owing to the power of modern GPUs very large models (>100 million cells) with fine grids can now be run within a sensible timeframe (TUFLOW, 2014). This allowed for a high resolution 1 m DEM, derived from LiDAR, to be used to describe the topography of the river system. This represents a major advantage of this approach. The model configurations are shown in Figure 2.

Manning's roughness coefficient *n*

Surface roughness is defined using the Manning's *n* roughness coefficient. The roughness coefficients adopted for this study were determined according to Chow (1959), which takes into consideration channel irregularities, variation in cross section, obstructions, vegetation density and meandering of the reach. These factors were assessed using aerial photography and confirmed during a site visit. The adopted Manning's *n* roughness coefficient for the Robe River and Jimmawurrada Creek was 0.045, while the Robe River tributary immediately west of Mesa J was assigned a Manning's *n* roughness coefficient of 0.035. These values were applied to all applicable active cells in the model, which was limited to the river/creek channels, as can been seen in Figure 2.

Model inflows

Multiple steady-state scenarios were assessed, namely a continuous discharge of 5, 10, 15, 20, 25 and 30 ML/day.

Model outflows

The maximum discharge extent is achieved when equilibrium is reached between the inflows to and the outflows from the system. Water flowing in a watercourse is removed from the surface through evaporation and/or infiltration.

Evaporation

Annual and monthly potential evaporation rates (A-pan) are available from the Bureau of Meteorology (BoM) website. However, evaporation from open water bodies can be significantly less than A-pan estimates owing to a variety of climatic factors. As such, correction factors are often required to relate A-pan evaporation to evaporation from open water bodies. From Figure 3 it can be seen that evaporation from open water bodies for most of the Pilbara region of Western Australia is between 60-70% of the A-pan evaporation rates.

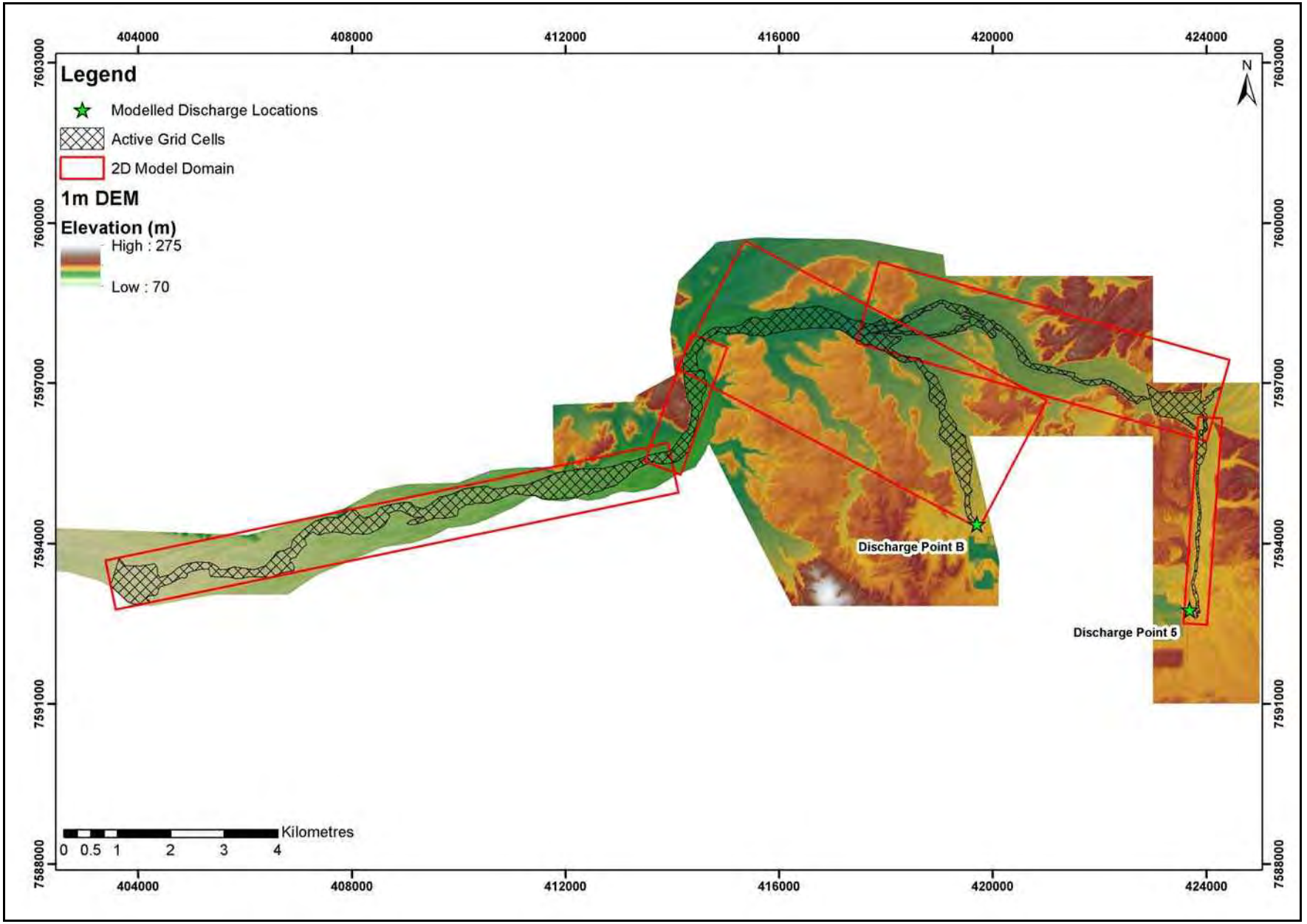

Figure 2: TUFLOW model configuration

From Figure 3, the A-pan evaporation rate for Mesa H was determined to be 3400 mm per year. However, the lowest monthly A-pan evaporation occurs in June (157 mm). This was multiplied by 0.65 (Luke et al., 1987) to relate A-pan to open water body evaporation. Consequently the adopted evaporation rate was 102 mm per month, which translates to an average rate of 0.14 mm/h.

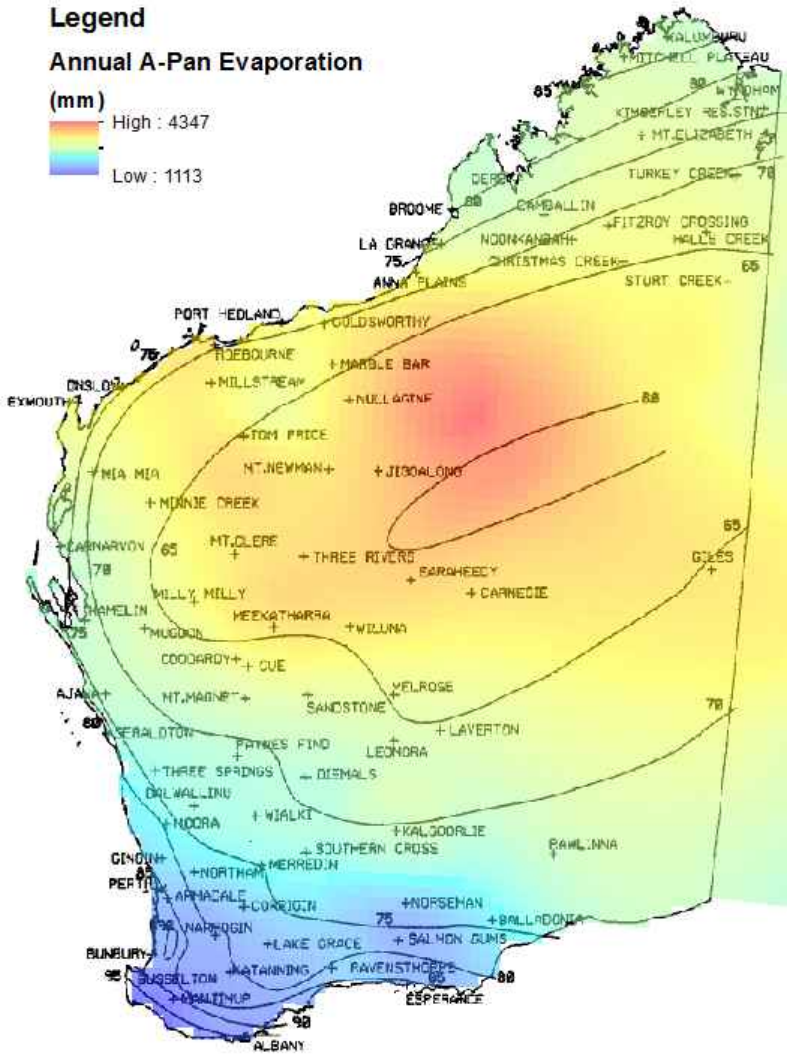

Figure 3: Gridded annual A-pan evaporation and A-pan correction factors (contours) for Western Australia (from BoM and Luke et al., 1987)

Infiltration

The maximum discharge extent is achieved when equilibrium is reached between the inflows to and the outflows from the system. As the soil moisture content increases so the infiltration rate of the soil decreases until the saturated hydraulic conductivity (K_{sat}) of the soil is reached. Consequently, equilibrium between the inflows and outflows, and hence the maximum discharge extent, can only be achieved once the soils have reached saturation. As such, when the aim of the discharge extent modelling is to determine the maximum discharge extent for long-term discharge there is no need to simulate losses in unsaturated conditions, and a continuing loss equal to K_{sat} may be adopted.

Although the Soil Hydrological Properties for Australia (Western and McKenzie, 2006) provides K_{sat} values for the whole of Australia, experience has shown that these values can be up to three orders of magnitude too high, thereby overestimating losses from the system and drastically under estimating the maximum discharge extent. As a result, a texture based approach to estimate K_{sat} in the absence of measured data has been applied. This approach derives a weighted clay content for each Map Unit in the Atlas of Australian Soils (Northcote

et al., 1960-1968), which places the Map Unit into one of six Texture Groups documented by McKenzie et al. (2000), shown in Table 1.

Table 1: Texture groups according to clay content - adapted from McKenzie et al. (2000)

Weighted Clay Content (%)	Texture Group	Texture Grade
0 – 8	Sands	Sand Clayey Sand Loamy Sand
8 – 17.5	Sandy Loams	Sandy Loam Fine Sandy Loam Light Sandy Loam
17.5 – 25	Loams	Loam Loam, Fine Sandy Silt Loam Sandy Clay Loam
25 – 35	Clay Loams	Clay Loam Silty Clay Loam Fine Sandy Clay Loam
35 – 47.5	Light Clays	Sandy Clay Silty Clay Light Clay Light Medium Clay
47.5 – 100	Clays	Medium Clay Heavy Clay

The least permeable texture grade is adopted as the representative texture for each Texture Group, and is therefore considered to be a conservative estimate. The adopted K_{sat} values for each Texture Group are presented in Table 2.

Table 2: Saturated hydraulic conductivities for different texture groups – adapted from Clapp and Hornberger (1978), Cosby et al. (1984) and van Gool et al., (2005)

Texture Group	Adopted K_{sat} (mm/h)
Sands	50.6
Sandy Loams	18.8
Loams	10.1
Clay Loams	6.1
Light Clays	3.7
Clays	3.0

Figure 4 shows that the creeks and rivers downstream of the discharge locations cross four different soil Map Units, namely, B27, Fa13, My1 and Oc66. Using the approach outlined above the Texture Group and K_{sat} for each Map Unit was derived, and is presented in Table 3.

Table 3: Soil Map Units in study area and adopted saturated hydraulic conductivities

Soil Map Unit	Weighted Clay Content of Limiting Soil Horizon (%)	Texture Group	Adopted K_{sat} (mm/h)
B27	30.0	Clay Loams	6.1
Fa13	27.5	Clay Loams	6.1
My1	36.5	Light Clays	3.7
Oc66	44.0	Light Clays	3.7

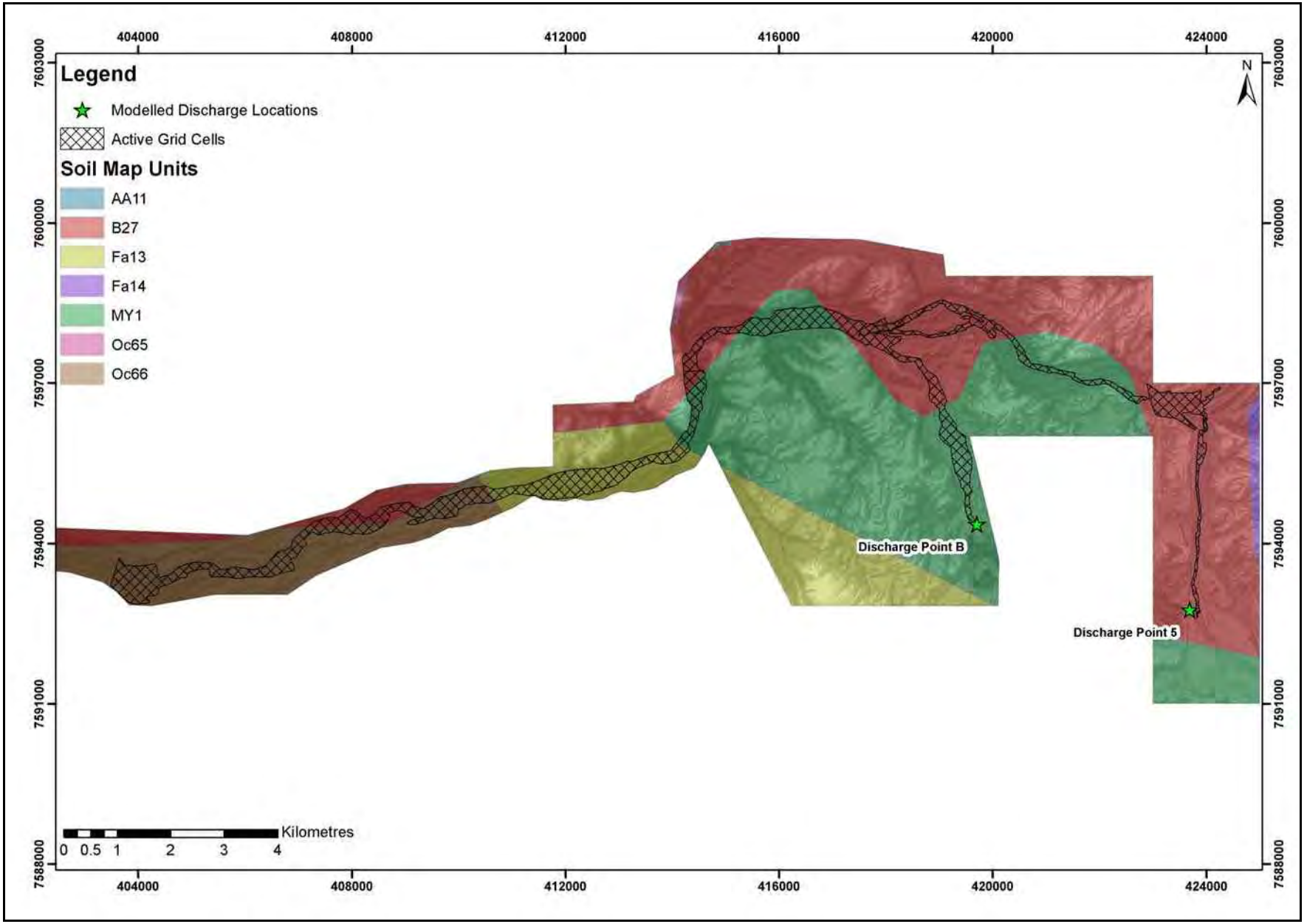

Figure 4: **Soil Map Units intersected by the watercourses downstream of the proposed surplus water discharge locations**

Results

Results for the various discharge modelling scenarios are presented in Table 4 and Figure 5. It is estimated that the surplus water discharge extent will range from 3.5 km to 20 km down gradient of the assumed discharge point depending on the discharge rate and discharge location, before completely infiltrating/evaporating.

Table 4: Estimated discharge extent from discharge location for various discharge rates

Scenario	Distance Travelled (km)	
	Discharge Point 5	Discharge Point B
5 ML/d	3.5	4.7
10 ML/d	5.2	8.8
15 ML/d	5.2	11.8
20 ML/d	5.9	14.4
25 ML/d	9.3	17.2
30 ML/d	11.8	19.9

The braided nature of typical Pilbara watercourses creates a complex hydrodynamic environment where the flow behaviour is essentially 2D in nature. Often braided flows are thought of as a consequence of flooding where flows break out onto poorly defined floodplains. Figure 6 clearly demonstrates that complex bifurcations can also be a characteristic of the low flow regime, and was found in this assessment to be typical in the Robe River, thereby justifying the selection of a 2D hydraulic model.

The surplus water discharge volume would be significantly smaller than the volume generated by the catchment during flood events. Based on model results, discharged water would be contained within the low flow channel/s, hence overtopping of the creek banks in dry conditions is not anticipated.

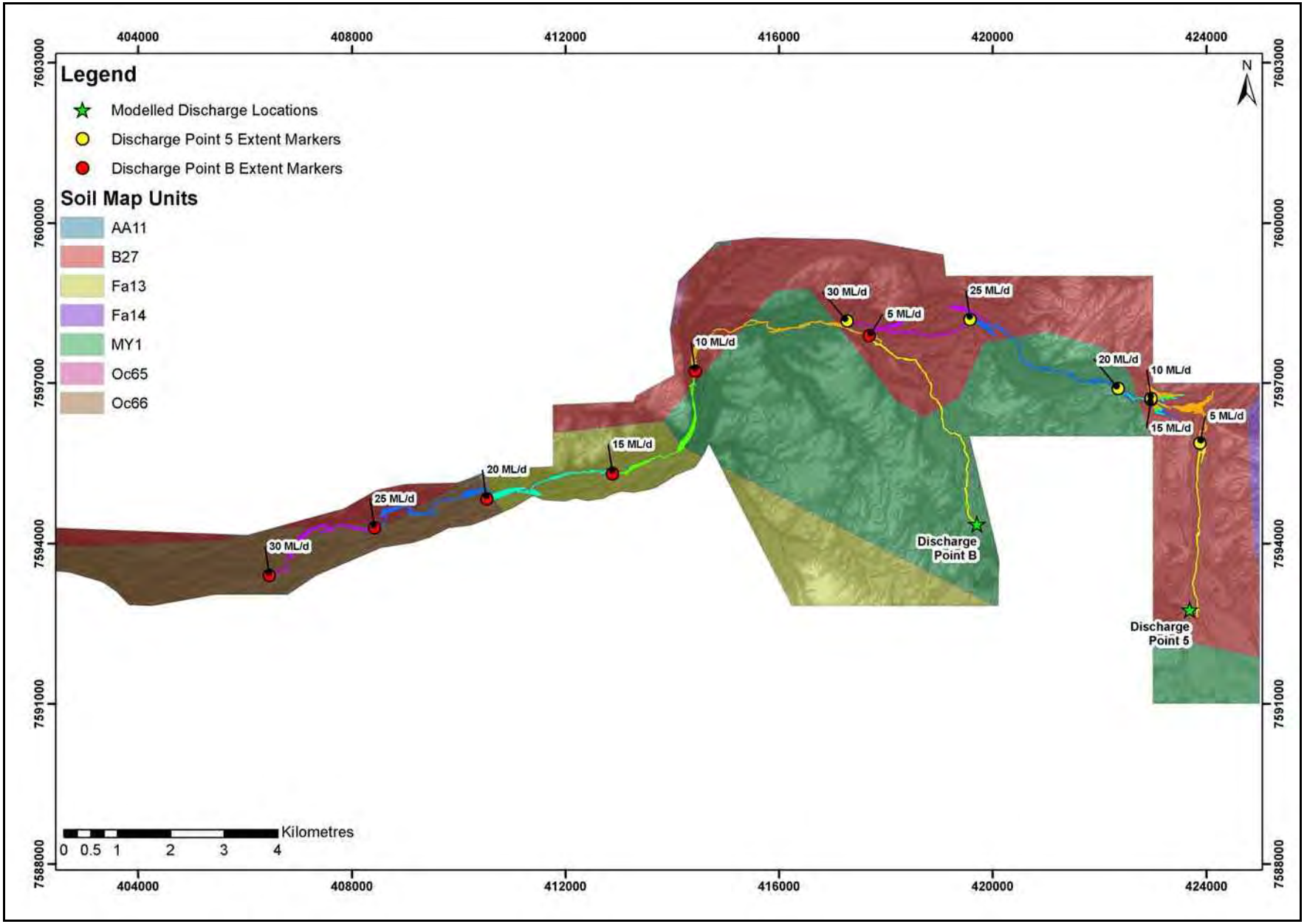

Figure 5: **Modelled maximum discharge extents for various discharge rates**

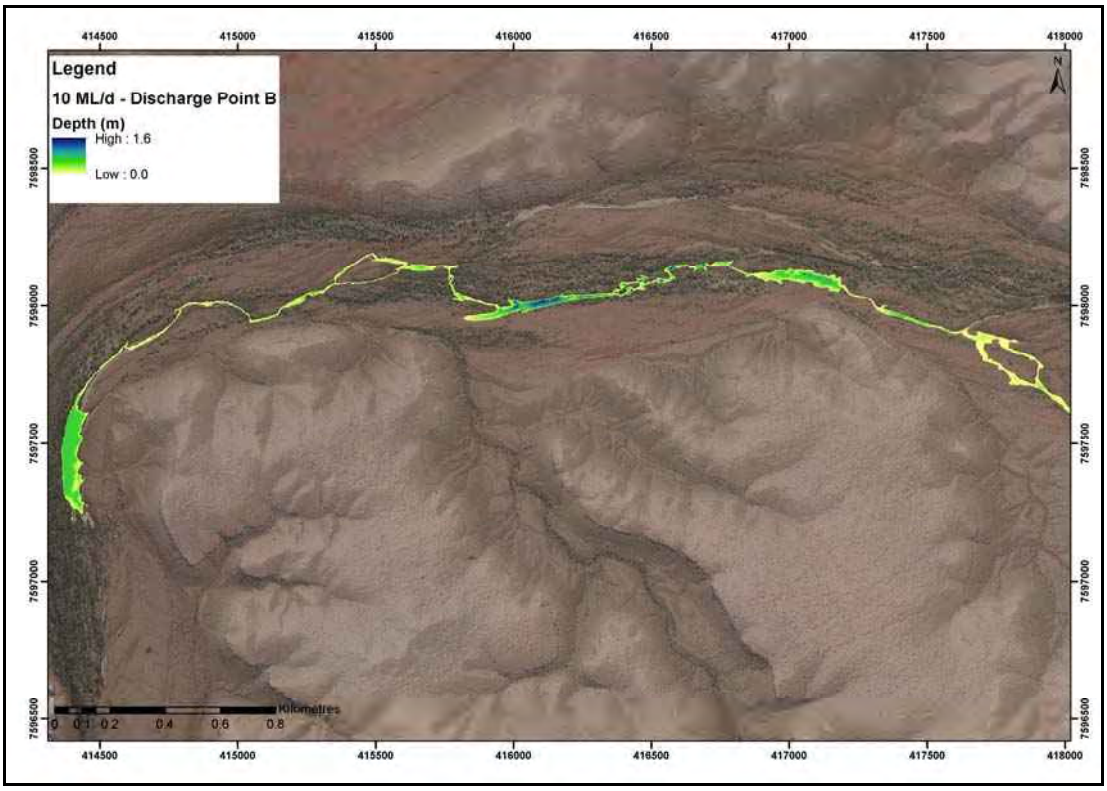

Figure 6: **Complex flow regime of the Robe River modelled in TUFLOW**

Conclusion

A 2D hydraulic model of the Robe River and relevant tributaries has been developed to estimate the extent of future potential surplus water discharge from the proposed Mesa H operations. The key advantage of the approach was the ability to hydraulically simulate the complex hydrodynamic environment while simultaneously accounting for hydrologic processes such as infiltration and evaporation.

The maximum surface water extents from five discharge scenarios were modelled: namely a continuous rate of 5, 10, 15, 20, 25 and 30 ML/day. It is estimated that the surplus water discharge extent will range from 3.5 km to 20 km down gradient of the assumed discharge point depending on the discharge rate and discharge location, before completely infiltrating/evaporating.

The surplus water discharge volume would be significantly smaller than the volume generated by the catchment during flood events. Based on model results, discharged water would be contained within the low flow channel/s, hence overtopping of the creek banks in dry conditions is not anticipated.

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APPENDIX D: PEER REVIEW REPORTS

PEER REVIEW: MESA H: H3 HYDROGEOLOGICAL ASSESSMENT

INTRODUCTION

The Robe River Joint Venture (the Proponent) is undertaking studies to support additional mining operations that will sustain production from the Robe Valley. A number of channel iron deposits (CID) resources in the Robe Valley have been considered.

Mesa H is proposed as the next development to sustain the Mesa J hub production and is scheduled to commence Q1 2020 utilising existing Mesa J infrastructure including existing wet processing facilities.

Mining at Mesa H is scheduled to extend over a period of about 18 years. Water levels in much of the Mesa H mine area have been lowered significantly by dewatering activities at the adjacent Mesa J but further dewatering will be required as approximately 13% of the resource lies below the current water-table (BWT). Water supply augmentation for the expanded mining and processing requirements is also planned.

Pre-Feasibility Studies (PFS) have been completed and it is currently anticipated that the works will progress to a Feasibility Study (FS) in 2017/2018 with planned Implementation in 2019. The Proponent is currently planning to submit API/PER approval documents to in Q4 2017 seeking to obtain a Part IV approval by Q4 2018 / Q1 2019.

PROJECT OVERVIEW

Mesa H is located immediately west and adjacent to the existing Mesa J mine, downstream from the confluence of the Robe River and Jimmawurrada Creek.

The deposit is bounded in the north and northwest by the Robe River where riparian vegetation is extensive and a series of pools exist. One of these pools - Yeera Bluff - is a Rights Reserve site of high significance to the traditional owners.

Dewatering at Mesa H, combined with operations at Mesa J, has potential to lower water levels along the drainage courses.

A significant data base and dewatering/water supply experience has been gained over many years at the adjacent Mesa J site, where similar geological conditions exist, but there have been limited investigations at Mesa H prior to 2015.

A detailed PFS investigation was undertaken through 2015-2016 to address hydrogeological risks identified during an earlier Order of Magnitude (OoM) study – specifically, identifying dewatering requirements and assessing potential associated impacts to the Robe River. The 2016 programme comprised drilling, construction and testing of four (4) water bores with 32 associated monitoring bores the results from which were used (in conjunction with Mesa J data) to develop a conceptual hydrogeological model and subsequent groundwater numerical model.

PEER REVIEW

Provisions were made in August 2016 for an independent peer review of the hydrogeological assessments of the Robe Valley projects.

The key objectives of the review were identified as:

- Review and verify the quantity and quality of hydrogeological information considered as part of the assessment is sufficient to satisfy PFS level understanding and to support API/PER approval submissions
- Review and verify the current conceptual hydrogeological models including an assessment of technical robustness, rigour and level of confidence in the interpretations and analyses;
- Review and verify the numerical groundwater model inputs, design, calibrations and outputs and assess in terms of National Water Commission's Australian Groundwater Modelling Guidelines (2012);
- Provide recommendation to address gaps in the conceptualisation and numerical models.

Independent Groundwater Consultants Pty Ltd was commissioned to undertake the review which has been undertaken by Graham Smith, a professional hydrogeologist with 40 years of local and international experience specializing in arid zone hydrogeology with familiarity of the Pilbara and Robe River through site visits, a number of mine development projects and previous Rio Tinto commissions (e.g. member of Expert Panel; 2015 Pre-Feasibility Study for the Bungaroo mine; Peer Reviewer hydrogeological assessments for Warramboo, Mesa C and West Angelas C&D).

The review has involved review of project technical documentation, a site visit and several discussions with technical personnel as the studies have progressed.

This report presents comment on the H3 Assessment Report for Mesa H with primary attention given to data availability, hydrogeological conceptualisation, analysis and assessment methods, groundwater modelling, impact assessments, mitigation measures if/as appropriate, water management planning and proposed future work programmes. The review of the hydrogeological conceptualisations and groundwater models draws on the Australian Groundwater Modelling Guidelines (Barnett et al, 2012).

Key Documents

The primary reference document provided for review was:

- Mesa H: H3 Hydrogeological Level Assessment v4.0 (RTIO, October, 2017).

Supporting documentation included:

- Mesa H: 2016 Pre-Feasibility Study Hydrogeological Drilling Program Completion Report (RTIO, May 2016).
- Mesa H: Groundwater Modelling rev.E (RPS, October, 2017).

Report Overview

The primary report has been well-prepared and is well supported by figures, tables and Appendices providing detail on the bore completions, the numerical model and an assessment of surplus water discharge extent. It includes the following Sections:

Introduction – provides an overview of the deposit (local aquifers, nearby water courses and environmental setting) and the adjacent Mesa J mine where dewatering occurs to facilitate BWT mining and provide process supplies.

Climate and Rainfall – describes climatic conditions, provides annual rainfall data, outlines contributing catchments and provides Robe River annual streamflow data (from upstream Ngalooin Pool and downstream Yarraloola).

Hydrogeology – describes local geology, aquifer occurrence (CID, Wittenoom and Robe River alluvium) well illustrated with cross-sections, hydrographs illustrating water level drawdown resulting from Mesa J dewatering and responses to rainfall, predicted pre-mining and current water level contours, recharge/discharge processes, water balance, an extended section on Robe River hydraulics where an estimate of mean annual flow (50GL/year) is given and contributing factors associated with the occurrence and status of permanent and semi-permanent pools occurring along the drainage are discussed, with supporting hydrographs. This is followed by an overview of flooding within Jimmawurrada Creek and connectivity with upstream Bungaroo palaeochannels.

Four (4) hydrogeological conceptualisations are presented in recognition of stated uncertainties around the characteristics of the Brockman Iron Fm and continuity of the Wittenoom Fm. Constraints associated with the heterogeneity of the local Robe River alluvial aquifer and the paucity of drilling information north of Mesa H and in Jimmawurrada Creek are also identified.

Existing Groundwater Use – describes dewatering (sumps/trenches), abstraction from an external borefield (Southern Cutback Borefield – SCB – that provides process and potable water supplies) and re-cycling at Mesa J, the Pannawonica town supply borefield drawing ~0.7GL/yr since 1981 from the Robe River alluvium (~10km northwest of Mesa H) and the Bungaroo Coastal Water Supply borefield (permitted to supply up to 10GL/yr for the West Pilbara Water Scheme) located upstream ~20km southeast of Mesa H.

Groundwater Investigation – summarises the extensive hydrogeological investigations to support water supply and dewatering at Mesa J since 1987, establishment of 14 monitor bores at Mesa H in 2015 and the 2016 works comprising installation of four (4) test production bores and 18 monitor bores (with reference to bore completion reports given as Appendix A). A summary of pumping tests and results (3 bores in Mesa H and 18 in Mesa J) is provided. Reference is made to RTIO-PDE-0143871 (not sighted) in presentation of Robe Rive alluvial aquifer characteristics as determined from analysis of long-term abstraction from the Pannowonica town supply borefield.

Groundwater Chemistry – presents detail on extensive programme of groundwater (43 bores) and surface water (7 pools) sampling and analysis (since 1993 at Mesa J) with discussion of

major ions, minor ions and isotopic composition to characterise the three main aquifers at the site and assess their potential contribution to the Robe River alluvial aquifer.

Groundwater Flow Model – summarises previous modelling works to predict inflows to Mesa J (initiated in 2002 and subsequently updated in 2003, 2004 and 2006), describes development of a new groundwater model in 2016 that combines both Mesa H and Mesa J (Modflow_Surfact v4.0 with Groundwater Vistas graphical user interface). Reference made to details provided in supporting Appendix B – Groundwater Numerical Model.

Difficulties associated with steady-state calibration and need for a dynamic calibration process are described with resultant good agreement between conceptual and model inflows and outflows.

Transient calibration, using annual time steps, compared predicted and observed groundwater levels through period 1990-2017 (using 37 bores with long-term records and 33 recently installed bores). Calibrated aquifer parameters are tabulated and a water balance presented. Zone budget analyses are described for the confluence of the Robe River and Jimmawurrada Creek and sites of inflow/outflow from the Robe River alluvium.

Model predictions are provided for dewatering of Mesa J and Mesa H and drawdown along the Robe River; these include augmentation of the SCB with an additional 3-5 water supply bores to meet the increased demand of the wet plant (8.7GL/yr) and continued discharge of surplus water along Jimmawurrada Creek the footprint of which as determined from a separate model. Reference made to details provided in supporting Appendix C –Surplus Water Discharge Extent Assessment.

Prediction uncertainty is discussed and eleven (11) additional model runs described for uncertainty analysis.

Assessment of Potential Impacts – using predicted 2037 water level drawdown resulting from dewatering and water supply discusses potential impacts (on water levels, the Robe river and Jimmawurrada Creek environments and the aquifer including predictions on post-mining water level recovery).

Site Water Balance – presents a detailed site water balance for each year through 2019-2037 identifying supply sources to meet demand for wet plant processing, infrastructure and dust-suppression.

Groundwater Monitoring – provides information on current (and planned) monitoring schedule from the approved site Groundwater Operating Strategy. Ongoing monitoring of flora, fauna and pools will continue in accordance with the Mesa J Environmental Management Plan. Risk to the environment with development of Mesa H is cited as high with acknowledgement that formal triggers (biological and water levels) will need definition prior to commencement of dewatering at Mesa H in 2024.

Management Approach/Conclusions – outlines defined Water Strategy, discharge system, maintenance and monitoring.

Key Findings

The key findings reported may be summarized as follows:

Aquifers

Groundwater occurs in three (3) main aquifers – the Robe River alluvials, the CID and the weathered basement (Marra Mamba Iron and Wittenoom Formations). Connectivity between the CID (to be dewatered during mining) and the underlying basement is constrained by the basal pisolites. Regional groundwater throughflow (CID and weathered basement) is estimated to be ~1.6GL/year.

Depth to water along the Robe River channel is shallow (2-5mbgl) and may fluctuate up to 3m annually in response to high rates of recharge and evapotranspiration. Natural groundwater throughflow is estimated to be ~0.8GL/year.

Conceptualisation

Groundwater flow in the CID and basement is from SE to NW following the trend of the CID palaeochannel deposits from upstream Bungaroo valley. The CID and Wittenoom aquifers are bounded by bedrock aquicludes (in the east by fresh Marra Mamba Iron Formation and by the Brockman Iron Formation in the west). Natural recharge is limited to direct inputs from rainfall but this has been locally augmented by leakage from Mesa J reservoirs.

Groundwater throughflow in the streambed alluvials of the Robe River and Jimmawurrada Creek naturally follows the drainage courses and are primarily recharged by infiltration of surface water flows that are generated by major rainfall events (supplemented locally by discharge of surplus water). The two principal drainages coalesce just upstream of Mesa H.

The pools that occur along the Robe River appear to be related to the alluvial aquifer and are groundwater dependent in drought periods.

A number of key uncertainties have been identified all of which may have significant impact on groundwater flow processes and responses to dewatering; these include aquifer characteristics of the Robe River and Jimmawurrada Creek alluvial systems. Four (4) different concepts are presented to accommodate primary uncertainties related to (a) whether the Brockman Iron Formation underlying Yeera Bluff is impermeable and (b) whether flow in the Wittenoom Formation discharges into the overlying Robe River alluvium or continues to the north.

Dewatering

Dewatering at Mesa H will commence 2024/2025 and, for all years, can be affected by in-pit sump pumping. Peak abstraction of 6.5ML/day will occur in 2033; total abstraction during LoM will be 11.3GL. Total abstraction 2019-2037 from the combined Mesa H and Mesa J operations, including water supply, will be 170GL with a peak of 9.5GL/year.

Water Disposal

Surplus water will be discharged to Jimmawurrada Creek at average rate of 2.1GL/year (peak 4.5GL). With potential discharge rates in range 5-30ML/day, the distance travelled by the surface water flow is predicted to be between 3.5km to 11.8km.

Water Demand and Supply

Water demand is dominated by the requirements of the Wet Plant which will require between 8.8 GL/year to 14.2 GL/year (average 11.9GL/year). Total water demand (including evaporative losses from on-site reservoirs) will range from 9.5GL/year to 15.6GL/year (average 13.3GL/year).

Dewatering product, seepage and decant recovery will make a significant contribution to supply but an external source will continue to be required; expansion of the SCB is planned to meet a maximum requirement of 8.5GL/year.

Impacts

Discharge of surplus water from Mesa J operations to Jimmawurrada Creek has likely contributed to maintaining water levels in the alluvial aquifer where no evidence of any impact on the aquatic environment has been found.

Combined dewatering operations at Mesa H and Mesa J will have minimal (<1m) impact on water levels along the Robe River north of the mines.

It is not expected that there will be significant impact to permanent pools in the Robe River (e.g. Yeera Bluff) but shallow semi-permanent and seasonal pools may dry out at a faster rate during prolonged periods when no surface water flows occur. Significant water level drawdowns will occur along a 9km reach of Jimmawurrada Creek as a result of the cumulative, combined impacts of Mesa J dewatering, abstraction from the SCB and the upstream Coastal Water Supply (CWS) borefield operation.

It is not anticipated that there will be any significant impact to riparian vegetation along the Robe River but there will likely be impact on phreatophytic vegetation along a 4-9km reach of Jimmawurrada Creek. Reductions in stygofauna habitats may also occur with lowering of water levels there but this is expected to be localised and minor.

Natural water levels will recover to pre-mining levels after 60 years.

Uncertainties

Inherent uncertainties exist with the parameters adopted to describe the hydrogeological system. Uncertainty analysis has been undertaken to evaluate conceptual model, climate change and numerical model uncertainties; results tend to confirm conceptualization and model behaviour.

Mitigation

The requirement for a mitigation strategy to supplement water to the permanent and semi-permanent pools in Robe River from 2030 (given uncertainties, values and ecosystem sensitivity) is identified. It is envisaged that monitoring of water levels in the Robe River pools and the area predicted to be impacted along Jimmawurrada Creek will be used to develop and trigger mitigation actions Options for mitigation have been identified (eg supplemental discharge, modification of abstraction regime, aquifer reinjection, etc.).

Planned Future Works

Planned works, cited in Scope of Work Mesa H FS Hydrogeology Drilling June 2017 v2.2, seek to address the hydrogeological risks identified in the PFS and include:

- Installation of up to six (6) test bores, eleven (11) monitor bores and two (2) VwP.
- Aquifer testing of all installed bores.
- Discharge trial (up to 30 days) in the Robe River (to support design of an impact mitigation strategy for local pools).
- Investigation of water supply sources for construction camp.

Review Comments

Field Investigations

The PFS investigations have been conducted to a high standard. Drilling, monitor and test production bore construction methods and aquifer testing conform to best-practice, are well documented and provide a sound data set for the Mesa H mine area.

Data Availability

Available rainfall and Robe River streamflow records have been included in the assessment; these demonstrate frequency of major rainfall and flood events. Groundwater levels and quality are well established with an extensive monitor bore network. Whilst there is limited discrete aquifer data, the adopted parameters conform to experience in similar environments and appear reasonable. No test data is provided to support the assumption that the basal pisolites constrain flow between the CID and underlying bedrock aquifers; based on the recorded lithology and thickness, however, this is considered a reasonable assumption. Data to characterize the alluvial aquifers associated with the Robe River near Mesa H and Jimmawurrada Creek near Mesa J are similarly absent. Aquifer parameters deduced from operation of the Pannawonica borefield appear reasonable and provide support for the parameters adopted for the Robe River alluvial aquifer. Uncertainties remain with regard to the alluvial system associated with, and surface water flows within, Jimmawurrada Creek. Notwithstanding the above, the cumulative data set is considered to provide an adequate technical foundation for the conceptualisations and detailed numerical modelling process.

Hydrogeological Conceptualisation

The geological model and characteristics of the primary hydro-stratigraphic units are well-established and provide a sound foundation for hydrogeological assessment. The conceptual model is based on the integration of all available information including background information from previous investigations, extensive experience in water management gained over many years at Mesa J where similar hydrogeological conditions exist, ongoing monitoring at Mesa J and information generated by specific investigations.

The concepts re: pools and alluvial aquifer processes is based on detailed assessment of available water level and water quality data and appear sound.

Uncertainties in conceptualisation have been clearly identified and adequately addressed in the modelling process.

Modelling

The objectives of the modelling are clearly stated and the model set-up honours the documented hydrogeological conceptualisation. Standard modelling packages and techniques have been deployed and what appear to be appropriate boundary conditions established.

Calibrated aquifer parameters are in general conformity with field-derived values; adopted low fresh bedrock values are considered appropriate. Inherent uncertainty exists with storage parameters.

Model predictions accommodate a number of assumptions related to many operational processes. These appear well-considered and further demonstrate a sound site water management plan. The assignment of surface water flows in Jimmawurrada Creek as a proportion of Robe River flows (based on contributing catchment areas) is supported.

Uncertainty analysis has usefully assessed conceptualisation and climate variables. Summary results indicate that drawdowns in the Robe River alluvials in excess of 1m are predicted to only occur in the sustained absence, or large-scale reduction, of flood flows. It is noted, however, that drawdowns of similar magnitude are predicted with modification of the general head inflow boundary associated with the Robe River which warrants further assessment.

The documentation for the modelling effort is of high standard and well-presented. The claimed model confidence level classification – Class 2 – is supported.

Dewatering

The predicted rates/volumes appear reasonable and gain support from the longer-term experience gained in the adjacent Mesa J pits where similar conditions prevail.

Impacts

Potential impacts have been identified and assessed. The dominance of surface water flows in the water balance (or indirect recharge derived therefrom) has, as would be expected, been clearly demonstrated.

The prediction that impacts along the Robe River north of Mesa H and Mesa J will be minor appear sound. Under average annual streamflow conditions and assumption of vertical flow constraints imposed by the basal pisolites underlying the CID aquifer, such impacts are less than natural seasonal variations and consequently considered unlikely to be of such a magnitude to pose any threat to local environmental values. Any water level drawdowns in the alluvials that do result from dewatering operations will, however, be naturally augmented in the absence of flood events. The contention that there will be natural mitigation of minor drawdown impacts along the Robe River by infiltration of surface water flows is supported by hydrographs from monitor bores showing water level responses associated with significant rainfall events (and assumed floods) along the Robe River (at Pannawonica) and Jimmawurrada Creek (near Mesa J) and appears reasonable.

The predicted significant drawdown impacts along a section of Jimmawurrada Creek are as would be anticipated given location near the SCB and predicted groundwater flow reversal resulting from continued operation of the upstream CWS borefield.

Uncertainties

A number of uncertainties have been identified that primarily relate to the aquifer characteristics of various formations, groundwater flow paths and hydraulic connectivity between formations. These should be adequately addressed in the planned, follow-on work programmes with further insight provided by continued monitoring.

Summary

The quantity and quality of hydrogeological information presented is considered sufficient to satisfy PFS-level understanding and to support API/PER approval submissions.

The current conceptual hydrogeological models have been developed on an extensive data set taking due account of local geology, hydrology, hydrogeology and historic site water management and are supported; uncertainties have been identified and will be addressed in follow-on programmes.

The numerical groundwater model honours the hydrogeological conceptualization and is considered fit for purpose meeting key objectives of quantifying required dewatering rates and potential impacts. Design conforms with standard practices and is based on a sound geological model; calibrated parameters are in accordance with field-derived or acceptable values. Information on calibration, predictions and uncertainty runs is well documented. In terms of the National Water Commission's Australian Groundwater Modelling Guidelines (2012), the reported Class 2 level of confidence is supported.

Model predictions indicate that:

- dewatering drawdown impacts along the Robe River will be minor and less than natural water fluctuations. Evidence exists to support contention of natural mitigation through infiltration of surface water flows.

- significant water level drawdowns will occur along a reach of the Jimmawurrada Creek as a result of abstraction from the nearby SCB and upstream CWS.

A requirement for mitigation measures has been identified; options exist and are to be further assessed.

Recommendations

Whilst the proposed work to advance hydrogeological understanding to Feasibility Level and continued monitoring should address the key uncertainties that have been identified, consideration should also be given to:

- Augmentation of the monitoring network with facilities to record flood events along both the Robe River and Jimmawurrada Creek and water levels/quality in any pools therein.

- Further examination of the available data sets with a view to confirming the areal extent, thickness and hydraulic properties of the basal pisolite layer.

- Obtaining discrete hydraulic properties of the key formations.

In addition, as a prelude to future modelling work, a re-assessment of boundary conditions would be prudent and further analysis of zonal water balances to confirm, and improve definition of, expected fluxes between the key formations.

RPS

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Meeting date:	12 July 2018
To:	Milos Pavlovic; Alex Russo
From:	Cassie Turvey; Damien Janssen
Subject:	Mesa H Groundwater Modelling Review

Dear Milos,

RPS has undertaken a review of recent groundwater modelling for Mesa H completed by AQ2. Mesa H is an iron ore operation located immediately west of the existing Mesa J mine, 17 km south-west of Pannawonica. Mining at Mesa H is proposed from 2020 to 2037.

The following document was reviewed:

AQ2 ref – 182B_006c_FINAL / RTIO ref - RTIO-PDE-0161936 including associated figures and appendices.

The key objectives of the model were to:

- Assess the dewatering rates necessary to facilitate dry mining conditions at Mesa H and Mesa J; and
- Assess the impacts of dewatering and water supply abstraction (including cumulative impact of the Coastal Water Supply project at Bungaroo Valley) on regional groundwater levels and surface water pools along the Robe River and Jimmawurrada Creek.

Modelling Review Focus

It is understood that the model and the modelling report have been through several iterations over a number of years. The Mesa H Groundwater Modelling Report was reviewed by a third party in 2016. Minor changes to the 2016 model were made for this report with the majority of setups and results remaining consistent with the original 2016 model. However, for the purpose of documentation a review has been undertaken as per recommendations in the Australian Groundwater Modelling Guidelines (NWC, 2012). Results are presented in the following tables for (1) Overall Compliance, (2) Planning, (3) Conceptual Model, (4) Design and Construction, (5) Calibration and Sensitivity, (6) Prediction, (7) Uncertainty, (8) Surface Water-Groundwater Interaction.

In addition to the review from a numerical standpoint, we have also made some comment in terms of operational considerations in reference to the key objectives of the modelling exercise.

RPS

Overall Compliance	Yes/No	Comment
1. Are the model objectives and model confidence level classification clearly stated?	Yes	Dewatering requirements and impacts due to dewatering/water supply
2. Are the objectives satisfied?	Yes	
3. Is the conceptual model consistent with objectives and confidence level classification?	Yes	Level 2 confidence level
4. Is the conceptual model based on all available data, presented clearly and reviewed by an appropriate reviewer?	Yes	Conceptual model details within separate report
5. Does the model design conform to best practice?	Yes	
6. Is the model calibration satisfactory?	Yes	No statistics presented, but hydrographs indicate good calibration in most locations
7. Are the calibrated parameter values and estimated fluxes plausible?	Yes	
8. Do the model predictions conform to best practice?	Yes	
9. Is the uncertainty associated with the predictions reported?	Yes	Only for impacts to water levels along rivers
10. Is the model fit for purpose?	Yes	

2. Planning	Yes/No
1.1 Are the project objectives stated?	yes
1.2 Are the model objectives stated?	yes
1.3 Is it clear how the model will contribute to meeting the project objectives?	yes
1.4 Is a groundwater model the best option to address the project and model objectives?	yes
1.5 Is the target model confidence-level classification stated and justified?	yes
1.6 Are the planned limitations and exclusions of the model stated?	yes

RPS

3. Conceptualisation	Yes/No	Comment
2.1 Has a literature review been completed, including examination of prior investigations?	half	Very brief mention of previous AQT/RPS work, RTIO conceptual model. None by others - maybe isn't any.
2.2 Is the aquifer system adequately described?	yes	Separate conceptual report
2.2.1 hydrostratigraphy including aquifer type (porous, fractured rock ...)	yes	
2.2.2 lateral extent, boundaries and significant internal features such as faults and regional folds	yes	Separate conceptual report
2.2.3 aquifer geometry including layer elevations and thicknesses	yes	Separate conceptual report
2.2.4 confined or unconfined flow and the variation of these conditions in space and time?	yes	Separate conceptual report
2.3 Have data on groundwater stresses been collected and analysed?	yes	Separate conceptual report
2.3.1 recharge from rainfall, irrigation, floods, lakes	yes	Separate conceptual report
2.3.2 river or lake stage heights	unknown	
2.3.3 groundwater usage (pumping, returns etc)	yes	Separate conceptual report
2.3.4 evapotranspiration	yes	Separate conceptual report
2.3.5 other?	yes	TSF seepage
2.4 Have groundwater level observations been collected and analysed?	yes	
2.4.1 selection of representative bore hydrographs	no	Not discussed in modelling or conceptual report
2.4.2 comparison of hydrographs	no	Not discussed in modelling or conceptual report
2.4.3 effect of stresses on hydrographs	no	Not discussed in modelling or conceptual report
2.4.4 watertable maps/piezometric surfaces?	yes	Separate conceptual report
2.4.5 If relevant, are density and barometric effects taken into account in the interpretation of	unsure	Not discussed in modelling or conceptual

3. Conceptualisation	Yes/No	Comment
groundwater head and flow data?		report
2.5 Have flow observations been collected and analysed?	yes	Robe River only at Ngalooin Pool
2.5.1 baseflow in rivers	no	Not discussed in modelling or conceptual report
2.5.2 discharge in springs	no	Not discussed in modelling or conceptual report
2.5.3 location of diffuse discharge areas?	no	Not discussed in modelling or conceptual report
2.6 Is the measurement error or data uncertainty reported?	no	Not discussed in modelling or conceptual report
2.6.1 measurement error for directly measured quantities (e.g. piezometric level, concentration, flows)	no	Not discussed in modelling or conceptual report
2.6.2 spatial variability/heterogeneity of parameters	no	Not discussed in modelling or conceptual report
2.6.3 interpolation algorithm(s) and uncertainty of gridded data?	no	Not discussed in modelling or conceptual report
2.7 Have consistent data units and geometric datum been used?	yes	
2.8 Is there a clear description of the conceptual model?	yes	Separate conceptual report
2.8.1 Is there a graphical representation of the conceptual model?	half	Lithology and water table presented, no indication of recharge/discharge/flow directions or changes due to mining
2.8.2 Is the conceptual model based on all available, relevant data?	yes	
2.9 Is the conceptual model consistent with the model objectives and target model confidence level classification?	yes	
2.9.1 Are the relevant processes identified?	yes	Separate conceptual report

3. Conceptualisation	Yes/No	Comment
2.9.2 Is justification provided for omission or simplification of processes?	yes	
2.10 Have alternative conceptual models been investigated?	unsure	

4. Design and Construction	Yes/No	Comment
3.1 Is the design consistent with the conceptual model?	yes	
3.2 Is the choice of numerical method and software appropriate (Table 4-2)?	yes	MODFLOW-Surfact
3.2.1 Are the numerical and discretisation methods appropriate?	yes	
3.2.2 Is the software reputable?	yes	
3.2.3 Is the software included in the archive or are references to the software provided?	yes	
3.3 Are the spatial domain and discretisation appropriate?	yes	
3.3.1 1D/2D/3D	3D	
3.3.2 lateral extent		
3.3.3 layer geometry?	half	Reasonable layer thicknesses, layer elevations could be improved
3.3.4 Is the horizontal discretisation appropriate for the objectives, problem setting, conceptual model and target confidence level classification?	yes	
3.3.5 Is the vertical discretisation appropriate? Are aquitards divided in multiple layers to model time lags of propagation of responses in the vertical direction?	yes	
3.4 Are the temporal domain and discretisation appropriate?	yes	
3.4.1 steady state or transient		Both
3.4.2 stress periods		Annual

4. Design and Construction	Yes/No	Comment
3.4.3 time steps?		Not stated in report (monthly)
3.5 Are the boundary conditions plausible and sufficiently unrestrictive?	yes	
3.5.1 Is the implementation of boundary conditions consistent with the conceptual model?	yes	
3.5.2 Are the boundary conditions chosen to have a minimal impact on key model outcomes? How is this ascertained?	yes	GHB and STR boundary conditions for river flow affect model outcomes (as intended and consistent with conceptual model). No flow at basement outcrop.
3.5.3 Is the calculation of diffuse recharge consistent with model objectives and confidence level?	yes	
3.5.4 Are lateral boundaries time-invariant?	yes	Except where lowered to simulate dewatering by CWS borefield
3.6 Are the initial conditions appropriate?	yes	
3.6.1 Are the initial heads based on interpolation or on groundwater modelling?		Steady state modelling to provide initial heads to transient calibration
3.6.2 Is the effect of initial conditions on key model outcomes assessed?	NA	
3.6.3 How is the initial concentration of solutes obtained (when relevant)?	NA	
3.7 Is the numerical solution of the model adequate?	yes	
3.7.1 Solution method/solver	not stated	Milos old GWV: PCG5, pseudo soil with upstream weighting
3.7.2 Convergence criteria	not stated	Milos old GWV: head change 0.005
3.7.3 Numerical precision	not stated	Mass balance values imply ~0% error

5. Calibration and sensitivity	Yes/No	Comment

5. Calibration and sensitivity	Yes/No	Comment
4.1 Are all available types of observations used for calibration?		
4.1.1 Groundwater head data	yes	
4.1.2 Flux observations	no	Should report obs v mod for dewatering volumes and pumped volumes to date.
4.1.3 Other: environmental tracers, gradients, age, temperature, concentrations etc	no	
4.2 Does the calibration methodology conform to best practice?	yes	
4.2.1 Parameterisation	yes	
4.2.2 Objective function	yes	Comparison of obs v modelled (visual in hydrographs). Assume some statistical measure considered during calibration (e.g. minimising sum of squares, SRMS etc)
4.2.3 Identifiability of parameters	yes	
4.2.4 Which methodology is used for model calibration?	not stated	Assume only manual
4.3 Is a sensitivity of key model outcomes assessed against?	not stated	
4.3.1 parameters	not stated	Intrinsic sensitivity during calibration assumed but not reported
4.3.2 boundary conditions	not stated	Intrinsic sensitivity during calibration assumed but not reported
4.3.3 initial conditions	not stated	Intrinsic sensitivity during calibration assumed but not reported
4.3.4 stresses	not stated	Intrinsic sensitivity during calibration assumed but not reported
4.4 Have the calibration results been adequately reported?	half	Hydrographs, no stats

5. Calibration and sensitivity	Yes/No	Comment
4.4.1 Are there graphs showing modelled and observed hydrographs at an appropriate scale?	yes	Indicate good calibration
4.4.2 Is it clear whether observed or assumed vertical head gradients have been replicated by the model?	no	Multilevel VWP's or nested piezos should be plotted on single chart
4.4.3 Are calibration statistics reported and illustrated in a reasonable manner?	no	Not reported, but likely good based on hydrographs
4.5 Are multiple methods of plotting calibration results used to highlight goodness of fit robustly? Is the model sufficiently calibrated?	no	
4.5.1 spatially	no	Map of residuals to indicate any areas which perform less well
4.5.2 temporally	yes	Hydrographs
4.6 Are the calibrated parameters plausible?	yes	
4.7 Are the water volumes and fluxes in the water balance realistic?	yes	
4.8 has the model been verified?	no	Recommendation for verification and re-calibration was made in report

6. Prediction	Yes/No	Comment
5.1 Are the model predictions designed in a manner that meets the model objectives?	yes	
5.2 Is predictive uncertainty acknowledged and addressed?	yes	Particularly in relation to rivers and mine plan
5.3 Are the assumed climatic stresses appropriate?	yes	
5.4 Is a null scenario defined?	yes	
5.5 Are the scenarios defined in accordance with the model objectives and confidence level classification?	yes	
5.5.1 Are the pumping stresses similar in magnitude to those of the calibrated model? If not, is there	yes	

6. Prediction	Yes/No	Comment
reference to the associated reduction in model confidence?		
5.5.2 Are well losses accounted for when estimating maximum pumping rates per well?	NA	
5.5.3 Is the temporal scale of the predictions commensurate with the calibrated model? If not, is there reference to the associated reduction in model confidence?	yes	
5.5.4 Are the assumed stresses and timescale appropriate for the stated objectives?	yes	
5.6 Do the prediction results meet the stated objectives?	yes	
5.7 Are the components of the predicted mass balance realistic?	yes	
5.7.1 Are the pumping rates assigned in the input files equal to the modelled pumping rates?	unknown	
5.7.2 Does predicted seepage to or from a river exceed measured or expected river flow?	no	
5.7.3 Are there any anomalous boundary fluxes due to superposition of head dependent sinks (e.g. evapotranspiration) on head-dependent boundary cells (Type 1 or 3 boundary conditions)?	no	
5.7.4 Is diffuse recharge from rainfall smaller than rainfall?	yes	
5.7.5 Are model storage changes dominated by anomalous head increases in isolated cells that receive recharge?	unknown	
5.8 Has particle tracking been considered as an alternative to solute transport modelling?	NA	

7. Uncertainty	Yes/No	Comment
6.1 Is some qualitative or quantitative measure of uncertainty associated with the prediction reported together with the prediction?	yes	Ranked by drawdown
6.2 Is the model with minimum prediction-error variance chosen for each prediction?	no	No consideration of impact on calibration results
6.3 Are the sources of uncertainty discussed?	yes	

7. Uncertainty	Yes/No	Comment
6.3.1 measurement of uncertainty of observations and parameters	yes	
6.3.2 structural or model uncertainty	yes	
6.4 Is the approach to estimation of uncertainty described and appropriate?	yes	
6.5 Are there useful depictions of uncertainty?	yes	

8. Surface water–groundwater interaction	Yes/No	Comment
8.1 Is the conceptualisation of surface water–groundwater interaction in accordance with the model objectives?	yes	Noted uncertainty due to limited data
8.2 Is the implementation of surface water–groundwater interaction appropriate?	yes	
8.3 Is the groundwater model coupled with a surface water model?	no	
8.3.1 Is the adopted approach appropriate?	na	
8.3.2 Have appropriate time steps and stress periods been adopted?	na	
8.3.3 Are the interface fluxes consistent between the groundwater and surface water models?	na	

RPS

Guideline Model Review Discussion

The modelling has been undertaken to a high standard and is fit for its intended purpose, being the prediction of dewatering and water supply volumes, and the prediction of impacts to water levels along the Robe River and Jimmawurrada Creek. There are no areas of concern that would have a material effect on the predicted outputs of interest. General comments and minor corrections have been included as tracked changes in the report document.

It is understood that the model has been dramatically simplified in recent years in order to improve run-times. However, considerations for model improvements during future work may include the following:

- Verification of model predictions and re-calibration if required to recent monitoring along the Robe River (as indicated within the report)
- Representation of actual topographic surface as top of model Layer 1.
- Layer bottom elevations more indicative of key lithological horizons shown in conceptual models Figure 3 (assuming geological model for the site is readily available)
- Reduction of stress period length from annual to monthly in order to more accurately represent seasonal fluctuations in both calibration and prediction runs to end of mining. Refine recharge, EVT and stream flow volumes accordingly.
- Inclusion of recorded dewatering volumes from existing mining as a calibration target.
- Characterisation of hydrogeological properties of major faults mentioned in conceptual model for inclusion in the model. Due to the often uncertain nature of faults acting as barriers or conduits (typically both), uncertainty analyses on fault properties may be most appropriate. The conceptual model report notes Yeera Bluff Pool exists as a result of fault structures.
- Application of fill properties/recharge post completion of mining using the TMP package in predictive runs
- Depending on need for water management planning purposes, additional uncertainty analyses with focus on predicted ranges in results of dewatering/water supply volumes and resulting drawdowns may be warranted using standard conductivity/storage parameter perturbation (+/- inclusion of faults as above).

Operational / Planning Considerations

Reviewing the modelling work with regards to the key objectives, and with consideration of the implications of uncertainties for planning and operational management purposes, we make some comments below.

Assessment of Future Dewatering Requirements

In reviewing the model report, it is noted that the calibration and prediction runs focused on the hydrographs and water levels for a verification of calibration confidence. In terms of water balance, the various water balance components within the model seem to be at the lower end of ranges identified in the conceptual hydrogeology report for the area. It may be worth additional enquiry of the calibration model to better understand the modelled abstraction volumes simulated to achieve the drawdowns and cross-check those against the actual dewatering volumes historically. This will enable a greater degree of confidence in the predicted dewatering volumes – as you may gain an appreciation that the model has a tendency to over-predict or under-predict abstraction volumes required to achieve a target water level.

Confidence in the dewatering requirement predictions in terms of volumes will provide greater confidence in the planning and budgeting of required dewatering infrastructure (number of bores, sizing of sump pumps and transfer pipelines, etc).

Assessment of Drawdown Impacts – Particularly on Pools / GDE's

On review of the conceptual hydrogeology report, it is clear that groundwater-fed pools in the proximity of the mining operations are a particular focus – namely Yeera Bluff Pool and Japanese Pool. The modelling exercise was seeking to better understand the potential for dewatering operations to negatively impact upon groundwater levels in proximity to these pools. On that basis, there may be value in exploring a few of the modelling assumptions and key sensitivities to better understand the impact potential. The aspects in question are:

- ***The annual time step / creek recharge application*** – given the seasonality of groundwater levels, especially in the Robe River Alluvium, annual time steps has the potential to mask a drawdown trend in the vicinity of pools that may be more severe within a given year than is currently represented; and
- ***General Head Boundary on Robe River*** – given that the model outcomes were sensitive to this, there may be value in exploring the implications of a seasonal fluctuation on the boundary condition, and/or some piezometer validation to gain confidence in this modelled factor.

In the absence of high confidence in these predictions, there may need to be some consideration given to management approaches that will ensure groundwater levels can be maintained at acceptable limits in proximity to these Pools should operational data indicate unfavourable trends toward these receptors.

It was also noted that the predicted drawdown below the riparian vegetation aligned with Jimmawurrada Creek is significant and sustained, and it could be expected that there is potential for vegetation with a high level of groundwater dependence to be negatively impacted by these local dewatering influences – it is currently not clear if such an impact would be acceptable, or if irrigation measures might be required.

If you have any questions or comments regarding this review, please do not hesitate to get in touch.

Kind regards,

RPS

Cassie Turvey

Senior Groundwater Modeller

Damien Janssen

Principal Hydrogeologist

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PO Box 170 West Perth WA 6872
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Meeting date:	12 July 2018
To:	Milos Pavlovic; Alex Russo
From:	Cassie Turvey; Damien Janssen
Subject:	Mesa H Groundwater Modelling Review

Dear Milos,

RPS has undertaken a review of recent groundwater modelling for Mesa H completed by AQ2. Mesa H is an iron ore operation located immediately west of the existing Mesa J mine, 17 km south-west of Pannawonica. Mining at Mesa H is proposed from 2020 to 2037.

The following document was reviewed:

AQ2 ref – 182B_006c_FINAL / RTIO ref - RTIO-PDE-0161936 including associated figures and appendices.

The key objectives of the model were to:

- Assess the dewatering rates necessary to facilitate dry mining conditions at Mesa H and Mesa J; and
- Assess the impacts of dewatering and water supply abstraction (including cumulative impact of the Coastal Water Supply project at Bungaroo Valley) on regional groundwater levels and surface water pools along the Robe River and Jimmawurrada Creek.

Modelling Review Focus

It is understood that the model and the modelling report have been through several iterations over a number of years. The Mesa H Groundwater Modelling Report was reviewed by a third party in 2016. Minor changes to the 2016 model were made for this report with the majority of setups and results remaining consistent with the original 2016 model. However, for the purpose of documentation a review has been undertaken as per recommendations in the Australian Groundwater Modelling Guidelines (NWC, 2012). Results are presented in the following tables for (1) Overall Compliance, (2) Planning, (3) Conceptual Model, (4) Design and Construction, (5) Calibration and Sensitivity, (6) Prediction, (7) Uncertainty, (8) Surface Water-Groundwater Interaction.

In addition to the review from a numerical standpoint, we have also made some comment in terms of operational considerations in reference to the key objectives of the modelling exercise.

Overall Compliance	Yes/No	Comment
1. Are the model objectives and model confidence level classification clearly stated?	Yes	Dewatering requirements and impacts due to dewatering/water supply
2. Are the objectives satisfied?	Yes	
3. Is the conceptual model consistent with objectives and confidence level classification?	Yes	Level 2 confidence level
4. Is the conceptual model based on all available data, presented clearly and reviewed by an appropriate reviewer?	Yes	Conceptual model details within separate report
5. Does the model design conform to best practice?	Yes	
6. Is the model calibration satisfactory?	Yes	No statistics presented, but hydrographs indicate good calibration in most locations
7. Are the calibrated parameter values and estimated fluxes plausible?	Yes	
8. Do the model predictions conform to best practice?	Yes	
9. Is the uncertainty associated with the predictions reported?	Yes	Only for impacts to water levels along rivers
10. Is the model fit for purpose?	Yes	

2. Planning	Yes/No
1.1 Are the project objectives stated?	yes
1.2 Are the model objectives stated?	yes
1.3 Is it clear how the model will contribute to meeting the project objectives?	yes
1.4 Is a groundwater model the best option to address the project and model objectives?	yes
1.5 Is the target model confidence-level classification stated and justified?	yes
1.6 Are the planned limitations and exclusions of the model stated?	yes

RPS

3. Conceptualisation	Yes/No	Comment
2.1 Has a literature review been completed, including examination of prior investigations?	half	Very brief mention of previous AQT/RPS work, RTIO conceptual model. None by others - maybe isn't any.
2.2 Is the aquifer system adequately described?	yes	Separate conceptual report
2.2.1 hydrostratigraphy including aquifer type (porous, fractured rock ...)	yes	
2.2.2 lateral extent, boundaries and significant internal features such as faults and regional folds	yes	Separate conceptual report
2.2.3 aquifer geometry including layer elevations and thicknesses	yes	Separate conceptual report
2.2.4 confined or unconfined flow and the variation of these conditions in space and time?	yes	Separate conceptual report
2.3 Have data on groundwater stresses been collected and analysed?	yes	Separate conceptual report
2.3.1 recharge from rainfall, irrigation, floods, lakes	yes	Separate conceptual report
2.3.2 river or lake stage heights	unknown	
2.3.3 groundwater usage (pumping, returns etc)	yes	Separate conceptual report
2.3.4 evapotranspiration	yes	Separate conceptual report
2.3.5 other?	yes	TSF seepage
2.4 Have groundwater level observations been collected and analysed?	yes	
2.4.1 selection of representative bore hydrographs	no	Not discussed in modelling or conceptual report
2.4.2 comparison of hydrographs	no	Not discussed in modelling or conceptual report
2.4.3 effect of stresses on hydrographs	no	Not discussed in modelling or conceptual report
2.4.4 watertable maps/piezometric surfaces?	yes	Separate conceptual report
2.4.5 If relevant, are density and barometric effects taken into account in the interpretation of	unsure	Not discussed in modelling or conceptual

3. Conceptualisation	Yes/No	Comment
groundwater head and flow data?		report
2.5 Have flow observations been collected and analysed?	yes	Robe River only at Ngalooin Pool
2.5.1 baseflow in rivers	no	Not discussed in modelling or conceptual report
2.5.2 discharge in springs	no	Not discussed in modelling or conceptual report
2.5.3 location of diffuse discharge areas?	no	Not discussed in modelling or conceptual report
2.6 Is the measurement error or data uncertainty reported?	no	Not discussed in modelling or conceptual report
2.6.1 measurement error for directly measured quantities (e.g. piezometric level, concentration, flows)	no	Not discussed in modelling or conceptual report
2.6.2 spatial variability/heterogeneity of parameters	no	Not discussed in modelling or conceptual report
2.6.3 interpolation algorithm(s) and uncertainty of gridded data?	no	Not discussed in modelling or conceptual report
2.7 Have consistent data units and geometric datum been used?	yes	
2.8 Is there a clear description of the conceptual model?	yes	Separate conceptual report
2.8.1 Is there a graphical representation of the conceptual model?	half	Lithology and water table presented, no indication of recharge/discharge/flow directions or changes due to mining
2.8.2 Is the conceptual model based on all available, relevant data?	yes	
2.9 Is the conceptual model consistent with the model objectives and target model confidence level classification?	yes	
2.9.1 Are the relevant processes identified?	yes	Separate conceptual report

3. Conceptualisation	Yes/No	Comment
2.9.2 Is justification provided for omission or simplification of processes?	yes	
2.10 Have alternative conceptual models been investigated?	unsure	

4. Design and Construction	Yes/No	Comment
3.1 Is the design consistent with the conceptual model?	yes	
3.2 Is the choice of numerical method and software appropriate (Table 4-2)?	yes	MODFLOW-Surfact
3.2.1 Are the numerical and discretisation methods appropriate?	yes	
3.2.2 Is the software reputable?	yes	
3.2.3 Is the software included in the archive or are references to the software provided?	yes	
3.3 Are the spatial domain and discretisation appropriate?	yes	
3.3.1 1D/2D/3D	3D	
3.3.2 lateral extent		
3.3.3 layer geometry?	half	Reasonable layer thicknesses, layer elevations could be improved
3.3.4 Is the horizontal discretisation appropriate for the objectives, problem setting, conceptual model and target confidence level classification?	yes	
3.3.5 Is the vertical discretisation appropriate? Are aquitards divided in multiple layers to model time lags of propagation of responses in the vertical direction?	yes	
3.4 Are the temporal domain and discretisation appropriate?	yes	
3.4.1 steady state or transient		Both
3.4.2 stress periods		Annual

4. Design and Construction	Yes/No	Comment
3.4.3 time steps?		Not stated in report (monthly)
3.5 Are the boundary conditions plausible and sufficiently unrestrictive?	yes	
3.5.1 Is the implementation of boundary conditions consistent with the conceptual model?	yes	
3.5.2 Are the boundary conditions chosen to have a minimal impact on key model outcomes? How is this ascertained?	yes	GHB and STR boundary conditions for river flow affect model outcomes (as intended and consistent with conceptual model). No flow at basement outcrop.
3.5.3 Is the calculation of diffuse recharge consistent with model objectives and confidence level?	yes	
3.5.4 Are lateral boundaries time-invariant?	yes	Except where lowered to simulate dewatering by CWS borefield
3.6 Are the initial conditions appropriate?	yes	
3.6.1 Are the initial heads based on interpolation or on groundwater modelling?		Steady state modelling to provide initial heads to transient calibration
3.6.2 Is the effect of initial conditions on key model outcomes assessed?	NA	
3.6.3 How is the initial concentration of solutes obtained (when relevant)?	NA	
3.7 Is the numerical solution of the model adequate?	yes	
3.7.1 Solution method/solver	not stated	Milos old GWV: PCG5, pseudo soil with upstream weighting
3.7.2 Convergence criteria	not stated	Milos old GWV: head change 0.005
3.7.3 Numerical precision	not stated	Mass balance values imply ~0% error

5. Calibration and sensitivity	Yes/No	Comment

5. Calibration and sensitivity	Yes/No	Comment
4.1 Are all available types of observations used for calibration?		
4.1.1 Groundwater head data	yes	
4.1.2 Flux observations	no	Should report obs v mod for dewatering volumes and pumped volumes to date.
4.1.3 Other: environmental tracers, gradients, age, temperature, concentrations etc	no	
4.2 Does the calibration methodology conform to best practice?	yes	
4.2.1 Parameterisation	yes	
4.2.2 Objective function	yes	Comparison of obs v modelled (visual in hydrographs). Assume some statistical measure considered during calibration (e.g. minimising sum of squares, SRMS etc)
4.2.3 Identifiability of parameters	yes	
4.2.4 Which methodology is used for model calibration?	not stated	Assume only manual
4.3 Is a sensitivity of key model outcomes assessed against?	not stated	
4.3.1 parameters	not stated	Intrinsic sensitivity during calibration assumed but not reported
4.3.2 boundary conditions	not stated	Intrinsic sensitivity during calibration assumed but not reported
4.3.3 initial conditions	not stated	Intrinsic sensitivity during calibration assumed but not reported
4.3.4 stresses	not stated	Intrinsic sensitivity during calibration assumed but not reported
4.4 Have the calibration results been adequately reported?	half	Hydrographs, no stats

5. Calibration and sensitivity	Yes/No	Comment
4.4.1 Are there graphs showing modelled and observed hydrographs at an appropriate scale?	yes	Indicate good calibration
4.4.2 Is it clear whether observed or assumed vertical head gradients have been replicated by the model?	no	Multilevel VWP's or nested piezos should be plotted on single chart
4.4.3 Are calibration statistics reported and illustrated in a reasonable manner?	no	Not reported, but likely good based on hydrographs
4.5 Are multiple methods of plotting calibration results used to highlight goodness of fit robustly? Is the model sufficiently calibrated?	no	
4.5.1 spatially	no	Map of residuals to indicate any areas which perform less well
4.5.2 temporally	yes	Hydrographs
4.6 Are the calibrated parameters plausible?	yes	
4.7 Are the water volumes and fluxes in the water balance realistic?	yes	
4.8 has the model been verified?	no	Recommendation for verification and re-calibration was made in report

6. Prediction	Yes/No	Comment
5.1 Are the model predictions designed in a manner that meets the model objectives?	yes	
5.2 Is predictive uncertainty acknowledged and addressed?	yes	Particularly in relation to rivers and mine plan
5.3 Are the assumed climatic stresses appropriate?	yes	
5.4 Is a null scenario defined?	yes	
5.5 Are the scenarios defined in accordance with the model objectives and confidence level classification?	yes	
5.5.1 Are the pumping stresses similar in magnitude to those of the calibrated model? If not, is there	yes	

6. Prediction	Yes/No	Comment
reference to the associated reduction in model confidence?		
5.5.2 Are well losses accounted for when estimating maximum pumping rates per well?	NA	
5.5.3 Is the temporal scale of the predictions commensurate with the calibrated model? If not, is there reference to the associated reduction in model confidence?	yes	
5.5.4 Are the assumed stresses and timescale appropriate for the stated objectives?	yes	
5.6 Do the prediction results meet the stated objectives?	yes	
5.7 Are the components of the predicted mass balance realistic?	yes	
5.7.1 Are the pumping rates assigned in the input files equal to the modelled pumping rates?	unknown	
5.7.2 Does predicted seepage to or from a river exceed measured or expected river flow?	no	
5.7.3 Are there any anomalous boundary fluxes due to superposition of head dependent sinks (e.g. evapotranspiration) on head-dependent boundary cells (Type 1 or 3 boundary conditions)?	no	
5.7.4 Is diffuse recharge from rainfall smaller than rainfall?	yes	
5.7.5 Are model storage changes dominated by anomalous head increases in isolated cells that receive recharge?	unknown	
5.8 Has particle tracking been considered as an alternative to solute transport modelling?	NA	

7. Uncertainty	Yes/No	Comment
6.1 Is some qualitative or quantitative measure of uncertainty associated with the prediction reported together with the prediction?	yes	Ranked by drawdown
6.2 Is the model with minimum prediction-error variance chosen for each prediction?	no	No consideration of impact on calibration results
6.3 Are the sources of uncertainty discussed?	yes	

7. Uncertainty	Yes/No	Comment
6.3.1 measurement of uncertainty of observations and parameters	yes	
6.3.2 structural or model uncertainty	yes	
6.4 Is the approach to estimation of uncertainty described and appropriate?	yes	
6.5 Are there useful depictions of uncertainty?	yes	

8. Surface water–groundwater interaction	Yes/No	Comment
8.1 Is the conceptualisation of surface water–groundwater interaction in accordance with the model objectives?	yes	Noted uncertainty due to limited data
8.2 Is the implementation of surface water–groundwater interaction appropriate?	yes	
8.3 Is the groundwater model coupled with a surface water model?	no	
8.3.1 Is the adopted approach appropriate?	na	
8.3.2 Have appropriate time steps and stress periods been adopted?	na	
8.3.3 Are the interface fluxes consistent between the groundwater and surface water models?	na	

RPS

Guideline Model Review Discussion

The modelling has been undertaken to a high standard and is fit for its intended purpose, being the prediction of dewatering and water supply volumes, and the prediction of impacts to water levels along the Robe River and Jimmawurrada Creek. There are no areas of concern that would have a material effect on the predicted outputs of interest. General comments and minor corrections have been included as tracked changes in the report document.

It is understood that the model has been dramatically simplified in recent years in order to improve run-times. However, considerations for model improvements during future work may include the following:

- Verification of model predictions and re-calibration if required to recent monitoring along the Robe River (as indicated within the report)
- Representation of actual topographic surface as top of model Layer 1.
- Layer bottom elevations more indicative of key lithological horizons shown in conceptual models Figure 3 (assuming geological model for the site is readily available)
- Reduction of stress period length from annual to monthly in order to more accurately represent seasonal fluctuations in both calibration and prediction runs to end of mining. Refine recharge, EVT and stream flow volumes accordingly.
- Inclusion of recorded dewatering volumes from existing mining as a calibration target.
- Characterisation of hydrogeological properties of major faults mentioned in conceptual model for inclusion in the model. Due to the often uncertain nature of faults acting as barriers or conduits (typically both), uncertainty analyses on fault properties may be most appropriate. The conceptual model report notes Yeera Bluff Pool exists as a result of fault structures.
- Application of fill properties/recharge post completion of mining using the TMP package in predictive runs
- Depending on need for water management planning purposes, additional uncertainty analyses with focus on predicted ranges in results of dewatering/water supply volumes and resulting drawdowns may be warranted using standard conductivity/storage parameter perturbation (+/- inclusion of faults as above).

Operational / Planning Considerations

Reviewing the modelling work with regards to the key objectives, and with consideration of the implications of uncertainties for planning and operational management purposes, we make some comments below.

Assessment of Future Dewatering Requirements

In reviewing the model report, it is noted that the calibration and prediction runs focused on the hydrographs and water levels for a verification of calibration confidence. In terms of water balance, the various water balance components within the model seem to be at the lower end of ranges identified in the conceptual hydrogeology report for the area. It may be worth additional enquiry of the calibration model to better understand the modelled abstraction volumes simulated to achieve the drawdowns and cross-check those against the actual dewatering volumes historically. This will enable a greater degree of confidence in the predicted dewatering volumes – as you may gain an appreciation that the model has a tendency to over-predict or under-predict abstraction volumes required to achieve a target water level.

Confidence in the dewatering requirement predictions in terms of volumes will provide greater confidence in the planning and budgeting of required dewatering infrastructure (number of bores, sizing of sump pumps and transfer pipelines, etc).

Assessment of Drawdown Impacts – Particularly on Pools / GDE's

On review of the conceptual hydrogeology report, it is clear that groundwater-fed pools in the proximity of the mining operations are a particular focus – namely Yeera Bluff Pool and Japanese Pool. The modelling exercise was seeking to better understand the potential for dewatering operations to negatively impact upon groundwater levels in proximity to these pools. On that basis, there may be value in exploring a few of the modelling assumptions and key sensitivities to better understand the impact potential. The aspects in question are:

- ***The annual time step / creek recharge application*** – given the seasonality of groundwater levels, especially in the Robe River Alluvium, annual time steps has the potential to mask a drawdown trend in the vicinity of pools that may be more severe within a given year than is currently represented; and
- ***General Head Boundary on Robe River*** – given that the model outcomes were sensitive to this, there may be value in exploring the implications of a seasonal fluctuation on the boundary condition, and/or some piezometer validation to gain confidence in this modelled factor.

In the absence of high confidence in these predictions, there may need to be some consideration given to management approaches that will ensure groundwater levels can be maintained at acceptable limits in proximity to these Pools should operational data indicate unfavourable trends toward these receptors.

It was also noted that the predicted drawdown below the riparian vegetation aligned with Jimmawurrada Creek is significant and sustained, and it could be expected that there is potential for vegetation with a high level of groundwater dependence to be negatively impacted by these local dewatering influences – it is currently not clear if such an impact would be acceptable, or if irrigation measures might be required.

If you have any questions or comments regarding this review, please do not hesitate to get in touch.

Kind regards,

RPS

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Senior Groundwater Modeller

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Mesa H
Level 2 Vegetation and Flora Assessment

May 2016

Prepared for
Robe River Mining Co. Pty Ltd

astron

Report Reference: 14269-16-BISR-2Rev3_171110

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Mesa H
Level 2 Vegetation and Flora Assessment

Prepared for
Robe River Mining Co. Pty Ltd (Rio Tinto)

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Abbreviations

Abbreviation	Definition
Astron	Astron Environmental Services
BAM Act	*Biosecurity and Agriculture Management Act 2007 (*State)
Biota	Biota Environmental Sciences
BOM	Bureau of Meteorology
DAFWA	Department of Agriculture and Food Western Australia (State)
DRF	Declared Rare Flora
EPA	Environmental Protection Authority (State)
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999* (Commonwealth)
ESA	Environmentally Sensitive Areas
GDA94	Geocentric Datum of Australia 1994
GDE	Groundwater Dependent Ecosystem
GPS	Global Positioning System
IBRA	Interim Biogeographic Regionalisation for Australia
MNES	Matters of National Environmental Significance (under the EPBC Act)
MGA94	Map Grid of Australia 1994
Parks and Wildlife	Department of Parks and Wildlife (State)
P	Priority
PEC	Priority Ecological Community
RNE	Register of the National Estate
sp.	Species (singular)
spp.	Species (plural)
The Proponent	Robe River Mining Co. Pty Ltd (part of the Rio Tinto group)
The 'survey area'	Mesa H survey area (4,930 ha)
TEC	Threatened Ecological Community
TPFL	Threatened and Priority Flora Database (administered by Parks and Wildlife)
TP List	Threatened and Priority Flora List (administered by Parks and Wildlife)
WAHerb	Western Australian Herbarium
WC Act	*Wildlife Conservation Act 1950* (State)
WoNS	Weeds of National Significance

Executive Summary

Rio Tinto, on behalf of Robe River Mining Co. Pty Ltd (The Proponent), is evaluating the potential development of the Mesa H deposit located adjacent to the Mesa J Operation and approximately 13 kilometres to the south-west of the town of Pannawonica. Astron Environmental Services were commissioned to undertake a two-phase Level 2 vegetation and flora assessment in the Mesa H survey area which is approximately 4,930 hectares in size.

Thirty-eight vegetation associations were described during the survey, none of which represent a Threatened Ecological Community. All but three vegetation associations recorded are well represented beyond the survey area and do not support assemblages of species that are unique, on restricted landforms, or of high conservation significance.

One vegetation association, AprTwTsr, is considered to represent the Priority 3 Priority Ecological Community '*Triodia sp. Robe River assemblages of mesas of the West Pilbara'*. Vegetation representing this Priority Ecological Community accounted for 15.7 hectares and was restricted to the tops, breakaways and gullies of mesa landforms.

Two additional vegetation associations, ChAsppGOrGsppPlSsTeTw and MaEcCv, may be considered locally significant. ChAsppGOrGsppPlSsTeTw was the only vegetation association to contain all three of the recorded Priority flora species. This vegetation was associated with drainage lines throughout the survey area and accounts for approximately 135 hectares (3%) in the survey area. Similar vegetation has been recorded from other regional surveys. Vegetation association MaEcCv, representing approximately 174 hectares (3%), can be considered a groundwater dependent ecosystem as it is characterised by the obligate phreatophyte *Melaleuca argentea* and the facultative phreatophyte *Eucalyptus camaldulensis* var. *refulgens*. MaEcCv fringed permanent and semi-permanent water pools in the survey area and the main flow channels of the Robe River, and as such supported a number of species that were unique to this habitat. Approximately 60% of the Priority 4 species *Rhynchosia bungarensis* P4 occurred in MaEcCv.

Vegetation condition ranged from 'very poor' to 'excellent'. An estimated 67% of the survey area was rated as 'excellent' condition. Approximately 367 hectares (7%) of the survey area was 'disturbed'; disturbed areas generally comprised tracks and rail infrastructure. Weed diversity and abundance was highest in drainage lines and alluvial plains; mesas, hilltops and slopes generally had very low weed abundance. Other disturbances included parts of the ranges being burnt within the past five years and grazing on alluvial plains and in drainage lines.

There were 310 vascular flora species from 53 families and 150 genera recorded in the survey area. The most represented families were Fabaceae, Poaceae and Malvaceae. No Threatened flora were recorded during the survey and based on the results of the desktop assessment no Threatened flora are expected to occur. Three State-listed Priority flora were identified: *Indigofera* sp. Bungaroo Creek (S. van Leeuwen 4301) P3, *Triodia* sp. Robe River (M.E. Trudgen et al. MET 12367) P3 and *Rhynchosia bungarensis* P4. Priority flora records were generally restricted to mesa, drainage line and floodplain habitats.

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1 Introduction

1.1 Project Background

Rio Tinto, on behalf of Robe River Mining Co. Pty Ltd (the Proponent), is evaluating the potential development of the Mesa H deposit located adjacent to the Mesa J Operation and approximately 13 km to the south-west of the town of Pannawonica. Key components of the pre-feasibility and feasibility studies being undertaken are the environmental surveys which are required to inform the environmental assessment process for the potential development of the Mesa H deposit. Astron Environmental Services (Astron) has been commissioned to undertake some of these environmental surveys. This report presents the outcome of the Level 2 vegetation and flora assessment of the Mesa H deposit (the survey area). The survey area is approximately 4,930 ha (Figure 1).

1.2 Scope and Objectives

The objective of the assessment was to undertake a two-phase Level 2 assessment of vegetation and flora values through a desktop assessment and field survey. The resultant data has been utilised to produce this report which is intended to support and inform the environmental assessment process in accordance with the requirements of the Environmental Protection Authority (EPA).

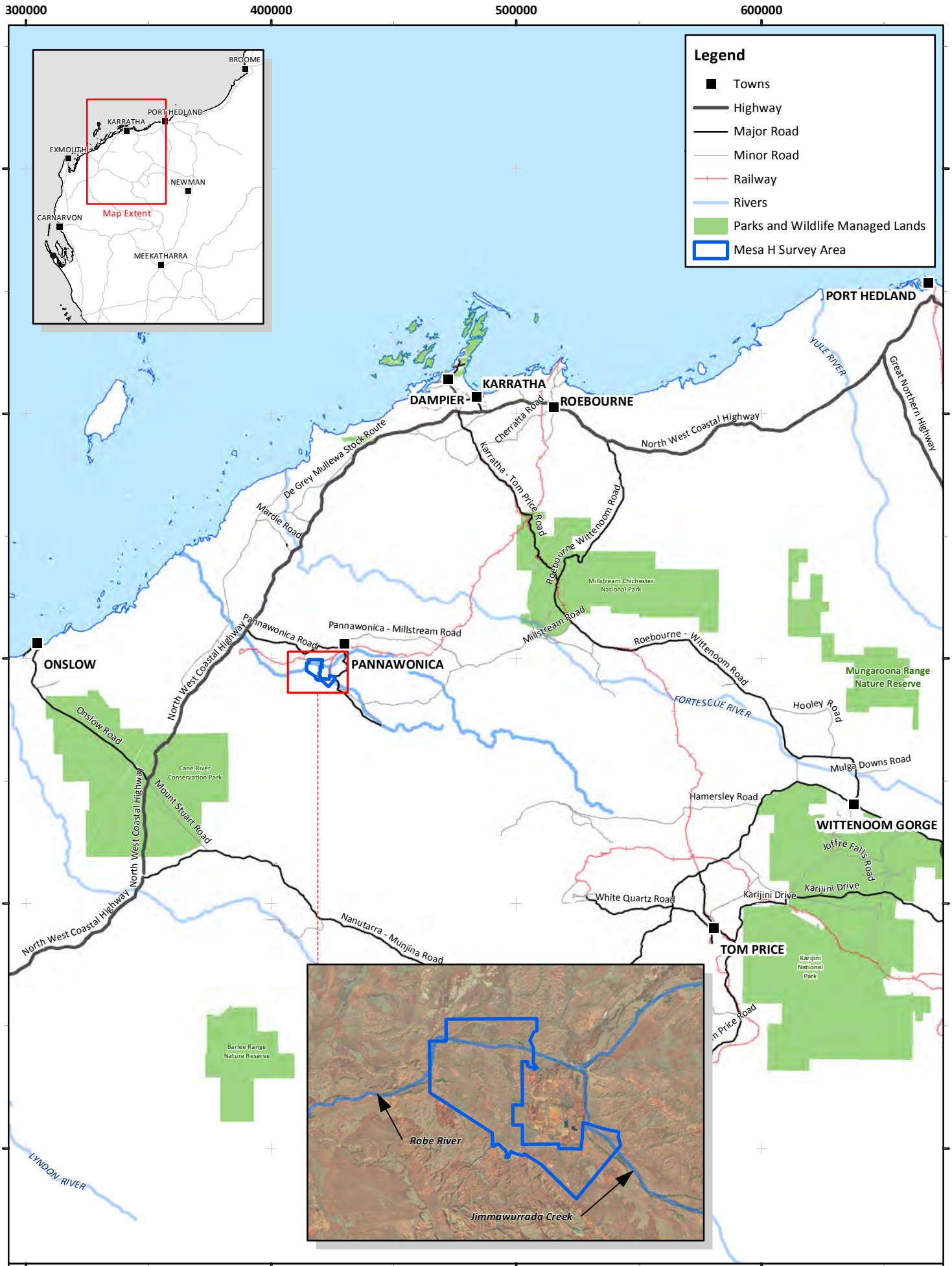
The scope of work was to undertake a:

- desktop assessment, including database searches and literature review of available contextual and project related resources
- two-phase vegetation and flora assessment, including:
    - establishment of new quadrats to ensure adequate replication within vegetation associations
    - ground-truthing, verification and refinement of existing vegetation mapping using quadrats, relevés and mapping notes
    - targeted searches for the presence of Threatened and Priority (P) flora, and weeds and vegetation of conservation significance
    - mapping of vegetation condition and disturbance within the survey area
    - generation of a vascular flora species list for the survey area.

This report presents information pertaining to both the Phase 1 and Phase 2 surveys of the vegetation and flora assessment. Table 1 summarises the scope and key limitations. Section 3.5 of this report provides more detail on the limitations of the Phase 1 and Phase 2 surveys.

Table 1: Summary of Astron's vegetation and flora assessment.

Level of survey	Survey area size	Survey timing	Relevant regulatory guidance documents	Key survey limitations
Level 2 two-phase survey	4,930 ha	23 to 30 October 2014 and 24 September to 4 October 2015 (Phase 1). 27 April to 14 May 2016 and 19 to 22 July 2016 (Phase 2).	• Environmental Protection Authority (EPA) Position Statement No. 3 (Environmental Protection Authority 2002) • EPA Guidance Statement No. 51 (Environmental Protection Authority 2004) • EPA & Department of Parks and Wildlife Technical Guide (Environmental Protection Authority and Department of Parks and Wildlife 2015)	• One post-wet season (primary) survey conducted in below-optimal seasonal conditions.



Robe River Mining Co. Pty Ltd

Mesa H – Level 2 Vegetation and Flora Assessment, May 2016

Figure 1: Survey Area Location

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Author: D. Roocke	Date: 09-08-2017	Datum: GDA 1994 - Projection: MGA Zone 50
Drawn: T. Pedersen	Figure Ref: 14269-16-BIDR-2Rev1_170809_Fig01	0 20 40 60 80 100 Km, N

2 Environmental Context

2.1 Physical Environment

2.1.1 Climate

The climate of the Pilbara region of Western Australia is classified as arid tropical with two distinct seasons: a hot, wet summer (October – April) and a mild, dry winter (May – September) (Bureau of Meteorology 2016).

Based on long-term climatic data from the nearest Bureau of Meteorology (BOM) weather station at Pannawonica (Station 5069) (approximately 13 km north-east of the survey area) the mean annual rainfall since 1971 is 403.5 mm (Bureau of Meteorology 2016). The mean maximum daily temperatures range between 28°C and 41°C, and range above 30°C for much of the year (Bureau of Meteorology 2016) (Figure 2).

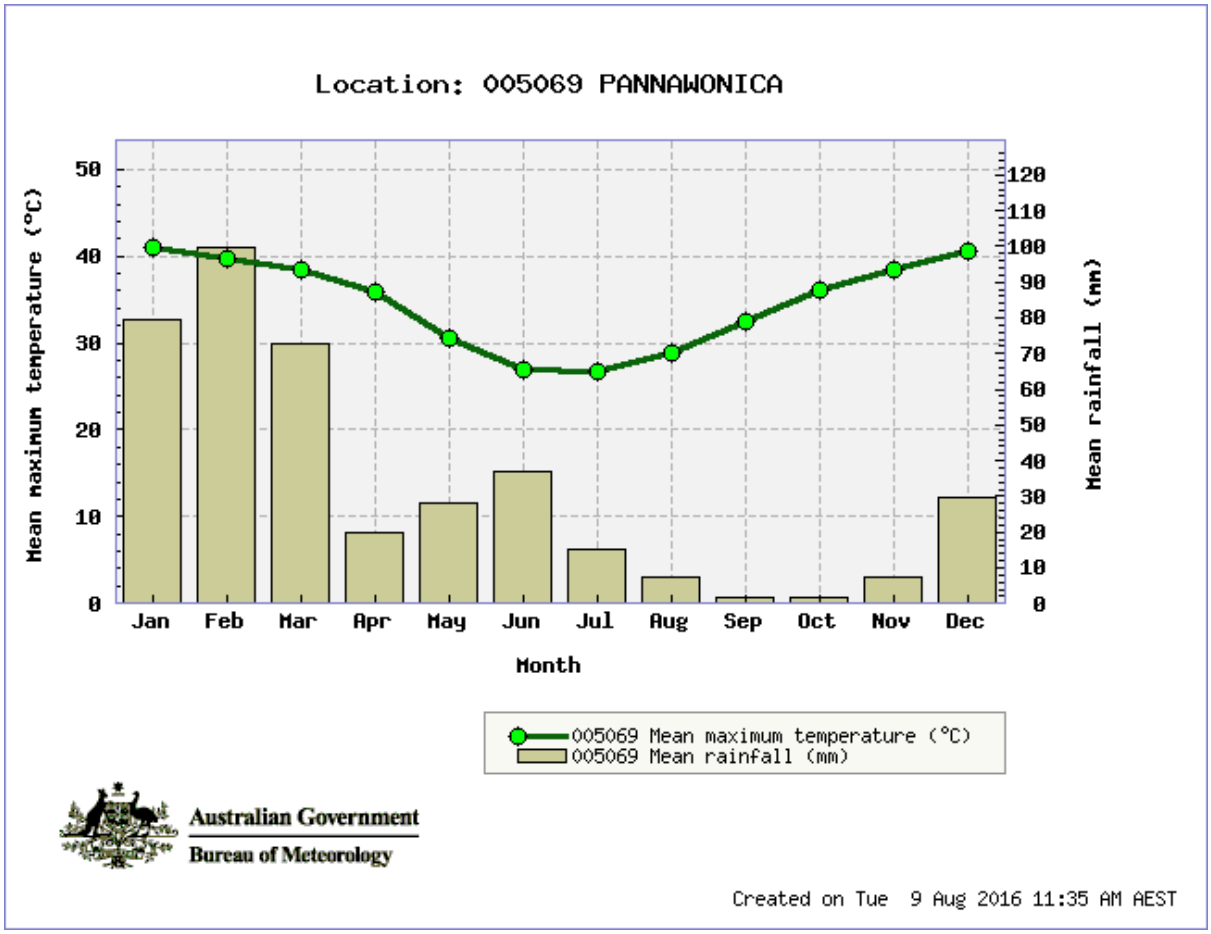


Figure 2: Climate data for Pannawonica (Station 5069). Mean annual rainfall data has been calculated from 1971 – 2016 and mean maximum temperature has been calculated from 1971 – 2005 (Bureau of Meteorology 2016).

2.1.2 Geology and Soils

The survey area occurs on the Hamersley Basin which overlies the Archaean Pilbara Craton and comprises of mafic and felsic volcanics, shale, siltstone, sandstone and conglomerate, as well as dolomite and banded iron formation. The area is extensively deformed with the rocks being folded and faulted (van Vreeswyk et al. 2004). The surface geology of the survey area is comprised of seven

units (Stewart et al. 2008), with Robe Pisolite the most dominant (Table 3). Geological mapping of the survey area and surrounds is presented in Figure A.1 (Appendix A).

Table 2: Geological units of the survey area (Stewart et al. 2008).

Geological name	Label	Area within survey area (ha)
Alluvium 38485: channel and flood plain alluvium; gravel, sand, silt, clay, locally calcreted.	Qa	762.3
Brockman Iron Formation: banded iron-formation, chert, mudstone and siltstone.	Lchk	114.0
Colluvium 38491: colluvium, sheetwash, talus; gravel piedmonts and aprons over and around bedrock; clay-silt-sand with sheet and nodular kankar; alluvial and aeolian sand-silt-gravel in depressions and broad valleys in Canning Basin; local calcrete, reworked laterite.	Qrc	778.2
Marra Mamba Iron Formation: chert, ferruginous chert, jaspilite, banded iron formation, minor shale, siltstone, mudstone.	Achm	635.9
Mount McRae Shale and Mount Sylvia Formation: interbedded shale, chert, banded iron-formation.	Ashm	289.7
Robe Pisolite: pisolitic, oolitic and massive limonite, goethite and hematite deposits containing fossil wood fragments; iron ore.	Czlr	2,261.6
Woongarra Rhyolite: rhyolite, rhyodacite, rhyolitic volcaniclastic breccia and banded iron formation.	Lfhw	88.5

The survey area is mapped as soil landscape zone 285 – Hamersley Plateaux in the Fortescue Province and soil landscape zone 296 – Stuart Plains and Hills Zone of the Ashburton Province (Tille 2006).

The Hamersley Plateaux soil unit is described as hills and dissected plateaux with some stony plains and hardpan wash plains on volcanic and sedimentary rocks. It is comprised predominately of stony soils with red shallow loams and some red-brown non-cracking clays and red loamy earths (Tille 2006). Some drainage habitats occur and these are characterised by sand, gravel, pebbles and stones (van Vreeswyk et al. 2004).

The Stuart Plains and Hills Zone consists of hills and ranges with some floodplains and stony plains on sandstone, shale and conglomerate of the Ashburton Basin. Soils are typically stony with red loamy earth and red shallow loams (Tille 2006).

2.1.3 Surface Water and Hydrology

The Robe River is considered a seasonal watercourse and intersects the northern section of the survey area, flowing in an east-west orientation. A number of permanent pools in the river were observed within the survey area. Numerous creeks and smaller drainage lines stem from the Robe River; drainage lines also occur down the gullies of the surrounding mesas. Springs and pools of the Robe River are listed as 'Wetlands of Subregional Significance' (Kendrick 2001) and are in proximity to the survey area. These wetland ecosystems are distributed from 40 km east of Pannawonica downstream to the North West Coastal Highway. Approximately 998 ha in the south-eastern corner of the survey area is within a Public Drinking Water Source Area: the Bungaroo Water Reserve (Department of Water 2008).

2.2 Biological Environment

2.2.1 Interim Biogeographic Regionalisation of Australia

The Interim Biogeographic Regionalisation for Australia (IBRA version 7) divides the Australian continent into 89 bioregions and 419 subregions (Department of the Environment and Energy 2016a). The IBRA regions represent a landscape-based approach to classifying the land surface, including attributes of climate, geomorphology, landform, lithology, and characteristic flora and fauna. The survey area occurs in the Pilbara Bioregion, of which 5% to 10% is represented in the national reserve system (Department of the Environment and Energy 2016b).

The biodiversity of the 53 subregions recognised in Western Australia was documented as part of a national audit to provide priorities for conservation action (Department of Conservation and Land Management 2002). The survey area occurs within the Hamersley subregions of the Pilbara region. The Hamersley subregion is described in the audit as:

- Hamersley PIL3 – dissected bold plateaux and ranges of flat lying, moderately folded sandstone and quartzite with vegetation described as Mulga low woodland over tussock grasses occurring on fine textured soils in valley floors, with scattered Snappy gum (*Eucalyptus leucophloia*) over *Triodia brizoides* on skeletal soils of the ranges (Kendrick 2001).

2.2.2 Land Systems

Land systems of the Western Australian rangelands have been mapped and described by the Department of Agriculture and Food (DAFWA) outlining the distributions and providing comprehensive descriptions of biophysical resources, including soil and vegetation condition. A total of 102 land systems occur in the Pilbara bioregion covering 181,723 km^2. Six land systems occur in the survey area, with Robe being the most dominant (Table 3). The layout of these land systems within the survey area is shown in Figure A.2 (Appendix A).

Table 3: Distribution of land systems within the survey area and Pilbara bioregion (van Vreeswyk et al. 2004).

Land system	Total area within Pilbara bioregion (ha)	Total area within survey area (ha)	Proportion within survey area (%)
Boolgeeda - stony lower slopes and plains below hill systems supporting hard and soft spinifex grasslands and mulga shrublands.	961,847	559.9	<0.1
McKay - hills, ridges, plateaux remnants and breakaways of meta sedimentary and sedimentary rocks supporting hard spinifex grasslands.	425,967	0.2	<0.1
Newman - rugged jaspilite plateaux, ridges and mountains with hard spinifex.	1,994,339	673.5	<0.1
River - active flood plains, major rivers and banks supporting grassy eucalypt woodlands, tussock grasslands and soft spinifex grasslands.	481,994	816.7	0.2
Robe - low limonite mesas and buttes supporting soft spinifex (and occasionally hard spinifex) grasslands.	128,680	2,758.1	2.1
Urandy - stony plains, alluvial plains and drainage lines supporting shrubby soft spinifex grasslands.	132,039	121.8	<0.1
TOTAL	**4,124,866**	**4,930.2**	-

2.2.3 Pre-European Vegetation

Pre-European vegetation was mapped across the Pilbara region at a scale of 1: 1,000,000 (Beard 1975). The survey area is located in the Stuart Hills and Hamersley Plateau physiographic units of the Fortescue Botanical District (Figure A.3, Appendix A). These physiographic units are described as:

Hamersley: a compact unit defined by the outcropping of jaspilite and dolomite, with some shale, siltstone and volcanics. Vegetation is described as:

- ranges – tree steppe of *Eucalyptus brevifolia* (likely to represent *E. leucophloia*) over *Triodia wiseana* hummock grasslands
- valley plains – mulga (*Acacia aneura* complex) low woodlands, or tussock grasslands on cracking clay soils
- basalt hills – mosaic of mulga low woodland and *Acacia pyrifolia* and *Triodia* species shrub steppe.

Stuart Hills: this unit consists mostly of plains, gently undulating pediplains extending out from Breakaways and residuals capped by Robe pisolites, and stony hills and steeply dissected pediments on fine-grained sandstone, shale and dolomite. Vegetation is described as:

- hills and plains – *T. wiseana* and *Triodia basedowii* hummock grasslands with sparse shrubs, particularly *Acacia bivenosa*
- drainage lines – *Corymbia hamersleyana* and *Corymbia candida* occur occasionally, with *Senna* species and ephemerals
- major rivers – *Eucalyptus camaldulensis* and *Acacia citrinoviridis* along river and mulga low woodland on river flats and tributaries.

Four pre-European vegetation units, 82, 603, 605 and 609 (Shepherd, Beeston, and Hopkins 2002), are associated with the survey area:

> 82: 'Hummock grasslands, low tree steppe; snappy gum over *Triodia wiseana*'
>
> 603: 'Hummock grasslands, sparse shrub steppe; *Acacia bivenosa* over hard spinifex'
>
> 605: 'Hummock grasslands, shrub steppe; *Acacia pachycarpa* and waterwood over soft spinifex'
>
> 609: 'Mosaic: Hummock grasslands, open low tree steppe; bloodwood with sparse kanji shrubs over soft spinifex/Hummock grasslands, open low tree steppe; snappy gum over *Triodia wiseana*'.

Table 4 summarises the current and pre-European extent of these four vegetation units in the Pilbara and the survey area.

Table 4: Extent of pre-European vegetation in the survey area (Government of Western Australia 2014).

Vegetation association	Mapping unit (Beard 1975)	Extent in survey area (ha)	Current extent in Pilbara bioregion (ha)	Pre-European extent (ha)	Proportion of pre-European extent remaining (%)
82	e16Lr t3Hi	2,023.7	2,550,898.98	2,563,583.23	99.51
603	a6Sb t3Hi	534.0	55,764.00	56,726.87	98.30
605	a5,11Sr t1Hi	965.5	114,115.85	114,115.85	100.00
609	e24Lr a2Sp t1Hi /e16Lr t3Hi	1407.0	72,765.18	74,186.11	98.08

2.3 State and Commonwealth Conservation Categories and Management

Commonwealth and State regulatory authorities maintain databases of the locations and conservation status of significant flora, fauna and ecological communities in Western Australia. The *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) provides a legal framework to protect and manage Matters of National Environmental Significance (MNES) including listed flora, fauna and ecological communities. These listed flora, fauna and ecological communities are allocated conservation categories, which are outlined in Tables B.1 to B.6 (Appendix B).

Ecological communities may be subject to processes that threaten to destroy or significantly modify it across much of its range. These communities are identified as Threatened Ecological Communities (TECs) and are listed at both Commonwealth level under the EPBC Act and State level by the Western Australian Minister for Environment (Table B.3, Appendix B). The Department of Parks and Wildlife (Parks and Wildlife) maintains a list of Priority Ecological Communities (PECs), which may also be under threat and are assigned one of four Priority rankings according to the criteria outlined in Table B.4 (Appendix B).

Under Western Australian legislation, all native flora is protected and it is an offence to 'take' protected flora. The *Wildlife Conservation Act 1950* (WC Act) also provides for native plant species to be specially protected when they are under identifiable threat of extinction, are rare, or otherwise in need of special protection (Department of Parks and Wildlife 2015a). Such specially protected flora is considered under the WC Act to be 'declared rare' (Threatened) (Table B.5, Appendix B). In addition, due to the diversity of Western Australia's flora, many species are known from only a few collections or locations, but have not been adequately surveyed. Such flora may be rare or

threatened, but cannot be considered for declaration as Threatened flora until adequate surveys have been undertaken. These flora species are included on a supplementary conservation list managed by Parks and Wildlife called the *Priority Flora List*. Priority flora are categorised according to level of threat and other information and the conservation categories are described in Table B.6 (Appendix B).

2.4 Introduced Flora (Weeds)

Significant weed species are identified at both the state and national level. The Australian Weeds Strategy (Australian Weeds Committee 2012) identifies Weeds of National Significance (WoNS) which have the potential to impact primary industry and/or environmental and social values. The management of weeds in Western Australia is primarily regulated through the *Biosecurity and Agriculture Management Act 2007* (BAM Act). Species listed under this act are allocated one of three declared pest categories which define the required level of management (Department of Agriculture and Food Western Australia 2016). Declared pest categories and listed weed species' priority ratings are presented in Table B.7 (Appendix B).

2.5 Land Use and Tenure

The survey area is located within the Shire of Ashburton. The majority of the survey area is on the Yalleen Station pastoral lease, with 100 ha (< 1% of the survey area) on the Yarraloola Station pastoral lease. The local area is used for pastoralism, mineral exploration and mining activity.

The Millstream-Chichester National Park is the nearest conservation reserve to the survey area, located approximately 79 km to the north-east. The Cane River Conservation Park is located approximately 48 km to the south-west, Murujuga National Park is approximately 120 km north and Karijini National Park is approximately 180 km south-east of the survey area (refer to Figure 1).

3 Methodology

3.1 Desktop Assessment

3.1.1 Database Searches

A search for Environmentally Sensitive Areas (ESAs) in the vicinity of the survey area was conducted using the WA Atlas (Landgate 2015) and Register of the National Estate (RNE) spatial database (Department of the Environment and Energy 2008). Despite all references to the RNE being removed from Commonwealth legislation in 2012, current State regulations (*Environmental Protection (Clearing of Native Vegetation) Regulations 2004*) declare any area registered on the RNE as an ESA (Department of the Environment and Energy 2016c).

In addition, database searches were conducted to identify listed conservation significant ecological communities and flora species within, or in close proximity to, the survey area. Search results are presented in Appendix C and details are summarised in Table 5. Conservation categories for ecological communities and flora are presented in Appendix B. Introduced flora species were compared to the DAFWA list to determine if any have been listed as declared pests (Department of Agriculture and Food Western Australia 2016) and the WoNS list (Australian Weeds Committee 2012). Introduced flora categories are also presented in Appendix B.

Table 5: Database searches requested.

Database name	Date search results received	Search focus	Search area
Protected Matters Search Tool (Department of the Environment and Energy 2016d)	25/07/2016	MNES - flora	40 km radius from an approximate survey area centre point, defined by the coordinates: 21°44’11 S, 116°11’50 E.
Threatened and Priority Ecological Communities database (Department of Parks and Wildlife 2015b)	05/10/2015	Listed Threatened and Priority Ecological Communities	20 km radius surrounding survey area boundary (shapefiles provided).
Threatened and Priority Flora Database (TPFL) (Department of Parks and Wildlife 2015c)	29/09/2015	Threatened and Priority flora	20 km radius surrounding survey area boundary (shapefiles provided).
Threatened and Priority Flora Species List (TP list) (Department of Parks and Wildlife 2015d)			
Western Australian Herbarium flora (Department of Parks and Wildlife 2015e)			
NatureMap (Department of Parks and Wildlife 2016a)	25/07/2016	Terrestrial flora and fauna of conservation significance	40 km radius from an approximate survey area centre point, defined by the coordinates: 21°44’11 S, 116°11’50 E.

3.1.2 Vegetation and Flora

The 30 PECs listed by Parks and Wildlife for the Pilbara region (Department of Parks and Wildlife 2016b) were reviewed to determine if any were analogous with ecological communities recorded in the survey area.

Prior to conducting the field survey, aerial imagery was interpreted to identify potential habitat types. The conservation significant flora species returned from the database searches were then categorised according to the criteria in Table 6 for potential occurrence within the survey area.

Table 6: Pre-survey criteria used to assess the likely presence of conservation significant flora in the survey area.

Likelihood of occurrence	Pre-survey
Likely	Species previously recorded within the survey area or within 10 km of the survey area and suitable habitat appears to be present in the survey area.
Potential	Species previously recorded within 10 km to 20 km of the survey area and/or suitable habitat appears to be present in the survey area.
Unlikely	No suitable habitat appears to be present in the survey area.

Following the field survey, the conservation significant flora species identified during the desktop assessment as having the highest potential to occur within the survey area, yet were not recorded during the current survey, were again assessed to determine their likelihood of occurrence within the survey area. Post-field survey likelihood of occurrence was primarily based on validating the presence (and thorough inspection) of suitable habitats within the survey area, combined with life form, habitat and flowering information for each flora species.

3.1.3 Literature Review

Vegetation and flora surveys which have previously been commissioned by Rio Tinto and that are within the vicinity of the survey area were supplied to Astron for the desktop assessment. The reports reviewed as part of this assessment were:

- Astron Environmental Services 2011, '*Mesa J Tail Track Extension Vegetation, Flora and Fauna Survey*', unpublished report to Rio Tinto
- Astron Environmental Services 2016a, '*Bungaroo Iron Ore Mine and Infrastructure Project Level 2 Vegetation and Flora Assessment*', unpublished report to Rio Tinto
- Astron Environmental Services 2016b, '*Middle Robe and East Deepdale Level 2 Vegetation and Flora Assessment*, unpublished report to Rio Tinto
- Biota Environmental Sciences 2003, '*Mesa J Extension Vegetation, Flora and Fauna Assessment*', unpublished report to Rio Tinto
- Biota Environmental Sciences 2006a, '*A Vegetation and Flora Survey of the Proposed Mesa A Transport Corridor, Warramboo Deposit and Yarraloola Borefield*', unpublished report to Rio Tinto
- Biota Environmental Sciences 2007, '*A Vegetation and Seasonal Flora Survey of the Bungaroo Trial Pit and Transport Corridor to Mesa J, near Pannawonica and Sampling of the Broader Bungaroo Valley*', unpublished report to Rio Tinto
- Biota Environmental Sciences 2011, '*Baseline Flora and Vegetation Assessment of Robe Valley Mesas (Mesas B, C, D, E, F, H and I*', unpublished report to Rio Tinto

- Biota Environmental Sciences 2012, '*Greater Bungaroo Flora and Vegetation Survey*', unpublished report to Rio Tinto
- Rio Tinto 2014, '*Flora Vegetation and Fauna Habitat Assessment at Jimmawurrada*', unpublished report.

The Astron (2011, 2016a), Biota Environmental Sciences (Biota) (2003, 2006a, 2007, 2011, 2012) and Rio Tinto (2014) survey areas overlap part of the current survey area. These reports were most relevant for obtaining contextual information relating to vegetation and flora values recorded within, or in close proximity to, the survey area. Survey area locations for the above listed reports are presented in Figure D.1 (Appendix D). Biota (2007, 2012) are the Phase 2 reports for Biota (2006b, 2009) respectively and contain the final combined Phase 1 and Phase 2 results for those surveys. As such they are not presented separately to avoid duplication and misrepresentation of information.

3.2 Field Survey

Phase 1 surveys were completed 23 to 30 October 2014 and 24 September to 4 October 2015. The two Phase 2 surveys were completed 27 April to 14 May 2016 and 19 to 22 July 2016 (Table 7).

Table 7: Dates and Personnel of Phase 1 and Phase 2 surveys.

Survey	Date	Personnel
Phase 1	23 to 30 October 2014	Janelle Atkinson (Flora permit SL010911 Declared Rare Flora (DRF) 107-1516) Daniel Roocke (Flora permit SL010827; DRF 139-1314) Alice Bott (Flora permit SL011640); DRF 140-1314
	24 September to 4 October 2015	Natalie Cadd (Flora permit SL011621; DRF 170-1415) Dr Kellie McMaster (Flora permit SL011404)
Phase 2	27 April to 14 May 2016	Janelle Atkinson (Flora permit SL011617), DRF 141-1415 Daniel Roocke (Flora permit SL011627), DRF 131-1516 Linda Vaughan (Flora permit SL011631) Dr Kellie McMaster (Flora permit SL011810)
	19 to 22 July 2016	Janelle Atkinson (Flora permit SL011617), DRF 141-1415 Daniel Roocke (Flora permit SL011627), DRF 131-1516

Daily weather observations recorded from Mesa J were used to describe local rainfall and temperatures preceding the surveys (Figure 3). Annual rainfall was 22 mm below the long-term mean prior to the 2014 survey, although more than double the monthly average rainfall was recorded in January, and triple the monthly average rainfall was recorded in May, eight and five months preceding the survey, respectively. Average rainfall was recorded in the six months prior to the 2015 survey, however the annual rainfall total was 67 mm below the long-term mean for the 12 months preceding the survey.

The annual rainfall recorded at Mesa J preceding the first Phase 2 survey in 2016 was 193 mm below the long-term mean of 404 mm at Pannawonica. Rainfall in the 12 weeks preceding the survey was less than half of the long-term mean for the same period, with 56 mm recorded. May, June and July 2016 recorded above average rainfall, with 137 mm (60 mm greater than the long term mean) recorded prior to the second Phase 2 trip. The maximum daily temperatures were lower than the long-term mean, ranging between 25.8°C and 35.4°C (Figure 3)

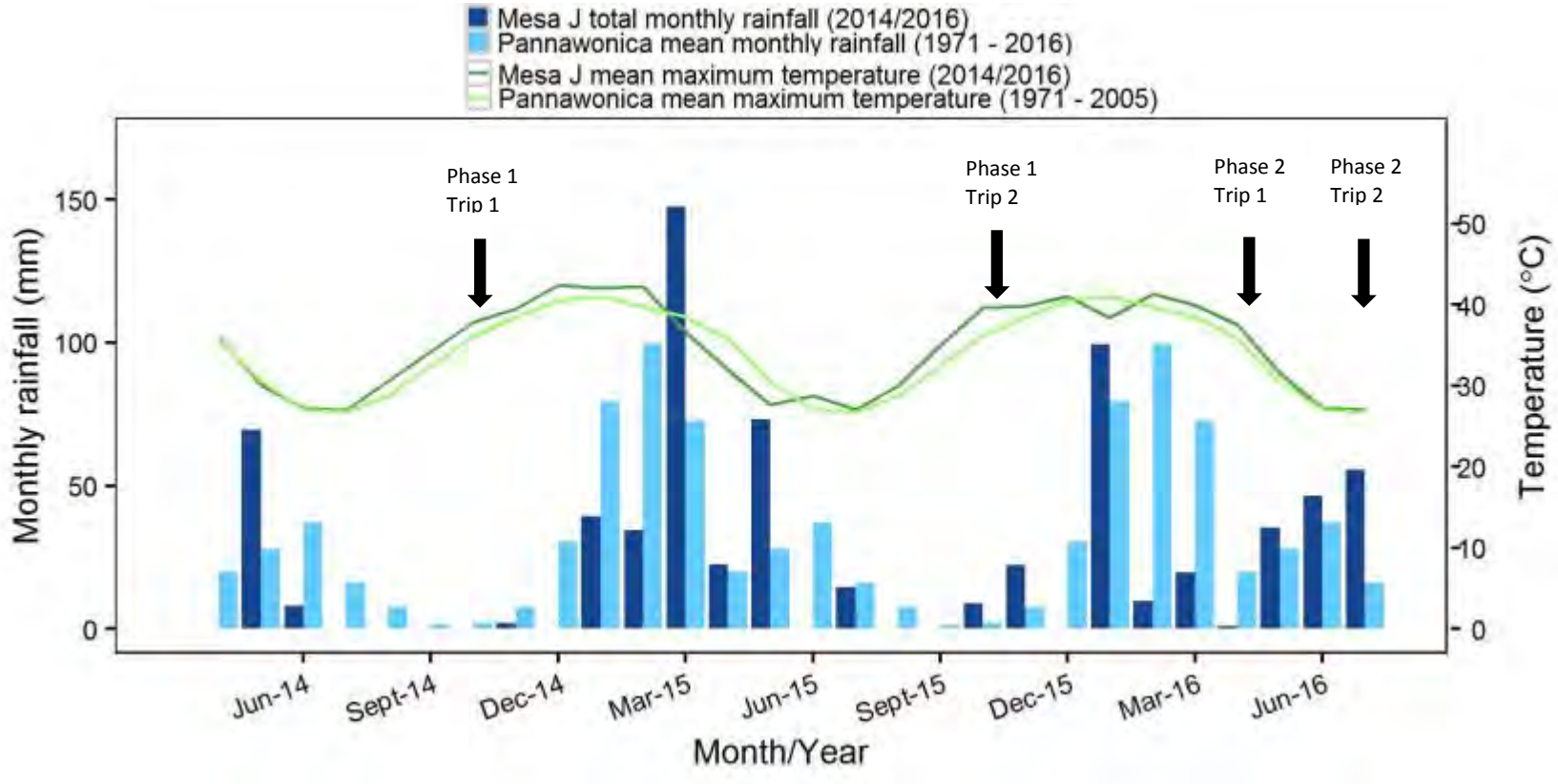


Figure 3: Pannawonica mean monthly rainfall (1971 – 2016) and Mesa J total recorded rainfall (2014 - 2016), and Pannawonica mean monthly maximum temperatures (1971 – 2005) and Mesa J mean monthly maximum temperatures, commencing 12 months preceding the first Phase 1 survey. Black arrows indicates field survey timing. Pannawonica data from Bureau of Meteorology (2016) and Rio Tinto (2016a).

3.2.1 Vegetation and Flora Assessment

The vegetation and flora field survey was undertaken in accordance with the requirements outlined in the EPA and Rio Tinto policy and guidance documents (Environmental Protection Authority 2002, 2004; Rio Tinto Iron Ore 2015).

Information acquired during the desktop assessment assisted in the design of the field survey. Pre-survey planning involved the examination of 1:10,000 scale aerial photography to identify potentially different landforms, habitat and vegetation types. It also involved a review of the flora and vegetation assessment previously completed at Mesa H (Biota Environmental Sciences 2012) to provide context and identify data gaps. Proposed quadrat locations were identified prior to the field survey according to the replicates required to support the previous vegetation mapping (Biota Environmental Sciences 2012).

There were 154 sites, comprising 138 quadrats and 16 relevés, sampled within the survey area. Forty-four quadrats and three relevés installed during the Phase 2 survey had a single season of survey only. Fifteen quadrats which informed a previous survey report (Astron Environmental Services 2016a) were incorporated into the assessment due to overlapping survey areas. Three of these had their second phase of survey during the current assessment. Survey effort is detailed in Table 8. The data from each surveyed site were used for mapping and floristic analysis purposes.

Quadrats were positioned by measuring a square of 50 m x 50 m, in suitable terrain, with the four corners of the quadrat permanently marked with fence droppers. Dimensions of the quadrat were adjusted according to terrain, drainage and landform features, to represent an estimated 2,500 m^2. Data from relevé locations was sampled from an area of approximately 2,500 m^2; in challenging terrain, visual estimation was used to approximate the area.

The following information was collected at each quadrat and relevé:

- Location – coordinates measured using a handheld Global Positioning System (GPS) (Map Grid of Australia 1994 (MGA94), Geocentric Datum of Australia 1994 (GDA94)). One set of coordinates taken from the north-west corner of each unmarked quadrat and relevé.
- Recorder and date – personnel involved in sampling that location and the survey date.
- Species – representative vascular plant species present. The inventory of associated species was more comprehensive for a quadrat location, with each flora species present recorded; at relevés the species most typical of the vegetation unit and represented at that location were recorded. Species that could not be identified in the field were collected for later identification at the Astron herbarium or Western Australian Herbarium (WAHerb).
- Weeds – the coordinates and density of any introduced flora.
- Foliar cover – the percentage cover was estimated for each flora species.
- Vegetation description – vegetation was described according to the Aplin (Aplin 1979) modification of the vegetation classification system of Specht (Specht 1970) (Table E.1, Appendix E) and the National Vegetation Information System, level 5 (Department of the Environment and Energy 2016e). At this level, vegetation is described to 'association' where up to three dominant genera for each of the upper, middle and ground strata are categorised based on dominant growth form, cover and height.
- Vegetation condition – assessed according to the vegetation condition classification adapted from Trudgen (1988) (Table E.2, Appendix E).

- Habitat – a broad description of the surrounding landscape based on landform, topography and soil.
- Photographs – a representative photograph was taken of each quadrat and relevé.
- Disturbances – records of any obvious disturbances such as fire, tracks or grazing.
- Geology – rock type and abundance.
- Soil – including colour and texture.

Quadrat and relevé locations are presented in Figure F.1 (Appendix F).

Table 8: Survey effort for existing and newly installed quadrats and relevés occurring within the survey area.

Author; phase of survey	Number of sites	Name of sites
Two seasons of survey: Astron (current survey)	78 quadrats 14 relevés	MH01, MH02, MH05, MH06, MH07, MH09, MH10, MH11, MH12, MH17, MH18, MH19, MH20, MH21, MH22, MH24, MH25, MH26, MH27, MH28, MH29, MH30, MH31, MH32, MH33, MH34, MH35, MH36, MH37, MH38, MH39, MH40, MH41, MH42, MH43, MH44, MH100, MH101, MH103, MH104, MH105, MH106, MH200, MH203, MH204, MH300, MH301, MH302, MH303, MH305, MH306, MH307, MH308, MH309r, MH310, MH311r, MH312, MH313, MH314, MH315, MH316, MH317, MH318, MH319, MH320, MH321, MH322, MH324, MH325, MH326, MH327, MH328, MH329, MH330, MH331, MH332, MH333r, MH334r, MH335, MH336, MH337r MHJ301r, MHJ302, MHJ303, MHJ304, MHJ305, MHJ306, MHJ309r, MHJr02, MHJr04, MHJr06, MHr200
One season of survey: Astron (current survey)	44 quadrats 3 relevés	MH338, MH339, MH342, MH343, MH344, MH345, MH346, MH348, MH350, MH352, MH353, MH354, MH356, MH357, MH358, MH359, MH360r, MH361, MH363, MH364, MH365, MH368, MH370, MH371, MH373, MH374, MH375r, MH376, MH377, MH392, MH393, MH394, MH395, MH396, MH397, MH398, MH399r, MH400, MH401, MH402, MH403, MH404, MH405, MH406, MH407, MH408, MH409
Two seasons of survey: Astron (current survey) 1 phase and Astron (2016a) 1 phase	3 quadrats	BA209, BA210, BA219
Two seasons of survey: Astron (2016a)	12 quadrats	BA07, BA10, BA18, BA21, BA22, BA32, BA42A, BA111, BAKM15, BADRr05, GBR23, BUN06

3.2.2 Vegetation Description and Mapping

Where appropriate, vegetation was described and mapped to be consistent with the descriptions and mapping previously conducted in and adjacent to the survey area (Biota Environmental Sciences 2006a). Astron adopted these vegetation codes and descriptions, and reconciled vegetation polygon boundaries to maintain consistency with those datasets. The vegetation description for some codes was updated to reflect current nomenclature. Where vegetation was observed to no longer represent previous mapping, vegetation polygon boundaries were adjusted and new vegetation descriptions assigned. Vegetation units were described and mapped using the data collected from

quadrats and relevés, and followed the same convention as that previously used; the vegetation association code is described according to the initials of the dominant flora species defining the community. Mapping notes were also used to mark changes in vegetation throughout the survey area. The details collected at mapping note locations included coordinate, photograph and vegetation description.

3.2.2.1 Vegetation Condition Mapping

Vegetation condition was mapped according to vegetation association boundaries throughout the survey area, using a combination of quadrat and relevé data, opportunistic observations and the mean condition rating for each vegetation association. Vegetation condition was rated at each survey site using the five point Trudgen (1988) scale, and then applied to the whole vegetation association polygon in which it was mapped. A mean condition rating was calculated for each vegetation association using the data collected from survey sites and this was applied to any polygons not already attributed with a rating.

3.2.3 Targeted Flora Survey

Previously recorded conservation significant flora records (Astron Environmental Services 2016a; Biota Environmental Sciences 2003, 2006a, 2007, 2011; Department of Parks and Wildlife 2015c, 2015d, 2015e, 2016a) and associated habitat preference information were used to identify vegetation associations and habitat within the survey area that have the potential to support conservation significant flora. The habitats and vegetation associations considered to have the potential to support conservation significant flora were located within the survey area from 1:10,000 colour aerial imagery and on-ground observations. These areas were then targeted in the field to record the presence or absence of Priority flora. Where conservation significant flora were observed, the area was traversed to record the extent of the population.

Population information for conservation significant flora was captured electronically using ArcPad (Esri) on a handheld device. The information recorded included population size, density, landform, soil and reproductive characteristics.

3.3 Taxonomy and Nomenclature

Plant specimens that were not identified in the field were later identified in Perth by Astron Botanists Johan Hurter, Natalie Cadd, Daniel Roocke and Janelle Atkinson. Each of these botanists has worked extensively in the Pilbara and is very familiar with the flora of the region. The assigned nomenclature is consistent with the current listing of scientific names recognised by the WAHerb and was used for the species list and associated species information collected. Where specimens had inadequate descriptive material to allow confident identification, they were assigned a 'sp.' (species) epithet, indicating that identification could not be confirmed beyond genus level. Data from each quadrat, relevé and mapping note were entered into a customised database.

3.4 Floristic Analysis

A species accumulation curve was created in order to examine the adequacy of survey effort, while a numerical analysis using species presence/absence was conducted to identify statistically significant floristic groups. The species accumulation curve and cluster analysis were completed by Astron Senior Scientist Dr Aaron Gove using R 3.2.1 (R Development Core Team 2015) and PRIMER v6 software (Clarke and Gorley 2006), respectively. Following normal convention, statistically significant clusters were those distinguished by a P-value <0.05.

Cluster analyses were completed to test the relationship between:

- floristic groups and structural vegetation associations within the survey area
- survey area quadrats and relevés and regional quadrats and relevés.

The 154 quadrats and relevés sampled from the survey area were included in the analysis and treated as a single project area. A further 357 sites from appropriate surveys (Astron Environmental Services 2016a, 2016b; Biota Environmental Sciences 2006a, 2007, 2012) were included in a separate analysis in order to provide a regional comparison.

The species lists from all projects were reconciled to provide consistency in nomenclature. Any taxa not confirmed to species level were removed from the analyses. Singletons (species recorded from only one site) were retained. Few rainfall dependent annuals were recorded for three of the field visits. The final Phase 2 survey followed high rainfall and had a much higher diversity of annual and herbaceous species which were not otherwise recorded in the broader survey area. This included *Calotis* species (spp.), *Cheilanthes* spp. and *Dysphania melanocarpa* which were removed from the floristic analysis.

3.5 Limitations

Following completion of the desktop assessment and field survey, a review of any limitations that may affect a complete assessment of the data collected was conducted. The limitations listed in Table 9 are based on those suggested as considerations in Guidance Statement No. 51 (Environmental Protection Authority 2004).

Table 9: Statement of limitations.

Potential limitation	Degree of limitation	Statement regarding potential limitations
(i) Sources of information and availability of contextual information. Is the region well documented?	No limitation	Broad-scale contextual information is available from van Vreeswyk et al. (2004), IBRA (Kendrick 2001; Kendrick and McKenzie 2001) and Beard (1975) mapping. Numerous consultants' reports have been completed within a 50 km radius of the survey area; one of which intersects the Mesa H survey area.
(ii) Scope. The level of survey and detail required to undertake the survey. Was there adequate time to complete the survey to the desired standard?	Minor limitation	Following assessment and gap analysis of the Phase 1 data, and to ensure alignment with the Technical Guide (Environmental Protection Authority and Department of Parks and Wildlife 2015), a further 44 quadrats and 3 relevés were installed and sampled during the Phase 2 survey. These sites had only a single phase of survey. The single phase of survey did not impact on vegetation mapping reliability, nor is it likely to have affected the floristic analysis or interpretation of data significantly. It is possible that additional species may be recorded from these sites if they had a second phase of survey post-rainfall.
(iii) Proportion of flora collected and identified. Was the survey sampling, timing and intensity considered adequate? Was the survey conducted at what was considered	Minor limitation	The Phase 1 field surveys were conducted in October 2014 and September-October 2015. The Phase 2 surveys were conducted in April-May, and June-July 2016. Seasonal conditions for both Phase 1 surveys were considered dry, with below average rainfall in the months preceding. Seasonal conditions for the first

Potential limitation	Degree of limitation	Statement regarding potential limitations
an appropriate time of the year for plant identification? Were any taxonomic groups considered to be under-represented?		Phase 2 survey were also considered poor with below-mean rainfall recorded both 12 weeks and 12 months prior to the survey. Approximately 140 mm of rain was recorded in the 12 weeks prior to the second Phase 2 trip, which resulted in a number of annual and ephemeral species (which had otherwise not been recorded in the survey area) being recorded. Despite the unfavourable seasonal conditions for three trips, the specimens collected from both phases were generally of reasonable quality and with flowering and fruiting material available; few specimens were unable to be confidently identified to species level. Most taxonomic groups expected within the survey area were well represented, and the total floristic richness was considered comparable to other surveys in the area, given the relatively low diversity of landforms. Some species which may be expected to occur post-rainfall, such as *Dysphania* spp., Asteraceae spp. and annual grasses may be considered slightly under-represented. Although the species accumulation curve had reached an asymptote (indicating that sampling had been exhaustive at the time of the surveys), it is possible that additional species may occur post-rainfall.
(iv) Completeness. Is there further work which may be required i.e. was the relevant area fully surveyed?	No limitation	The survey area was considered adequately surveyed to compile a representative list of species, (including Priority and introduced flora species), as well as describe and map vegetation at a level appropriate for possible future management decisions.
(v) Mapping reliability. Were the aerial photographs, satellite images and site maps available considered adequate to fully understand the area surveyed? Was the mapping generated considered to have a high degree of reliability?	No limitation	Colour aerial photography at a scale of 1: 10,000 was used to locate the survey area and to assist in navigation and delineation of vegetation boundaries. The aerial photography was of good resolution and, in general, accurately represented ground conditions.
(vi) Timing. When was the survey conducted in terms of season, rainfall and severe weather events? Was the survey conducted at an appropriate time for access, observation of the optimal suite of species and for identification of flowering and fruiting species?	Minor limitation	The four surveys were conducted at what would normally be considered the optimal time for dry and post-wet season surveys in the Pilbara. The dry season surveys were considered adequate, however during the first post-wet season survey quadrat species richness may have been lower than might be expected. The total floristic richness of the survey area was in line with what may be expected, although a number of the flora species were recorded only from the sites sampled during the second Phase 2 survey.
(vii) Disturbance. Had the survey area been impacted by any disturbance which may have limited the survey, i.e. fire, flood, accidental human intervention?	No limitation	A history of pastoral activity and cattle grazing was evident on the plains, floodplains and drainage lines. A thin area of the ranges (approximately 2% to 5% of the survey area) had been burnt within five years, however this did not compromise the vegetation mapping for

Potential limitation	Degree of limitation	Statement regarding potential limitations
		these locations. *Triodia* sp. Robe River (M.E. Trudgen et al. 12367) P3 was the only conservation significant species considered likely to occur in these areas and regenerating hummocks were large enough to be able to be identified from other *Triodia* species. None of these disturbances limited the outcomes of this survey.
(viii) Intensity. In retrospect, was the intensity considered to be adequate?	No limitation	The intensity of the survey was considered adequate to compile a representative species list, map the vegetation of the survey area to association level with adequate quadrat replication and conduct targeted surveys for Priority flora in potential habitat.
(ix) Resources. Were the appropriate tools and materials available to complete the task effectively?	No limitation	Resources were adequate to complete the survey and all appropriate tools and materials required to complete the task were available.
(x) Access. Were there any factors limiting access to the survey area?	No limitation	Much of the survey area was able to be accessed by vehicle; areas that were unable to be reached by vehicle were accessed and traversed by foot.
(xi) Experience. Were personnel undertaking the field survey and plant identification trained and/or experienced in undertaking the required tasks?	No limitation	The botanists responsible for undertaking the field survey have considerable experience in conducting vegetation and flora surveys in the Pilbara. The identification of specimens brought back from the field was conducted by a taxonomist with extensive Pilbara botanical experience.

4 Results

4.1 Desktop Assessment

4.1.1 Vegetation and Flora

No State or Commonwealth listed TECs are known to occur within or adjacent to the survey area (Department of Parks and Wildlife 2015b).

Two PECs: '*Triodia sp. Robe River assemblages of mesas of the West Pilbara*' P3 and '*Four plant assemblages of the Wona Land System*' P1, have been previously recorded within 20 km of the survey area (Department of Parks and Wildlife 2015b) (Figure G.1, Appendix G). Several mapped occurrences of '*Triodia sp. Robe River assemblages of mesas of the West Pilbara*' are located between approximately 16 km and 19 km south-west of the survey area. The '*Four plant assemblages of the Wona Land System*' PEC is mapped as occurring approximately 21 km north-east of the survey area (Department of Parks and Wildlife 2015b).

Vegetation analogous with the '*Triodia sp. Robe River assemblages of mesas of the West Pilbara*' P3 PEC has been identified during previous surveys undertaken adjacent, and within close proximity, to the survey area (Table 10) (Astron Environmental Services 2016b; Biota Environmental Sciences 2011).

The Parks and Wildlife (TPFL) (Department of Parks and Wildlife 2015c) and WAHerb (Department of Parks and Wildlife 2015e) database searches indicated that no species listed as Threatened have been recorded within 20 km of the survey area. The Parks and Wildlife TP List (Department of Parks and Wildlife 2015d), which is searched according to place names rather than coordinates, listed two Threatened species: *Lepidium catapycnon* T and *Thryptomene wittweri* T. However, since receiving the TP List database search results, *L. catapycnon* has been removed from the Threatened flora list in Western Australia and is currently listed as P4 (Western Australian Government 2015). Under the EPBC Act, *L. catapycnon* is still classified as 'Vulnerable', however, the Finalised Priority Assessment List indicates it has been proposed to be assessed for potential deletion (Department of the Environment and Energy 2016). A review of recorded specimens of *T. wittweri* T, held by the WAHerb (Western Australian Herbarium 1998-2016), indicates that the closest occurrence of this species to the survey area is approximately 270 km to the south-east. In addition, this species has not been identified during previous surveys conducted within, or in close proximity to, the survey area (Astron Environmental Services 2011, 2014, 2016a, 2016b; Biota Environmental Sciences 2003, 2006a, 2007, 2011, 2012; Rio Tinto Iron Ore 2014).

Twelve Priority flora species have been previously recorded within 20 km of the survey area (Table H.1, Appendix H) (Department of Parks and Wildlife 2015c, 2015d, 2015e, 2016a). Of these, two are P1, four are P2, six are P3 and two are P4 status. The pre-survey desktop assessment indicated that three of the listed Priority flora species were considered likely to occur within the survey area; a further eleven were considered to have the potential to occur (Table H.1, Appendix H). A result of *Thryptomene wittweri* T was obtained from the TP List database, which is searched using place names, rather than geo-referenced locations. Due to no other database indicating its occurrence within 50 km of the survey area, it was considered unlikely to occur.

4.1.2 Literature Review

Results of the literature review indicate that no TECs have been previously recorded within, or in the vicinity of the survey area. One PEC has been previously recorded in the vicinity of the survey area,

the '*Triodia sp. Robe River assemblages of mesas of the West Pilbara'* (Astron Environmental Services 2016b; Biota Environmental Sciences 2011).

Ten currently listed Priority flora species have been previously recorded within, or in close proximity to, the survey area: *Dicladanthera glabra* P2, *Pentalepis trichodesmoides* subsp. *hispida* P2, *Stylidium weeliwolli* P2, *Eragrostis surreyana* P3, *Gymnanthera cunninghamii* P3, *Indigofera* sp. Bungaroo Creek (S. van Leeuwen 4301) P3, *Triodia* sp. Robe River (M.E. Trudgen et al. 12367) P3, *Livistona alfredii* P4, *Ptilotus mollis* P4 and *Rhynchosia bungarensis* P4 (Table 10) (Astron Environmental Services 2014, 2016a, 2016b; Biota Environmental Sciences 2003, 2006a, 2007, 2011, 2012; Rio Tinto Iron Ore 2014).

Of these species, *T.* sp. Robe River (M.E. Trudgen et al. 12367) P3 and *R. bungarensis* P4, were recorded in the greatest number of surveys (Astron Environmental Services 2014, 2016a, 2016b; Biota Environmental Sciences 2003, 2006a, 2007, 2011, 2012; Rio Tinto Iron Ore 2014) (Table 10).

Specifically within the survey area, two Priority flora species have been previously recorded: *T.* sp. Robe River (M.E. Trudgen et al. MET 12367) P3 and *R. bungarensis* P4 (Astron Environmental Services 2014; Biota Environmental Sciences 2003).

Table 10: Summary of relevant vegetation and flora surveys in the vicinity of the current survey area.

Survey parameter	Astron Environmental Services (2016a)	Astron Environmental Services (2016b)	Rio Tinto (2014)	Biota Environmental Sciences (2012)	Astron Environmental Services (2011)	Biota Environmental Sciences (2011)	Biota Environmental Sciences (2007)	Biota Environmental Sciences (2006)	Biota Environmental Sciences (2003)
Survey area size (ha)	9,795	11,816	4,323	8,765	79	9,494	5,678	Not specified	~300
Survey focus	Two phase Level 2	Two phase Level 2	Targeted flora	Two phase Level 2	Level 1	Baseline vegetation and flora	Two phase Level 2	Baseline vegetation and flora	Single phase Level 2
Survey timing	April/May 2015	June 2015 September/ October 2015	July and October 2013	July 2009 and June 2011	June 2011	October 2010	March 2005 and July 2006	7 surveys between July 2004 and September 2005	September 2003
Seasonal conditions	Excellent	Excellent	Adequate	Excellent	Excellent	Dry	Poor (2005) Excellent (2006)	Excellent (all surveys)	Dry
Survey effort (quadrats/relevés)	112 quadrats 30 relevés	106 quadrats 13 relevés	30 relevés	37 quadrats	9 relevés	51 quadrats 2 relevés	45 quadrats	50 quadrats	10 quadrats
Total vegetation associations mapped	38	37	14	16	9	50	28	72	10
Conservation significant ecological communities recorded	0	1 PEC	0	0	0	1 PEC	0	0	0
Total species recorded	331	399	116	284	73	221	364	437	119
Conservation significant flora species recorded (currently listed - as at May 2016)	4	6	2	3	0	3	3	1	1

Survey parameter	Astron Environmental Services (2016a)	Astron Environmental Services (2016b)	Rio Tinto (2014)	Biota Environmental Sciences (2012)	Astron Environmental Services (2011)	Biota Environmental Sciences (2011)	Biota Environmental Sciences (2007)	Biota Environmental Sciences (2006)	Biota Environmental Sciences (2003)
Dicladanthera glabra P2	✓								
Eragrostis surreyana P3			✓	✓					
Gymnanthera cunninghamii P3		✓							
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301) P3	✓	✓		✓					
Livistona alfredii P4		✓							
Pentalepis trichodesmoides subsp. *hispida* P2		✓							
Ptilotus mollis P4						✓			
Rhynchosia bungarensis P4	✓	✓				✓	✓	✓	✓
Stylidium weeliwolli P2							✓		
Triodia sp. Robe River (M.E. Trudgen et al. 12367) P3	✓	✓	✓	✓		✓	✓		✓ (undescribed at the time of survey)

Limitations affecting the results of previous surveys were minimal and are summarised below:

- Biota (2003): the survey was conducted after an extended dry period; vegetation was therefore visibly drought-affected and annual flora were uncommon.
- Biota (2006a) seasonal conditions for the 2005 survey were considered poor (Table 10); although substantial rainfall occurred in the month prior to the field survey, negligible rainfall was recorded for the 10 months prior to the survey.
- Biota (2012): some access constraints were experienced during the July 2009 field survey, due to some areas being inundated with water.
- Biota (2012): large sections of this survey area were noted as having been subject to recent intense fires and, as such, vegetation mapping for these areas was not an exact representation of the vegetation, rather an indicative account of the most common vegetation.
- Astron (2016a): approximately half of the survey area had been burnt within two years prior to the survey; this limited vegetation mapping verification and targeted surveys.
- Astron (2014): seasonal conditions were considered poor (Table 10) with only 9 mm of rain recorded in the four months prior to the survey.
- Astron (2014): up to 15% of the southern side of the survey area had been burnt in the three years preceding the survey and mapping needed to be extrapolated in this area.

4.1.3 Environmentally Sensitive Areas

No ESAs occur within or adjacent to the survey area. The nearest ESAs to the survey area are the Duck Creek Gorge Area, located approximately 78 km south of the survey area (Department of the Environment and Energy 2008). The Millstream Pools are listed in the Directory of Important Wetlands in Australia, and also represent an ESA 78 km east-north-east of the survey area (Department of the Environment 2015). The Millstream-Chichester National Park is located approximately 85 km east-north-east of the survey area (Department of the Environment and Energy 2008; Landgate 2015).

4.2 Field Survey

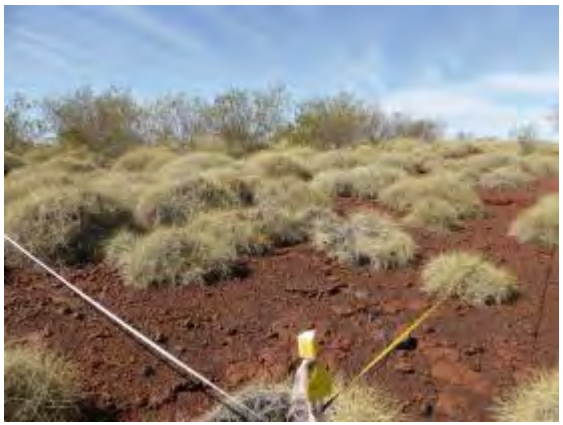
4.2.1 Vegetation

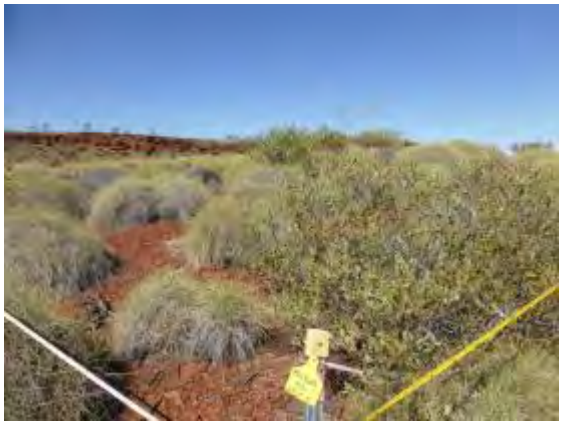
There were 38 vegetation associations described within the survey area (Table 11). Vegetation association mapping is provided in Figure I.1 (Appendix I) and the data collected from each quadrat, relevé and mapping note is presented in Appendix J.

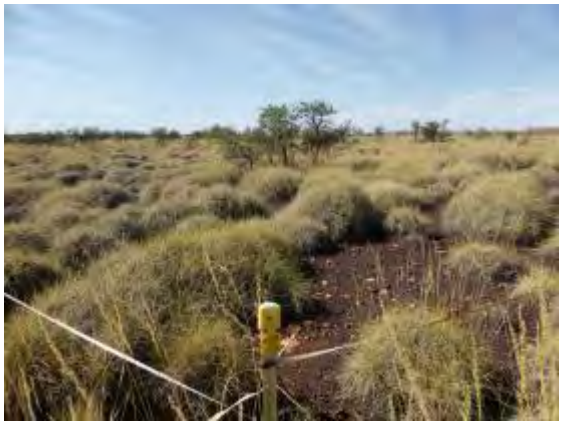
In addition, three mosaic vegetation associations, AiAaAbTw/ChAtuTw (177.4 ha, 3.6%), AiAaAbTw/AaTeTw/ChAtuTw (47.3 ha, 0.96%) and AaTeTw/ChAtuTw (10.6 ha, 0.2%), occur in the southern end of the survey area. This vegetation included a dense network of drainage lines and plains that occurred at a scale too fine to capture on the mapping. Unvegetated ('disturbed') land accounts for approximately 367 ha (7%).

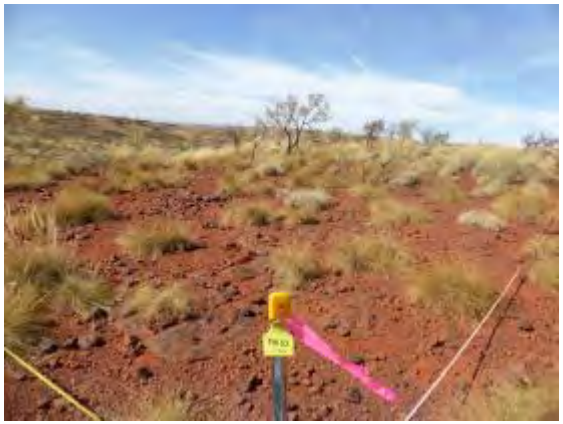
Table 11: Vegetation associations recorded for the survey area.

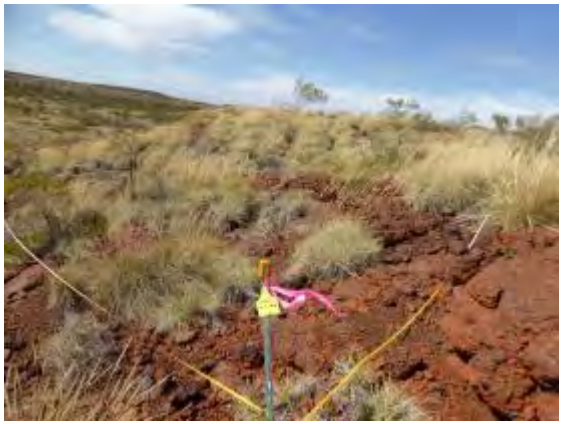
Vegetation association code and description	Sites	Vegetation Condition	Total area (ha) and area proportion (%)	Representative photograph
Mesa tops and hilltops and mesa slopes and hillslopes				
AaAbTwTspR *Acacia ancistrocarpa, A. bivenosa* scattered shrubs to open shrubland over *Triodia wiseana* (*T.* sp. Robe River (M.E. Trudgen et al. MET 12367)) open hummock grassland. **Associated species:** *Acacia tumida var. pilbarensis, A. inaequilatera, Dampiera candicans, Goodenia stobbsiana, Grevillea wickhamii, Petalostylis labicheoides* and *Ptilotus calostachyus.*	BA07, MH338, MH344, BADRr05	Excellent	60.5 (1.2%)	 **Plate 1: Vegetation representing AaAbTwTsr – facing north-west from GPS co-ordinate 421964mE and 7591753mN (MGA Zone 50).**

Vegetation association code and description	Sites	Vegetation Condition	Total area (ha) and area proportion (%)	Representative photograph
AacTw *Acacia acradenia* tall shrubland over *Triodia wiseana* hummock grassland. *Grevillea wickhamii* commonly occurs in the upper stratum where this vegetation occurs near the edge of mesas and gullies, and *A. inaequilatera* was a co-dominant species in a number of areas on the top of mesas. **Associated species:** *Acacia bivenosa, A. inaequilatera, A. trachycarpa, A. tumida* var. *pilbarensis, Cassytha capillaris, Eucalyptus leucophloia* subsp. *leucophloia, Grevillea wickhamii, Hakea chordophylla* and *Keraudrenia velutina subsp. elliptica.*	MH01, MH39, MH327, MH345, MH361	Excellent	42.9 (0.9%)	 **Plate 2: Vegetation representing AacTw – facing south-east from GPS co-ordinate 416340mE and 7597314mN (MGA Zone 50).**
AacTwTsr *Acacia acradenia* open shrubland to open heath over *Triodia wiseana* (*T.* sp. Robe River (M.E. Trudgen et al. MET 12367)) hummock grassland. **Associated species:** *Acacia inaequilatera, Gossypium robinsonii, Grevillea wickhamii* and *Triumfetta maconochieana.*	MH02, MH326, MH346	Excellent	4.8 (0.1%)	 **Plate 3: Vegetation representing AacTwTsr – facing south-east from GPS co-ordinate 415179mE and 7597153mN (MGA Zone 50).**

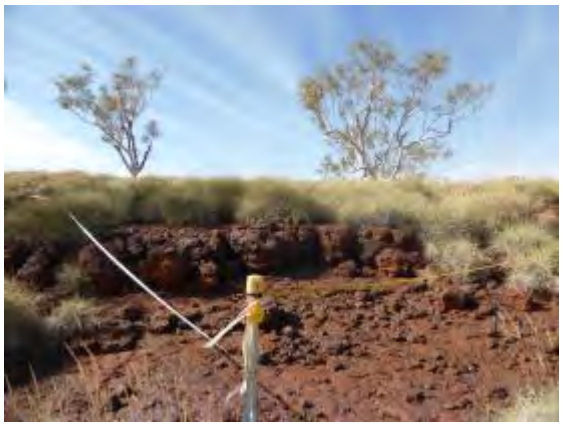
Vegetation association code and description	Sites	Vegetation Condition	Total area (ha) and area proportion (%)	Representative photograph
AbTw *Acacia bivenosa* open shrubland to open heath over *Triodia wiseana* hummock grassland. **Associated species:** *Acacia inaequilatera, A. synchronicia* and *Corymbia hamersleyana.*	BA10, BA210, MH32, MH324, MH325, MHJ303, MHJ304, MH309r	Very good - Excellent	265.5 (5.4%)	 **Plate 4: Vegetation representing AbTw – facing south-east from GPS co-ordinate 414561mE and 7597523mN (MGA Zone 50).**
AiAanTw *Acacia inaequilatera* and *A. ancistrocarpa* scattered tall shrubs to tall open shrubland over *Triodia wiseana* open hummock grassland to hummock grassland. **Associated species:** *Acacia atkinsiana, A. bivenosa, A. ptychophylla, A. trachycarpa, Grevillea wickhamii, Ptilotus calostachyus, P. nobilis* and *Triodia* sp. Robe River (M.E. Trudgen et al. MET 12367). Small stands of *Acacia pruinocarpa* can occasionally be located within this vegetation unit.	MH40, MH308, MH329, MH331, MH311r, MH330, MH343	Excellent	253.0 (5.1)	 **Plate 5: Vegetation representing AiAanTw – facing south-east from GPS co-ordinate 418157mE and 7598886mN (MGA Zone 50).**

Vegetation association code and description	Sites	Vegetation Condition	Total area (ha) and area proportion (%)	Representative photograph
AiAbTw *Acacia inaequilatera* scattered tall shrubs over *A. bivenosa* scattered shrubs over *Triodia wiseana* hummock grassland. The relative density of *A. inaequilatera* and *A. bivenosa* varied throughout this vegetation association, with one species often more dominant than the other. **Associated species:** *Acacia ancistrocarpa, A. acradenia, A. trachycarpa, Gossypium robinsonii, Grevillia pyramidalis subsp. leucadendron, Ptilotus calostachyus, P. nobilis, Senna artemisioides subsp. oligophylla, S. glutinosa subsp. glutinosa, S. notabilis, Sida* sp. Pilbara (A.A. Mitchell PRP 1543) and *Streptoglossa bubakii.*	MH07, MH19, MH319, MH328, MH377, MH334r, MHJr04	Excellent	603.0 (12.2%)	 **Plate 6: Vegetation representing AiAbTw – facing south-east from GPS co-ordinate 415639mE and 7596919mN (MGA Zone 50).**
AiAptTw *Acacia inaequilatera* scattered shrubs to scattered tall shrubs over *A. ptychophylla* scattered low shrubs to low open shrubland over *Triodia wiseana* open hummock grassland. **Associated species:** *Ptilotus astrolasius, P. calostachyus*, *Senna glutinosa* subsp. *glutinosa, S. glutinosa* subsp. *pruinosa* and *Triodia* sp. Robe River (M.E. Trudgen et al. MET 12367).	MH306, MH368, BA42a	Excellent	115.9 (2.4%)	 **Plate 7: Vegetation representing AiAptTw – facing south-east from GPS co-ordinate 419915mE and 7599310mN (MGA Zone 50).**

Vegetation association code and description	Sites	Vegetation Condition	Total area (ha) and area proportion (%)	Representative photograph
AiTwTsr *Acacia inaequilatera* scattered tall shrubs over *Triodia wiseana, T.* sp. Robe River (M.E. Trudgen et al. MET 12367) open hummock to hummock grassland. **Associated species:** A*cacia bivenosa, Cassytha capillaris, Eriachne mucronata, Goodenia stobbsiana, Grevillea pyramidalis, G. wickhamii, Hakea chordophylla, Ptilotus astrolasius* var. *astrolasius, P. calostachyus, Solanum cleistogamum, Trichodesma zeylanicum* and *Triumfetta chaetocarpa.*	MH10, MH11, MH301, MH352	Excellent	82.3 (1.7%)	 **Plate 8: Vegetation representing AiTwTsr – south-east from GPS co-ordinate 418548mE and 7593981mN (MGA Zone 50).**
AprTwTsr *Acacia pruinocarpa* low woodland over *Triodia wiseana, T.* sp. Robe River (M.E. Trudgen et al. MET 12367) open hummock grassland. **Associated species:** *Acacia tumida, Corymbia hamersleyana, Cymbopogon ambiguus, Eremophila fraseri* subsp. *fraseri, Eriachne mucronata, Eucalyptus leucophloia subsp. leucophloia, Grevillea pyramidalis, Jasminum didymum* subsp. *lineare, Mollugo molluginea, Rhyncharrhena linearis, Sarcostemma viminale, Senna stricta* and *Tephrosia uniovulata.*	MH12, MH42, MH103, MH101, MH105, MHJ309r	Very good - Excellent	15.7 (0.3)	 **Plate 9: Vegetation representing AprTwTsr – facing south-east from GPS co-ordinate 418228mE and 7594335mN (MGA Zone 50).**

Vegetation association code and description	Sites	Vegetation Condition	Total area (ha) and area proportion (%)	Representative photograph
AptTw *Acacia ptychophylla* low open shrubland over *Triodia wiseana* open hummock grassland. **Associated species:** *Acacia ancistrocarpa, A. inaequilatera, A. synchronicia, A. trachycarpa, Bulbostylis barbata, Dampiera candicans, Eriachne mucronata, Grevillea wickhamii, Hakea chordophylla, Indigofera monophylla* and *Triumfetta appendiculata.*	MH33, MH34, MH106, MH300, MH371	Excellent	71.7 (1.5%)	 **Plate 10: Vegetation representing AptTw – facing south-east from GPS co-ordinate 418720mE and 7595616mN (MGA Zone 50).**
AtuTwTsr *Acacia tumida* var. *pilbarensis* tall shrubland over *Triodia wiseana, T.* sp. Robe River (M.E. Trudgen et al. MET 12367) open hummock grassland. **Associated species:** *Acacia inaequilatera, Corymbia hamersleyana, Duperreya commixta, Eriachne mucronata, Gossypium robinsonii, Grevillea wickhamii* and *Petalostylis labicheoides.*	MH18, MH27, MH28, MH29, MH104	Very good - Excellent	29.0 (0.6%)	 **Plate 11: Vegetation representing AtuTwTsr – facing south-east from GPS co-ordinate 417922mE and 7595431mN (MGA Zone 50).**

Vegetation association code and description	Sites	Vegetation Condition	Total area (ha) and area proportion (%)	Representative photograph
ChAiAbTw *Corymbia hamersleyana* scattered low trees over *Acacia inaequilatera* scattered tall shrubs over *A. bivenosa* scattered shrubs over *Triodia wiseana* hummock grassland. This vegetation association was also recorded on plains habitat. **Associated species:** *Acacia synchronicia, Gossypium robinsonii, Ptilotus astrolasius, Senna glutinosa* subsp. *glutinosa, Stylobasium spathulatum* and *Trichodesma zeylanicum.*	MH09, MH22, MH26, MH305, MHJ301r, MH374	Very good - Excellent	800.7 (16.2%)	 **Plate 12: Vegetation representing ChAiAbTw – facing south-east from GPS co-ordinate 417168mE and 7594275mN (MGA Zone 50).**
ElAiAbTw *Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Acacia inaequilatera* scattered tall shrubs over *A. bivenosa* scattered shrubs to open shrubland over *Triodia wiseana* hummock grassland. **Associated species:** *Acacia acradenia, A. synchronicia, Corymbia hamersleyana, Cymbopogon ambiguus, Hakea chordophylla* and *Senna glutinosa* subsp. *glutinosa.*	MH31, GBR23, MH342, MH359	Excellent	56.7 (1.2%)	 **Plate 13: Vegetation representing ElAiAbTw – facing south-east from GPS co-ordinate 418236mE and 7598271mN (MGA Zone 50).**

Vegetation association code and description	Sites	Vegetation Condition	Total area (ha) and area proportion (%)	Representative photograph
ElAiTwTsr *Eucalyptus leucophloia* subsp. *leucophloia* low open woodland over *Acacia inaequilatera* scattered tall shrubs over *Triodia wiseana* (*T.* sp. Robe River (M.E. Trudgen et al. MET 12367) on breakaways) open hummock grassland. **Associated species:** *Acacia orthocarpa, Cassytha capillaris, Cymbopogon ambiguus, Eriachne mucronata, Hakea chordophylla, Senna venusta, Sida* sp. Articulation below (A.A. Mitchell PRP1605) and *Tephrosia uniovulata.*	MH35, MH314, MHr200, MH396	Very good - Excellent	70.0 (1.4%)	 **Plate 14: Vegetation representing ElAiTwTsr – facing south-east from GPS co-ordinate 417219mE and 7595183mN (MGA Zone 50).**
ElTw *Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees to low open woodland over *Triodia wiseana* very open hummock grassland. **Associated species:** *Acacia tumida* var. *pilbarensis, Bonamia pilbarensis, Cymbopogon ambiguus, Cyperus cunninghamii, Eriachne mucronata, Triodia* sp. Robe River (M.E. Trudgen et al. MET 12367).	MH36, MH37, MH41, MH399r, MH360r, MH313	Excellent	24.0 (0.5%)	 **Plate 15: Vegetation representing ElTw – facing south-east from GPS co-ordinate 416152mE and 7596637mN (MGA Zone 50).**

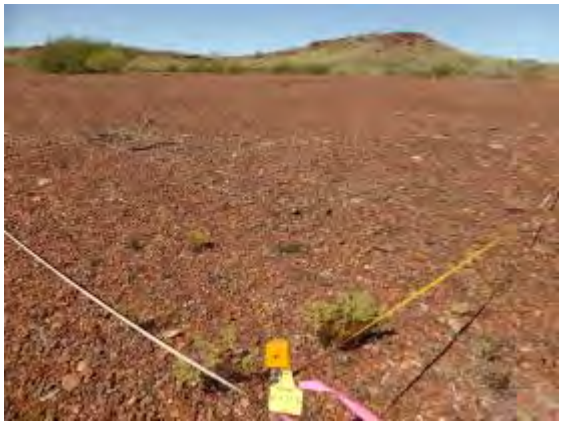
Vegetation association code and description	Sites	Vegetation Condition	Total area (ha) and area proportion (%)	Representative photograph
Tw *Triodia wiseana* open hummock grassland. **Associated species:** *Acacia bivenosa, A. inaequilatera, Bonamia pilbarensis, Corchorus lasiocarpus* subsp. *parvus, Grevillea wickhamii, Hakea chordophylla, Sida* sp. Pilbara (A.A. Mitchell PRP 1543).	MH17, MH312, MH365, MH375r	Excellent	23.1 (0.5%)	 **Plate 16: Vegetation representing Tw – facing south-east from GPS co-ordinate 416369mE and 7594935mN (MGA Zone 50).**

Vegetation association code and description	Sites	Vegetation Condition	Total area (ha) and area proportion (%)	Representative photograph
Major and Minor Drainage				
AtrPl *Acacia trachycarpa, Petalostylis labicheoides* tall open scrub. **Associated species:** *Acacia ancistrocarpa, A. bivenosa, A. pyrifolia var. pyrifolia, *Cenchrus ciliaris, Euphorbia schultzii, Ptilotus astrolasius* var. *astrolasius, P. nobilis, Tephrosia rosea* var. Fortescue Creeks (M.I.H Brooker 2186), *Triodia wiseana* and *T. epactia.*	MH203, MH321, MH354	Very good - Excellent	78.6 (1.6%)	 **Plate 17: Vegetation representing AtrPl – facing south-east from GPS co-ordinate 418754mE and 7598544mN (MGA Zone 50).**

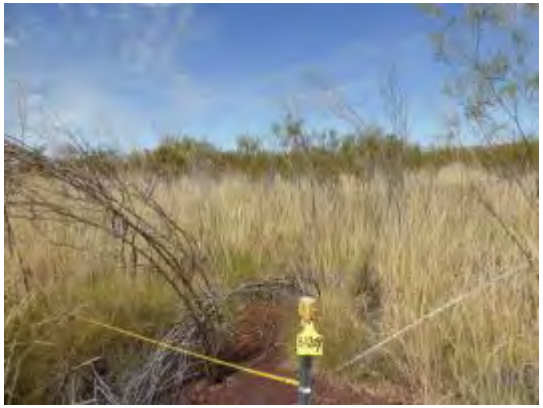
Vegetation association code and description	Sites	Vegetation Condition	Total area (ha) and area proportion (%)	Representative photograph
CcTeTw *Corymbia candida* low woodland over *Triodia epactia* and/or *T. wiseana* open hummock grassland. **Associated species:** *Abutilon* sp. Dioicum (A.A. Mitchell PRP 1618), *Acacia ancistrocarpa, A. colei* var. *ileocarpa, A. synchronicia, Goodenia forrestii, Gossypium australe, Ptilotus appendiculatus, Senna artemisioides* subsp. *oligophylla, Sesbania cannabina* and *Sida rohlenae.*	BA21, BA22, MH404	Good - Very good	10.4 (0.2%)	 **Plate 18: Vegetation representing CcTeTw – facing south-east from GPS co-ordinate 422756mE and 7591364mN (MGA Zone 50).**
ChAsppGOrGsppPlSsTeTw *Corymbia hamersleyana* scattered low trees to low open woodland over *Acacia* spp., *Gossypium robinsonii, Grevillea* spp., *Petalostylis labicheoides, Stylobasium spathulatum* tall shrubland over *Triodia epactia, T. wiseana* hummock grassland. **Associated species:** *Acacia ancistrocarpa, A. bivenosa, A. inaequilatera, A. pyrifolia, A. trachycarpa, A. tumida* var. *pilbarensis, *Cenchrus ciliaris, Grevillea robinsonii, G. pyramidalis* subsp. *leucadendron, Hybanthus aurantiacus, Indigofera monophylla, Jasminum didymum* subsp. *lineare, Pentalepis trichodesmoides, Senna artemisioides subsp. oligophylla* and *Tephrosia* sp. Fortescue (A.A. Mitchell 606).	MH24, MH30, MH38, MH376	Good - Excellent	135.3 (2.7%)	 **Plate 19: Vegetation representing ChAsppGOrGsppPlSsTeTw – facing south-east from GPS co-ordinate 418405mE and 7596289mN (MGA Zone 50).**

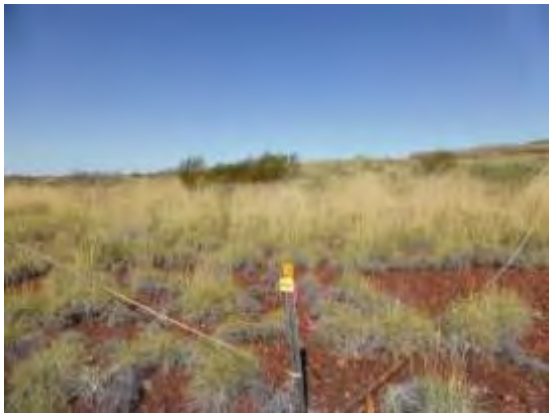
Vegetation association code and description	Sites	Vegetation Condition	Total area (ha) and area proportion (%)	Representative photograph
ChAtuTe *Corymbia hamersleyana* scattered low trees over *Acacia tumida* var. *pilbarensis* tall open scrub over *Triodia epactia* open hummock grassland to hummock grassland. **Associated species:** *Acacia ancistrocarpa, Corchorus lasiocarpus* subsp. *parvus, Euphorbia australis* var. *subtomentosa, Grevillea wickhamii, Isotropis atropurpurea, Petalostylis labicheoides Ptilotus astrolasius, P. calostachyus, Rhynchosia minima*, *Stylobasium spathulatum* and *Tephrosia uniovulata*.	MH406, MH405	Excellent	28.7 (0.6%)	 **Plate 20: Vegetation representing ChAtuTe – facing south-east from GPS co-ordinate 415894mE and 7596615mN (MGA Zone 50).**
ChAtuTw *Corymbia hamersleyana* and/or *Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Acacia tumida* var. *pilbarensis* tall open scrub over *Triodia wiseana* open hummock grassland. *Grevillea wickhamii* is characteristic where this vegetation occurs on mesas. **Associated species:** *Acacia ancistrocarpa, A. bivenosa, A. inaequilatera, A. pyrifolia* var. *pyrifolia, Cassytha capillaris, Cymbopogon ambiguus, Grevillea wickhamii, Indigofera monophylla, Petalostylis labicheoides, Ptilotus fusiformis, Rhynchosia minima, Triodia epactia, T.* sp. Robe River (M.E. Trudgen et al. MET 12367) P3 and *Triumfetta maconochieana.*	BA32, BAKM15, MH317, MH318, MH400	Excellent	197.1 (4%)	 **Plate 21: Vegetation representing ChAtuTw – facing south-east from GPS co-ordinate 415894mE and 7596615mN (MGA Zone 50).**

Vegetation association code and description	Sites	Vegetation Condition	Total area (ha) and area proportion (%)	Representative photograph
ChPlAbGOrTw *Corymbia hamersleyana* low open woodland over *Petalostylis labicheoides, Acacia bivenosa, Gossypium robinsonii* tall open scrub over *Triodia wiseana* (*T. angusta*) open hummock grassland. **Associated species:** *Cassytha capillaris, Codonocarpus cotinifolius, Corchorus crozophorifolius, C. lasiocarpus* subsp. *parvus* and *Stylobasium spathulatum.*	MH315, MH316, MH357	Excellent	20.5 (0.4%)	 **Plate 22: Vegetation representing ChPlAbGOrTw – facing south-east from GPS co-ordinate 417426mE and 7595042mN (MGA Zone 50).**
EcEvAtrApyPlTw *Eucalyptus camaldulensis* subsp. *refulgens* woodland over *E. victrix* low woodland over *Acacia trachycarpa, A. pyrifolia* var. *pyrifolia, Petalostylis labicheoides* tall open shrubland over mixed open herbland and *Triodia wiseana* scattered hummock grasses. **Associated species:** *Acacia ancistrocarpa, A. bivenosa, A. colei, A. trachycarpa, *Cenchrus ciliaris, *C. setiger, Cyperus vaginatus, Eulalia aurea, Melaleuca argentea, M. glomerata* and *Typha domingensis.*	MH43, MH44, MH303, MH373	Poor - Good	311.6 (6.3%)	 **Plate 23: Vegetation representing EcEvAtrApyPlTw – facing south-east from GPS co-ordinate 419534mE and 7595539mN (MGA Zone 50).**

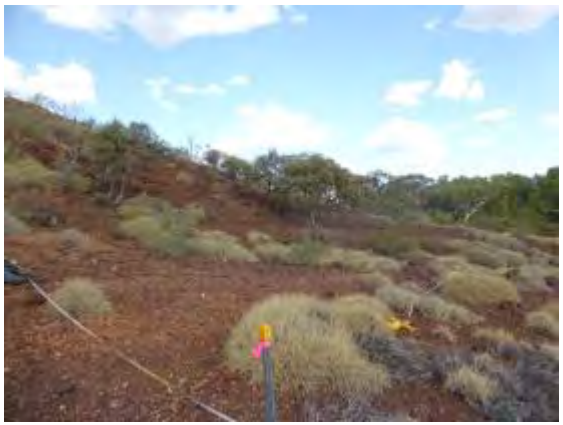
Vegetation association code and description	Sites	Vegetation Condition	Total area (ha) and area proportion (%)	Representative photograph
Es *Euphorbia schultzii* scattered herbs. **Associated species***: Acacia trachycarpa, Hybanthus aurantiacus, Ptilotus incanus, Ipomoea muelleri* and **Argemone ochroleuca* subsp. *ochroleuca.*	MH394, MH397, MH398	Very good - Excellent	66.5 (1.3%)	 **Plate 24: Vegetation representing Es – facing south-east from GPS co-ordinate 416275mE and 7597984mN (MGA Zone 50).**
EvAtrTwCspp *Eucalyptus victrix* low open woodland over *Acacia trachycarpa* tall open shrubland over *Triodia wiseana* open hummock grassland and **Cenchrus* spp. very open tussock grassland. **Associated species***: Acacia bivenosa, A. pyrifolia* var. *pyrifolia, Boerhavia coccinea, Gossypium robinsonii, Rhynchosia minima, Triumfetta appendiculata* and *Waltheria indica*.	MH392, MH393, MH401	Good	55.3 (1.1%)	 **Plate 25: Vegetation representing EvAtrTwCspp – facing south-east from GPS co-ordinate 424501mE and 7592735mN (MGA Zone 50).**

Vegetation association code and description	Sites	Vegetation Condition	Total area (ha) and area proportion (%)	Representative photograph
MaEcCv *Melaleuca argentea, Eucalyptus camaldulensis* subsp. *refulgens* open forest over *Cyperus vaginatus* scattered sedges to very open sedgeland. **Associated species:** *Acacia trachycarpa, *Cenchrus ciliaris, Eucalyptus victrix, *Passiflora foetida subsp. hispida, Petalostylis labicheoides*, *Rhynchosia bungarensis, Tephrosia rosea* var. Fortescue Creeks (M.I.H. Brooker 2186) and *Vigna lanceolata.*	MH204, MH332, MH337r MH363	Very good - Excellent	147.4 (3%)	 **Plate 26: Vegetation representing MaEvCv – facing south-east from GPS co-ordinate 414398mE and 7597069mN (MGA Zone 50).**
TspFCAoTe *Tephrosia rosea* var. Fortescue creeks (M.I.H. Brooker 2186) low open shrubland to low open heath over *Triodia epactia* scattered hummock grasses to very open hummock grassland, with **Argemone ochroleuca* subsp. *ochroleuca* scattered herbs. **Associated species:** *Acacia pyrifolia* var. *pyrifolia, Corymbia hamersleyana, Gossypium robinsonii, Grevillea wickhamii, Indigofera monophylla, Pentalepis trichodesmoides, Stylobasium spathulatum* and *Trachymene oleracea* subsp. *oleracea.*	MHJ305, MHJ306, MH364	Good - Excellent	9.9 (0.2%)	 **Plate 27: Vegetation representing TspFCAoTe – south-east from GPS co-ordinate 419638mE and 7592816mN (MGA Zone 50).**

Vegetation association code and description	Sites	Vegetation Condition	Total area (ha) and area proportion (%)	Representative photograph
Plains				
AaTeTw *Acacia ancistrocarpa* tall open shrubland over *Triodia epactia, T. wiseana* hummock grassland. **Associated species:** *Acacia bivenosa, A. inaequilatera, A. synchronicia, Corymbia hamersleyana, Eragrostis cumingii, Gossypium australe, Grevillea wickhamii, Indigofera colutea, Senna artemisioides* subsp. *helmsii* and *Stylobasium spathulatum.*	BA111, BA209, MH348	Very good - Excellent	27.6 (0.6%)	 **Plate 28: Vegetation representing AaTeTw – facing south-east from GPS co-ordinate 422677mE and 7590737mN (MGA Zone 50).**

Vegetation association code and description	Sites	Vegetation Condition	Total area (ha) and area proportion (%)	Representative photograph
AiAaAbTw *Acacia inaequilatera, A. bivenosa, A. ancistrocarpa* open shrubland over *Triodia wiseana* open hummock grassland. **Associated species:** *Acacia pyrifolia* var. *pyrifolia, Corymbia hamersleyana, Hakea lorea* subsp. *lorea, Ptilotus nobilis, Senna artemisioides* subsp. *oligophylla, Stylobasium spathulatum* and *Triodia epactia.*	BA219, MH339, MH350, BUN06	Very good - Excellent	193.2 (3.9%)	 **Plate 29: Vegetation representing AiAaAbTw – facing south-east from GPS co-ordinate 422704mE and 7589575mN (MGA Zone 50).**
AsAbTwCspp *Acacia synchronicia, A. bivenosa* tall open shrubland over *Triodia wiseana* very open hummock grassland and **Cenchrus ciliaris*, **C. setiger* open tussock grassland. **Associated species:** *Acacia ancistrocarpa, A. sclerosperma* subsp. *sclerosperma, A. trachycarpa, Petalostylis labicheoides, Sclerolaena costata, Senna notabilis* and *Triodia epactia.*	MH05, MH06, MH322, MH370	Very poor - Good	41.2 (0.8%)	 **Plate 30: Vegetation representing AsAbTwCspp – facing south-east from GPS co-ordinate 420586mE and 7596886mN (MGA Zone 50).**

Vegetation association code and description	Sites	Vegetation Condition	Total area (ha) and area proportion (%)	Representative photograph
AsTe *Acacia synchronicia* scattered shrubs over *Triodia epactia* hummock grassland. *Corymbia candida* is often a dominant upper stratum species in the lower-lying areas of this vegetation association. **Associated species:** **Cenchrus ciliaris*, **C. setiger*, *Dactyloctenium radulans*, *Euphorbia boophthona*, *Ptilotus appendiculatus*, *Ptilotus nobilis, Rhynchosia minima, Sclerolaena costata, Senna artemisioides subsp. oligophylla, Streptoglossa decurrens* and *Trianthema triquetrum.*	MH402, MH403, MH408	Good – Very good	190.8 (3.9%)	 **Plate 31: Vegetation representing AsTe – facing south-east from GPS co-ordinate 415410mE and 7598434mN (MGA Zone 50).**
AsTw *Acacia synchronicia* open shrubland over *Triodia wiseana* open hummock grassland. **Associated species:** *Aristida contorta, *Cenchrus ciliaris, *C. setiger, Ptilotus astrolasius* var. *astrolasius, P. auriculifolius, P. nobilis, Senna artemisioides* subsp. *oligophylla* and *Trianthema triquetrum.*	MH21, MH100, MH353	Very good - Excellent	47.2 (1%)	 **Plate 32: Vegetation representing AsTw – facing south-east from GPS co-ordinate 415589 mE and 7598719 mN (MGA Zone 50).**

Vegetation association code and description	Sites	Vegetation Condition	Total area (ha) and area proportion (%)	Representative photograph
AxTe *Acacia xiphophylla* tall open shrubland over *Triodia epactia* (*T. wiseana*) very open hummock grassland. **Associated species:** *Acacia ancistrocarpa, A. synchronicia, Gossypium australe, Hakea lorea* subsp. *lorea, Ptilotus nobilis, Senna artemisioides* subsp. *oligophylla, Salsola australis* and *Triodia wiseana.*	BA18, MH407, MH409	Very good	32.3 (0.6%)	 **Plate 33: Vegetation representing AxTe – facing south-east from GPS co-ordinate 422624mE and 7591284mN (MGA Zone 50).**
AxTw *Acacia xiphophylla* low woodland to tall shrubland over *Triodia wiseana* open hummock grassland. **Associated species:** *Acacia ancistrocarpa, A. bivenosa, A. pruinocarpa, A. synchronicia, A. tumida* var. *pilbarensis, *Cenchrus setiger, Cymbopogon ambiguus, Hakea chordophylla, Ptilotus auriculifolius, P. nobilis, Sclerolaena costata, Senna artemisioides subsp. oligophylla, S. glutinosa* subsp. *glutinosa* and *S. glutinosa* subsp. *x luerssenii.*	MH20, MH200, MH335	Very good - Excellent	13.1 (0.3%)	 **Plate 34: Vegetation representing AxTw – facing south-east from GPS co-ordinate 415410mE and 7598434mN (MGA Zone 50).**

Vegetation association code and description	Sites	Vegetation Condition	Total area (ha) and area proportion (%)	Representative photograph
CcAsppTeTwCEc *Corymbia candida* scattered low trees over mixed *Acacia* species tall open shrubland over *Triodia wiseana* and *T. epactia* very open hummock grassland to open hummock grassland, with **Cenchrus setiger* scattered tussock grasses to very open tussock grassland to hummock grassland. **Associated species:** *Acacia ancistrocarpa, A. bivenosa, A. synchronicia, A. trachycarpa, A. inaequilatera, Goodenia forrestii, Gossypium australe, Petalostylis labicheoides, Ptilotus astrolasius* and *Senna artemisioides* subsp. *oligophylla.*	MH307, MH333r, MH395	Good - Very good	28.4 (0.6%)	 **Plate 35: Vegetation representing CcAsppTeTwCEc – facing south-east from GPS co-ordinate 419057mE and 7598866mN (MGA Zone 50).**
ChAbTwTe *Corymbia hamersleyana* scattered low trees to low woodland over *Acacia bivenosa* open shrubland over *Triodia wiseana, T. epactia* hummock grassland. **Associated species:** *Acacia ancistrocarpa, A. inaequilatera, A. synchronicia, A. trachycarpa, Cucumis maderaspatanus, Gossypium australe, Hakea chordophylla, Jasminum didymum* subsp. *lineare, Lysiana casuarinae, Ptilotus astrolasius* var. *astrolasius, Scaevola spinescens, Senna notabilis* and *Stylobasium spathulatum.*	MH25, MH302, MH320, MHJ302, MHJr02, MHJr06, MH356	Good - Excellent	126.9 (2.6%)	 **Plate 36: Vegetation representing ChAbTwTe – facing south-east from GPS co-ordinate 419372mE and 7594494mN (MGA Zone 50).**

Vegetation association code and description	Sites	Vegetation Condition	Total area (ha) and area proportion (%)	Representative photograph
ChTe *Corymbia hamersleyana* scattered low trees to low open woodland over *Triodia epactia* open hummock grassland. **Associated species:** *Acacia ancistrocarpa, A. bivenosa, A. synchronicia, *Cenchrus ciliaris, Eragrostis eriopoda, Hakea chordophylla, Ptilotus axillaris* and *Triodia wiseana.*	MH310, MH336, MH358	Very good - Excellent	46.8 (0.9%)	 **Plate 37: Vegetation representing ChTe – facing south-east from GPS co-ordinate 415983mE and 7599288mN (MGA Zone 50).**

4.2.1.1 Vegetation Condition

Vegetation in the survey area ranged from 'very poor' to 'excellent' (Trudgen 1988) condition (Table 12; Figure K.1, Appendix K). Vegetation of the slopes and crests of the low hills was generally of high quality ('excellent' condition), with almost no weeds present nor signs of grazing. Vegetation of the plains and drainage lines typically occurred on deeper soils and weed species such as **Argemone ochroleuca* subsp. *ochroleuca* (Mexican Poppy) and **Cenchrus* spp. (Buffel and Birdwood Grasses) were a typical component of this vegetation. Grazing from cattle was also evident in these habitats. The density of weed species, in particular **Cenchrus* spp. and **A. ochroleuca* subsp. *ochroleuca,* varied considerably between season and grazing pressure (Plate 38 and Plate 39).

Plate 38: Weed cover in Jimmawarruda Creek in dry conditions and post-grazing.

Plate 39: Weed cover in Jimmawarruda Creek following rainfall.

An extensive network of drill lines, drill pads and tracks exists within the survey area. Rail lines occur in the northern and south-eastern parts of the survey area. Together this 'disturbed' vegetation accounts for approximately 367 ha (7 %) in the survey area. A number of colonising annual species were observed regenerating on some of these tracks, but most remained cleared of vegetation.

Table 12: Vegetation condition recorded for the survey area, based on the Trudgen (1988) scale.

Vegetation condition	Total mapped area within the survey area (ha)	Proportion of the survey area (%)
Excellent	3309.6	67
Very Good	657.2	13
Good	500.9	10
Poor	93.6	2
Very Poor	1.6	<1
Disturbed	367.3	7

4.2.1.2 Conservation Significance of Vegetation

No TECs were recorded in the survey area.

Vegetation representing the PEC '*Triodia sp. Robe River assemblages of mesas of the West Pilbara*' was recorded at the northern extent of the survey area in association with a mesa landform, where *Acacia pruinocarpa* occurred in conjunction with *T.* sp. Robe River (M.E. Trudgen et al. MET 12367)

P3 (Plate 40). This vegetation, mapped as AprTwTsr, covered an area of approximately 15.7 ha, representing 0.3% of the survey area. The abundance of *T.* sp. Robe River (M.E. Trudgen et al. MET 12367) varied across the delineated polygons for this vegetation unit. For example, the areas containing quadrats MH101 and MH105 have been mapped as AprTwTsr due to *Acacia pruinocarpa* and *T.* sp. Robe River (M.E. Trudgen et al. MET 12367) co-existing, even though *T.* sp. Robe River (M.E. Trudgen et al. MET 12367) was not a dominant species at those particular sites.

A number of permanent and semi-permanent pools occurred within the flow channels of the Robe River, inside the survey area. These areas supported an assemblage of species unique from other habitats and generally supported a high diversity of flora species. These pools occurred within vegetation association MaEcCv which covered 147.4 ha, representing 3% of the survey area, and distributed in the northern and western parts of the survey area (Plate 41).

Plate 40: Vegetation representing the *Triodia* sp. Robe River PEC.

Plate 41: Vegetation dominated by *Melaleuca argentea* and *Eucalyptus camaldulensis* subsp. *refulgens* surrounding a water pool in the Robe River.

Three species which may be considered indicator species for Groundwater Dependent Ecosystems (GDE) were recorded within the rivers and larger creeks of the survey area. *Melaleuca argentea* and *Eucalyptus camaldulensis* subsp. *refulgens* are the dominant upper stratum species of MaEcCv, and *E. camaldulensis* subsp. *refulgens* and *Eucalyptus victrix* are the dominant upper stratum species of EcEvAtrApyPlTw. The vegetation mapped as EcEvAtrApyPlTw covered approximately 311 ha, and represents 6.3% of the survey area. *Melaleuca argentea* is considered an obligate phreatophyte and therefore highly dependent on groundwater, while *E. camaldulensis* subsp. *refulgens* and *E. victrix* are facultative phreatophytes and use groundwater opportunistically during periods of drought or some life stages.

The remaining vegetation associations recorded in the survey area are considered typical of what may be expected on similar landforms in the broader Hamersley subregion.

4.2.1.3 Floristic Groups

Based on classification analysis, there were 32 significant floristic groups identified within the survey area. Of the 154 sites assessed from the survey area, all except six grouped with other survey sites. These six sites are therefore considered to be statistically distinct at a floristic level Table 13. These sites showed structural and floristic similarities with other quadrats and relevés within the survey area at the vegetation association level. Both survey sites and vegetation associations from similar landforms generally grouped together in the classification analysis. The results of the floristic analysis are presented in Appendix L.

Table 13: Floristic groups identified by one site in the survey area and corresponding vegetation association.

Quadrat/ relevé	Quadrat/relevé description	Structural vegetation association
MH27	*Acacia tumida* var. *pilbarensis* and *Grevillea wickhamii*, tall open scrub over *Petalostylis labicheoides* scattered shrubs over *Triodia wiseana* hummock grassland.	AtuTwTsr
MH302	*Corymbia hamersleyana* scattered low trees over *Stylobasium spathulatum*, *Acacia trachycarpa, A. pyrifolia* tall open shrubland over *Grevillea pyramidalis* subsp. *leucadendron, Abutilon* sp. Dioicum (A.A. Mitchell PRP 1618) scattered shrubs over *Triodia epactia* open hummock grassland and **Cenchrus setiger* scattered tussock grasses.	ChAbTwTe
MH325	*Acacia bivenosa* open shrubland over *Triodia wiseana* hummock grassland.	AbTw
MH350	*Acacia inaequilatera* and *A. ancistrocarpa* tall open shrubland over *A. bivenosa* open shrubland over *Triodia wiseana* hummock grassland.	AiAaAbTw
MH357	*Corymbia hamersleyana* low open woodland over *Petalostylis labicheoides* and *Gossypium robinsonii* tall open shrubland over *Triodia wiseana* and *T. angusta* open hummock grassland.	ChPlAbGOrTw
MH375r	*Triodia wiseana* and *T.* sp. Robe River (M.E. Trudgen et al. MET 12367) open hummock grassland.	Tw

Site MH302 occurs adjacent to a drainage line that has been truncated due to the Mesa J mine, approximately 500 m upstream. Two tracks also occur immediately east, and approximately 300 m south, of the quadrat. Water discharge has been noted to occur in this drainage line, causing short-term inundation and increasing frequency of cattle grazing. The combined effects of these disturbances have increased the floristic diversity of this site compared to other similar sites in the survey area, with a particularly high diversity of weed species.

Sites MH27, MH325, MH350 and MH357 each had at least two or three species that may be considered unusual for the vegetation type and/or landform. For some sites this may have been due to the placement of the quadrats capturing some species from adjacent vegetation types; site MH357, however, had been burnt within an estimated 2 to 5 years and therefore some coloniser species were recorded.

Site MH375r was surveyed during only one phase and had only three species recorded, which is considerably lower than the average floristic diversity for other sites. This is likely to be attributed to its exposed rocky hillslope landform and associated shallow soils.

There were 110 statistically significant clusters identified from the regional analysis, 22 of which consisted of only a single quadrat or relevé (Appendix L). Four significant clusters were represented by a single quadrat or relevé from the survey area. One site, MH302, is statistically significant at both a regional and within-project scale. Three of the single-site clusters were statistically significant at a regional scale, but not at a project scale, indicating that they had a similar assemblage of species to other sites in the survey area (Table 14). The remaining 88 clusters consisted of multiple survey sites.

Table 14: Floristic groups identified by one site in the regional analysis and corresponding vegetation association.

Quadrat	Quadrat description	Structural vegetation association
MH18	*Corymbia hamersleyana* low open woodland over *Acacia tumida* var. *pilbarensis* tall shrubland over *Triodia wiseana* and *T.* sp Robe River (M.E. Trudgen et al. MET 12367) P3 open hummock grassland.	AtuTwTsr
MH203	*Acacia trachycarpa, Petalostylis labicheoides* and *A. bivenosa* tall open scrub.	AtrPl
MH302	*Corymbia hamersleyana* scattered low trees over *Stylobasium spathulatum, Acacia trachycarpa, A. pyrifolia* tall open shrubland over *Grevillea pyramidalis* subsp. *leucadendron, Abutilon* sp. Dioicum (A.A. Mitchell PRP 1618) scattered shrubs over *Triodia epactia* open hummock grassland and **Cenchrus setiger* scattered tussock grasses.	ChAbTwTe
MH315	*Corymbia hamersleyana* scattered low trees over *Acacia bivenosa* and *Gossypium robinsonii* open shrubland over *Triodia wiseana* very open hummock grassland.	ChPlAbGOrTw

Site MH18 occurs in a gully and has a species assemblage that would be considered a mix of typical drainage line flora, combined with *Triodia wiseana* and *T.* sp. Robe River (M.E. Trudgen et al MET 12367) P3 as the dominant species at lower stratum, which are both considered common to hillslopes and the crests of mesas in the region. Site MH315 also occurs in a gully and has *T. wiseana* as the dominant species at the lower stratum. Here, there were some less common species recorded such as *Pimelea ammocharis* and *Heliotropium pachyphyllum*. Five species were recorded in MH203 that were not otherwise recorded in the sparsely vegetated AtrPl association. As previously noted, multiple disturbances at the location of MH302 resulted in higher species diversity causing this site to be identified during floristic analysis.

4.2.2 Flora

There were 310 plant species from 53 families and 150 genera confirmed in the survey area. A further 36 specimen collections were unable to have identification confirmed to species level and therefore may represent additional taxa. A species list and a site by species matrix for the survey area are presented, respectively, in Tables M.1 and M.2 (Appendix M). A combined species list, tabling flora species from both the current and previous surveys reviewed as part of this assessment, is also presented in Table M.3 (Appendix M). The dominant plant family was Fabaceae, with 58 species confirmed, while *Acacia* was the most frequently recorded genus (Table 15). Six taxonomically distinct species have not been previously recorded within or adjacent to the survey area (Table M.3, Appendix M) (Astron Environmental Services 2014; Biota Environmental Sciences 2003, 2006a, 2011; Astron Environmental Services 2016a, 2016b, 2011; Biota Environmental Sciences 2012; Rio Tinto Iron Ore 2014).

Table 15: Families and genera with the greatest number of taxa in the survey area.

Family	Number of taxa
Fabaceae	58
Poaceae	36
Malvaceae	35
Genus	**Number of taxa**
Acacia	21
Ptilotus	12
Senna	10

4.2.2.1 Conservation Significant Flora

No State or Commonwealth listed Threatened flora were recorded, or are likely to occur, within the survey area.

Targeted searches in potential habitat within the survey area identified three state-listed Priority flora species: *I.* sp. Bungaroo Creek (S. van Leeuwen 4301) P3, *T.* sp. Robe River (M.E. Trudgen et al. MET 12367) P3 and *R. bungarensis* P4. Habitat and abundance details for these species are summarised in the below text and Table 16. Detailed location information and abundance data for each recorded occurrence, for both this survey and previous surveys, along with representative photographs of each species, are presented in Tables N.1-N.6 (Appendix N). Conservation significant flora locations, for both this survey and previous surveys, are also mapped in Figure N.1.A (Appendix N).

One population of *I.* sp. Bungaroo Creek (S. van Leeuwen 4301) P3 was recorded from the eastern side of the survey area, from one vegetation association. The 20 *I.* sp. Bungaroo Creek (S. van Leeuwen 4301) P3 individuals were recorded from the floodplain of a tributary of the Robe River. *Indigofera* sp. Bungaroo Creek (S. van Leeuwen 4301) P3 has not been previously observed within the survey area, however has been recorded in surrounding areas, particularly in association with the Bungaroo Valley and Bungaroo Creek, immediately to the south (Astron Environmental Services 2016a).

Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3 was observed at several locations associated with the uplands of the survey area, with approximately 68,000 individuals recorded from 24 vegetation associations. Individuals were predominantly recorded along rocky slopes and crests of low hills, occasionally also occurring within rocky drainage gullies. The majority of individuals were recorded from vegetation associations AiAanTw, AiAptTw, AiTwTsR and ChAiAbTw. It was typically recorded in conjunction with *T. wiseana* in the lower stratum of vegetation. *Triodia* sp. Robe River (M.E. Trudgen et al. MET 12367) P3 has previously been recorded within the survey area (Astron Environmental Services 2014; Biota Environmental Sciences 2003).

An estimated 2,500 individuals of *R. bungarensis* P4 were recorded in the survey area, typically occurring in the Robe River. *Rhynchosia bungarensis* P4 was generally recorded from densely shaded vegetation in the river channels, under *E. camaldulensis* subsp. *refulgens* and *M. argentea* woodlands and forests. Although recorded from 15 vegetation associations, approximately 60% of records were associated with MaEcCv and a further 15% from EcEvAtrApyPlTw. *Rhynchosia bungarensis* P4 has previously been recorded within the survey area; and also adjacent to and in close proximity to the survey area (Astron Environmental Services 2016a, 2016b; Biota Environmental Sciences 2003, 2006a, 2007, 2011).

Table 16: Conservation significant flora recorded in the survey area.

Species	Estimated abundance	Habitat	Vegetation association/s
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301) P3	20	Floodplain of major creek	ChAsppGOrGsppPlSsTeTw
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	68,000	Crests and upper slopes of mesas, gullies/gorges	AacTw, AacTwTsr, AbTw, AiAaAbTw, AiAanTw, AiAbTw, AiAptTw, AiTwTsr, AprTwTsr, AsAbTwCspp, AsTw, AtuTwTsr, ChAbTwTe,ChAsppGOrGsppPlSsTeTw, ChAiAbTw, ChAtuTe, ChAtuTw, ChPlAbGOrTw, ElAiAbTw, ElAiTwTsr, ElTw, EvAtrTwCspp, TspFcAoTe, Tw
Rhynchosia bungarensis P4	2,500	Major drainage (Robe River)	AiAbTw, AptTw, AiTwTsr, AtrPl, ChAbTwTe, ChAsppGOrGsppPlSsTeTw, ChAtuTw, ChPlAbGOrTw, EcEvAtrApyPlTw, ElAiAbTw, ElAiTwTsr, Es, EvAtrTwCspp, MaEcCv, TspFCAoTe

4.2.2.2 Post-survey Likelihood of Occurrence of Conservation Significant Flora

Following the survey, and with greater understanding of the landforms, soils and habitats of the survey area, four priority flora species, *Triodia* sp. Pannawonica (B.M. Anderson & M.D. Barrett BMA 89) P1, *Euphorbia australis* var. *glabra* P2, *S. weeliwolli* P2 and *E. surreyana* P3 are considered to have potential to occur but were not recorded. These species have been previously recorded in close proximity to the survey area and suitable habitat for these species was identified within the survey area. If present, these species may have gone unnoticed due to their small habit and likely absence of flowers at the time of survey. None of these species would be restricted to the survey area if present, as indicated by the voucher records listed with the WAHerb (Western Australian Herbarium 1998-2016). Survey effort, as shown by tracklog traverses within the survey area, is presented in Figure O.1 (Appendix O).

4.2.2.3 Range Extensions

Although there are records in the Pilbara region, three species recorded in the survey area (*Cynanchum pedunculatum, Sauropus crassifolius* and *Senna* sp. Meekatharra (E. Bailey 1-26)) were beyond their normal range of occurrence and are therefore considered outliers. A single specimen of each of these species was observed. *Cynanchum pedunculatum* is a prostrate twining perennial species that was recorded from a floodplain on the eastern side of the survey area, near the Mesa J mine. *Sauropus crassifolius* is a small perennial shrub that was recorded from a steep-sided gully in the southern part of the survey area. *Senna* sp. Meekatharra (E. Bailey 1-26) is a perennial shrub that was recorded from the alluvial plains in the south-eastern part of the survey area.

4.2.2.4 Introduced Flora

Weed diversity in the survey area is considered high with 20 weed species recorded. Habitat and abundance details for these species are summarised in Table 17. All recorded weeds are not listed as declared pests under the BAM Act, or as a WoNS (Australian Weeds Committee 2012). The recorded

locations within the survey area and a description of each weed are presented in Tables N.7 and N.13 (Appendix N).

Table 17: Introduced flora species (weeds) recorded during the survey.

Species	Family	Estimated abundance	Habitat
**Aerva javanica* (Kapok Bush)	Amaranthaceae	2,050	Disturbed, major and minor drainage, plains
**Argemone ochroleuca* subsp. *ochroleuca* (Mexican Poppy)	Papaveraceae	7,000	Disturbed, major and minor drainage
**Bidens bipinnata* (Bipinnate Beggartick)	Asteraceae	600	Major and minor drainage
**Cenchrus ciliaris* (Buffel Grass)	Poaceae	75,200	Disturbed, plains, major and minor drainage
**Cenchrus setiger* (Birdwood Grass)	Poaceae	86,000	Disturbed, major and minor drainage, plains
**Chloris barbata* (Purpletop Chloris)	Poaceae	50	Disturbed, major and minor drainage, plains
**Citrullus colocynthis* (Colocynth)	Cucurbitaceae	65	Disturbed, major and minor drainage, plains
**Cynodon dactylon* (Couch Grass)	Poaceae	260	Major and minor drainage
**Echinochloa colona* (Awnless Barnyard Grass)	Poaceae	5	Major and minor drainage
**Euphorbia hirta* (Asthma Plant)	Euphorbiaceae	800	Major and minor drainage
**Flaveria trinervia* (Speedy Weed)	Asteraceae	140	Disturbed, major and minor drainage, plains
**Lactuca serriola* (Prickly Lettuce)	Asteraceae	40	Major and minor drainage, plains
**Malvastrum americanum* (Spiked Malvastrum)	Malvaceae	920	Disturbed, major and minor drainage, plains
**Ocimum basilicum* (Basil)	Lamiaceae	15	Major and minor drainage
**Passiflora foetida* subsp. *hispida* (Stinking Passion Flower)	Passifloraceae	890	Major and minor drainage
**Phoenix dactylifera* (Date Palm)	Araceae	8	Major and minor drainage
**Rumex vesicarius* (Ruby Dock)	Apocynaceae	640	Disturbed, major and minor drainage, mesa tops and hilltops and mesa slopes and hillslopes, plains
**Setaria verticillata* (Whorled Pigeon Grass)	Poaceae	1,270	Disturbed, major and minor drainage, plains
**Sonchus oleraceus* (Common Sowthistle)	Asteraceae	20	Major and minor drainage
**Tribulus terrestris* (Caltrop)	Zygophyllaceae	50	Major and minor drainage, plains
**Vachellia farnesiana* (Mimosa Bush)	Fabaceae	290	Disturbed, major and minor drainage, plains

5 Discussion

5.1 Overview of Study Area

The survey area is defined by low and broad mesa formations extending from the north-eastern footslopes of the Hamersley Ranges and flanked to the north and west by the Robe River. Low hills and plains surround the uplands and river. The mesas, hills and plains are dominated by open shrublands of *Acacia* species over *Triodia* species (Spinifex) hummock grasslands. The Robe River supports extensive woodlands of *Melaleuca argentea* (Silver Cadjeput) and *Eucalyptus camaldulensis* subsp. *refulgens* (River Red Gum) over sedges in the main channels, and is surrounded by sparely vegetated shingle beds and tall shrublands of *Acacia trachycarpa* and *Petalostylis labicheoides*.

5.2 Vegetation

The vegetation recorded generally represents what would be expected from similar landforms in the broader Hamersley subregion. Thirty-eight vegetation associations and three mosaic vegetation units were mapped within the survey area and 33 statistically significant groups were identified from the floristic analysis. This indicates that the scale of mapping based on visual interpretation was conservative and appropriate for the floristic diversity of the survey area.

There were no Commonwealth or State listed TECs recorded within the survey area. One vegetation association, AprTwTsr, is analogous with the PEC '*Triodia sp. Robe River assemblages of mesas of the West Pilbara*'. This vegetation association was recorded from discrete pockets on the edge of mesa landforms in the survey area. Vegetation association AprTwTsr typically occurred on the rocky tops of mesas adjacent to gullies and breakaways, and was dominated by an open shrub stratum of *Acacia pruinocarpa* over mixed open hummock grassland of *Triodia wiseana* and *Triodia* sp. Robe River (M.E. Trudgen et al. MET 12367) P3. The dominance of these two *Triodia* species varied between occurrences. Vegetation association AprTwTsr represents 15.7 ha (0.3%) within the survey area. The *Triodia* sp. Robe River PEC is listed as Priority 3, 'poorly-known ecological communities'.

One quadrat, MH302, did not group with other quadrats or relevés from within the survey area or other regional surveys in the floristic analysis. The effects of multiple disturbances, such as altered surface hydrology, tracks and grazing, combined with water discharge nearby, has probably contributed to the relatively high floristic diversity at this site. Although a number of additional species were recorded at MH302 relative to other similar quadrats and relevés, it had a similar structural composition to other sites within the survey area, did not occur on an under-represented landform and did not otherwise appear to be of local or regional significance.

Weed diversity and density were likely to have been under-represented on the alluvial plains at the northern side of the survey area at the time of the surveys, due to heavy grazing and poor seasonal conditions. This includes vegetation associations AsTw and AsAbTwCspp which occur on clay soils that are likely to have abundant individuals of *Cenchrus* spp. following rainfall. The survey in Jimmawurrada Creek was completed over two field visits, one pre-rainfall and one post-rainfall. There was a considerable increase in the density and diversity of weed species in Jimmawurrada Creek post-rainfall which had not been observed prior to the rain.

Vegetation condition in undisturbed vegetation in the upland areas, including mesas, ranges and hills, was 'excellent' with generally no weeds or evidence of other types of disturbance. The dominant mesa landform was highly fragmented due to the network of tracks and drill pads. Although a high diversity of weed species occurred in the Robe River, the vegetation structure was generally intact and floristic diversity was as would be expected for a major ephemeral watercourse in the Pilbara.

5.3 Flora

The suite of flora species recorded was considered typical of what may be expected in the area (Beard 1975; Payne et al. 1988) and aligns with what has been previously recorded in surrounding areas (Astron Environmental Services 2014, 2016a, 2016b; Biota Environmental Sciences 2003, 2006a, 2007, 2011, 2012; Rio Tinto Iron Ore 2014). Despite rainfall being below the long-term average for three of the four surveys, the floristic diversity was considered reasonably high. It is likely however, that many of the annuals and herbaceous species that were noted would have been more widespread throughout suitable habitats in better seasonal conditions. Specimens generally had adequate material to allow confident identification, however a number of samples collected during the first Phase 2 survey were of poor quality and were unable to be identified to species level.

Areas considered 'likely' or 'potential' habitat for Threatened or Priority flora were targeted and searched. Opportunistic searches were also conducted in a proportion of all other landform and vegetation types observed whilst traversing the survey area. Three Priority flora species were recorded within the survey area: *I.* sp. Bungaroo Creek (S. van Leeuwen 4301) P3, *T.* sp. Robe River (M.E. Trudgen et al. MET 12367) P3 and *R. bungarensis* P4. Priority flora records were distributed throughout the survey area, but were concentrated around the edges of mesas and throughout the Robe River.

Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301) P3 was recorded on floodplains at one location in the south-eastern part of the survey area. This species has not been previously recorded within the survey area but has been recorded from similar habitats adjacent to the survey area (Astron Environmental Services 2016a, 2016b; Biota Environmental Sciences 2012). There are 37 records of *I.* sp. Bungaroo Creek (S. van Leeuwen 4301) P3 listed at the WAHerb, with a range of approximately 215 km (Western Australian Herbarium 1998-2016). Nearly 17,000 *I.* sp. Bungaroo Creek (S. van Leeuwen 4301) P3 individuals from 2,119 locations are listed on the Rio Tinto database. These span from Mesa A in the west, to Tom Price in the east, with a range of approximately 225 km (Rio Tinto Iron Ore 2016b). The locations in the survey area may represent the northern extent of this species.

Populations of *T.* sp. Robe River (M.E. Trudgen et al. MET 12367) P3 were recorded in association with mesas, low hills and ranges, particularly favouring rocky ledges and breakaways in these habitats. This species has been previously recorded within and adjacent to the survey area (Astron Environmental Services 2016a, 2016b; Biota Environmental Sciences 2003, 2007, 2011, 2012; Rio Tinto Iron Ore 2014). Thirty-eight records of *T.* sp. Robe River (M.E. Trudgen et al. MET 12367) P3 are listed at the WAHerb, with a known range of approximately 175 km (Western Australian Herbarium 1998-2016). Rio Tinto holds 3,443 records consisting of more than 238,000 *T.* sp. Robe River (M.E. Trudgen et al. MET 12367) P3 individuals, with a geographical distribution spanning from Mesa A in the west to Mettawandy, a range of approximately 150 km (Rio Tinto Iron Ore 2016b).

Rhynchosia bungarensis P4 was recorded in locations along the Robe River. This species has previously been recorded from within the survey area (Biota Environmental Sciences 2006a, 2007). Seventy records of *R. bungarensis* P4 are listed at the WAHerb, with a known range of approximately 545 km (Western Australian Herbarium 1998-2016). The Rio Tinto database lists 10,865 individuals from 1,134 locations, distributed between Mesa A in the west, to Yandicoogina, with a range of approximately 360 km (Rio Tinto Iron Ore 2016b).

Four Priority flora species not found in the survey area are considered to have potential to occur: *T.* sp. Pannawonica (B.M. Anderson & M.D. Barrett BMA 89) P1, *E. australis* var. *glabra* P2, *S. weeliwolli* P2 and *E. surreyana* P3. Seasonal conditions were not ideal for locating any of these species.

Triodia sp. Pannawonica (B.M. Anderson & M.D. Barrett BMA 89) P1 is known from only one location, approximately 3 km north-east of the survey area. Due to the dry conditions the *Triodia* spp. were generally not flowering, or had incomplete racemes and spikelets during the surveys. Given the similar appearance of this species to other more common *Triodia* species, it may have been difficult to identify should it occur within the survey area.

Although some *E. australis* were recorded from the survey area, the specimens observed had hairs on the leaf laminae differentiating them from the priority form. Given the small habit (≤10 cm) and often frequent occurrence of *E. australis*, not all individuals were observed and there is potential that *E. australis* var. *glabra* P2 occurred but was not recorded. *Euphorbia australis* var. *glabra* P2 has previously been recorded from Jimmawurrada Creek, but more typically occurs in the vicinity of Tom Price (Western Australian Herbarium 1998-2016).

Stylidium weeliwolli P2 is a delicate annual species that is difficult to observe when not in flower and may not have been present, should it occur, due to the low rainfall prior to the surveys. *Stylidium weeliwolli* P2 has previously been recorded within the survey area, however this location may be erroneous given the unsuitable habitat at the locality.

The small annual tussock grass *E. surreyana* P3 is unlikely to occur during dry conditions and would be difficult to observe post-rainfall if occurring among a grass-dominated lower stratum (such as *Cenchrus* spp. tussock grassland). *Eragrostis surreyana* has previously been recorded in Jimmawurrada Creek (Western Australian Herbarium 1998-2016), which runs through the eastern side of the survey area.

Three species recorded in the survey area were beyond their normal range of distribution, and are considered species of interest. *Cynanchum pedunculatum* typically occurs further east, around Tom Price, or in the northern Kimberley region. *Sauropus crassifolius* has records from the southern Pilbara, as well as the Cape Range, Gascoyne, Murchison, Yalgoo and Geraldton sandplains regions. Records of *S.* sp. Meekatharra (E. Bailey 1-26) extend from the Tom Price area, to the Gascoyne, Cape Range, Murchison and Yalgoo regions (Western Australian Herbarium 1998-2016).

Weed diversity was relatively high in the survey area, with 20 species recorded. The majority of records were from drainage line habitats, with few weeds recorded from mesas or hill habitats. One weed species, **Ocimum basilicum* (Basil) is an unusual record for the area. The nearest previous record on Florabase is the junction of the Pannawonica Road and North West Coastal Highway; the other seven records are from the Broome and Derby areas (Western Australian Herbarium 1998-2016). **Bidens bipinnata* (Bipinnate Beggartick), **Lactuca serriola* (Prickly Lettuce), **O. basilicum* (Basil), **Phoenix dactylifera* (Date Palm), and **Tribulus terrestris* (Caltrop) are new records for the survey area. All other species have been previously recorded within the survey area (Astron Environmental Services 2011, 2016a; Biota Environmental Sciences 2003, 2006a, 2007, 2011, 2012; Rio Tinto Iron Ore 2014).

5.4 Contextual Analysis

Three vegetation associations recorded within the survey area are considered to be of local significance because of uniqueness, restricted occurrence and strong association with Priority flora.

Vegetation association AprTwTsr is likely to represent the '*Triodia sp. Robe River assemblages of mesas of the West Pilbara*' PEC. Floristically and structurally similar vegetation has previously been recorded in the broader area (Astron Environmental Services 2016b; Biota Environmental Sciences 2006a, 2007). Although similar vegetation was recorded during the 2014 to 2016 surveys, the PEC

had not been described during the 2006 and 2007 surveys and therefore the landforms may not consistently conform to the mesas characteristic of the PEC.

One vegetation association, ChAsppGOrGsppPlSsTeTw, has locations with each of the three recorded Priority flora species within it. This vegetation was associated with creeks throughout the survey area and is characterised by *C. hamersleyana* over a dense tall shrub layer of *Acacia, Gossypium* and *Grevillea* species, and *P. labicheoides* and *Stylobasium spathulatum,* over *Triodia epactia* and *T. wiseana*. A total of 20 *I.* sp. Bungaroo Creek P3, 114 *T.* sp. Robe River (M.E. Trudgen et al. MET 12367) P3 and six *R. bungarensis* P4 were recorded from ChAsppGOrGsppPlSsTeTw. This vegetation association accounted for 135.3 ha (2.3%) in the survey area and condition ranged from 'good' to 'excellent' (Trudgen 1988). Similar vegetation has been recorded from other regional surveys (Astron Environmental Services 2011, 2016a, 2016b; Biota Environmental Sciences 2003, 2011). Vegetation described for 'drainage floors and channels' landforms of the Robe land system is considered similar at a broad scale (van Vreeswyk et al. 2004).

A number of permanent and semi-permanent pools occur in the main flow channels of the Robe River, both within and adjacent to the survey area. These pools are typically fringed by vegetation association MaEcCv, characterised by *M. argentea* and *E. camaldulensis* var. *refulgens* in the upper stratum. Springs and pools of the Robe River are listed as 'Wetlands of Subregional Significance', and include the springs and pools occurring from 40 km east of Pannawonica, downstream to the North West Coastal Highway. These significant wetlands are described as 'running spring ecosystems with large deep permanent pools and consist of seasonal and irregular rivers and streams, and freshwater springs, oases and rock pools' (Kendrick 2001). The flora species that occur in MaEcCv are generally habitat restricted to damp and humid conditions and many therefore do not occur beyond this landform and vegetation. Approximately 60% of the *R. bungarensis* P4 individuals recorded in the survey area were observed in MaEcCv.

Vegetation association MaEcCv is also considered to be a GDE due to the dominant presence of *M. argentea* and *E. camaldulensis* var. *refulgens*. Instances of juvenile stands were observed in open shingle beds within the Robe River. Juvenile stands comprising purely of saplings are not necessarily GDE. This vegetation occurs both upstream and downstream of the survey area throughout the Robe River. *Melaleuca argentea* and *E. camaldulensis* var. *refulgens* may be sensitive to changes in groundwater availability and depth. Similar vegetation has been recorded in the broader area (Astron Environmental Services 2016b; Biota Environmental Sciences 2011), and the vegetation is typical of what is described for the minor and major channels within the River land system. The River land system accounts for 2.3% of the Pilbara and the river channels constitute 20% of this area (van Vreeswyk et al. 2004). Condition of this vegetation ranged from 'very good' to 'excellent' (Trudgen 1988) within the survey area, with weeds and grazing being the most common impacts.

The remaining 35 vegetation associations recorded within the survey area are considered to be well represented beyond the survey area and do not support assemblages of species that are unique, on restricted landforms, or of high conservation significance.

6 References

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Appendix A: Geology, Land Systems and Pre-European Vegetation Mapping of the Survey Area

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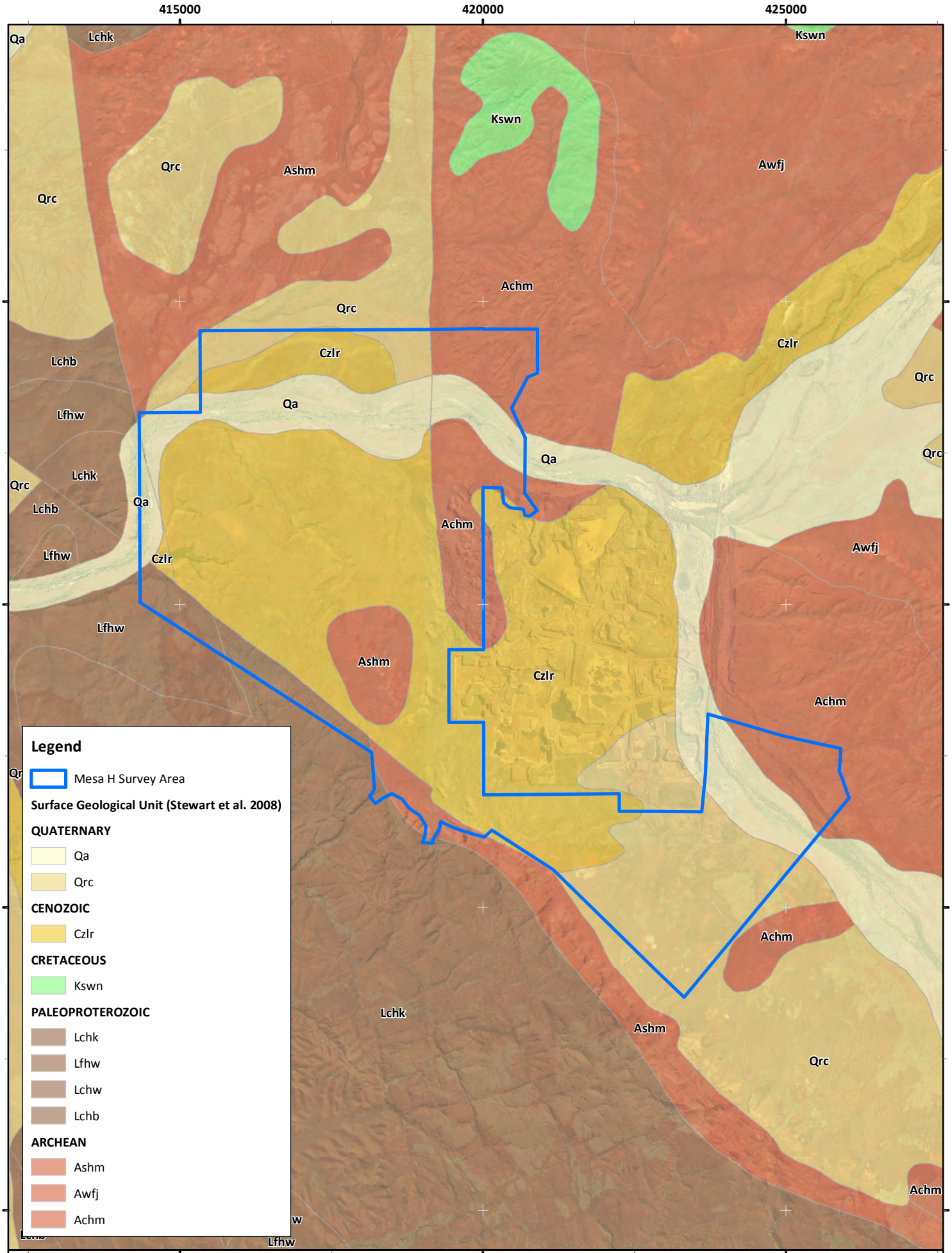

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Mesa H – Level 2 Vegetation and Flora Assessment, May 2016

Figure A.1: Geological Units of the Mesa H Survey Area

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Author: D. Roocke	Date: 09-08-2017
Drawn: T. Pedersen	Figure Ref: 14269-16-BIDR-2Rev1_170809_FigA1_Geo

Datum: GDA 1994 - Projection: MGA Zone 50

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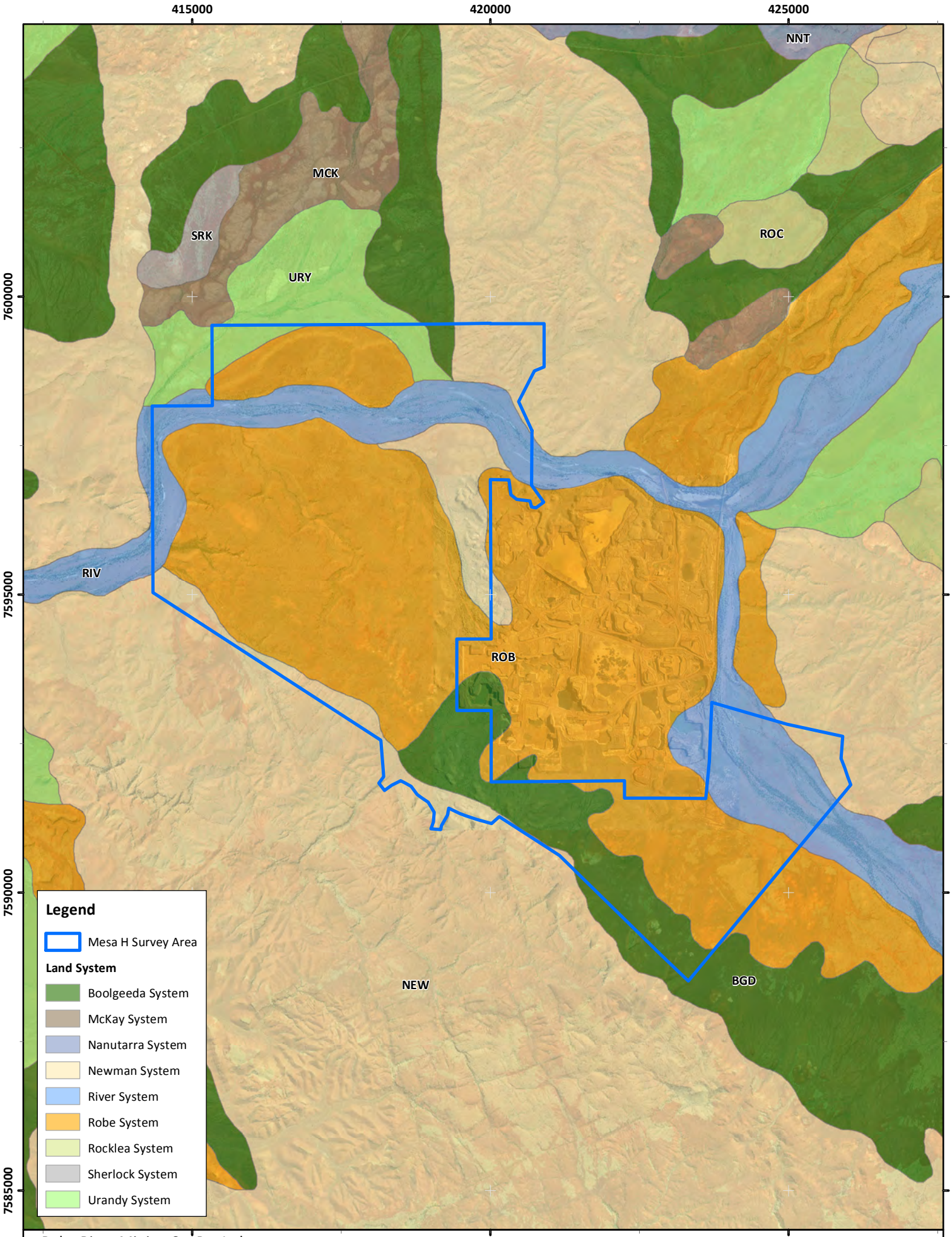
N



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Mesa H – Level 2 Vegetation and Flora Assessment, May 2016

Figure A.2: Land Systems of the Mesa H Survey Area

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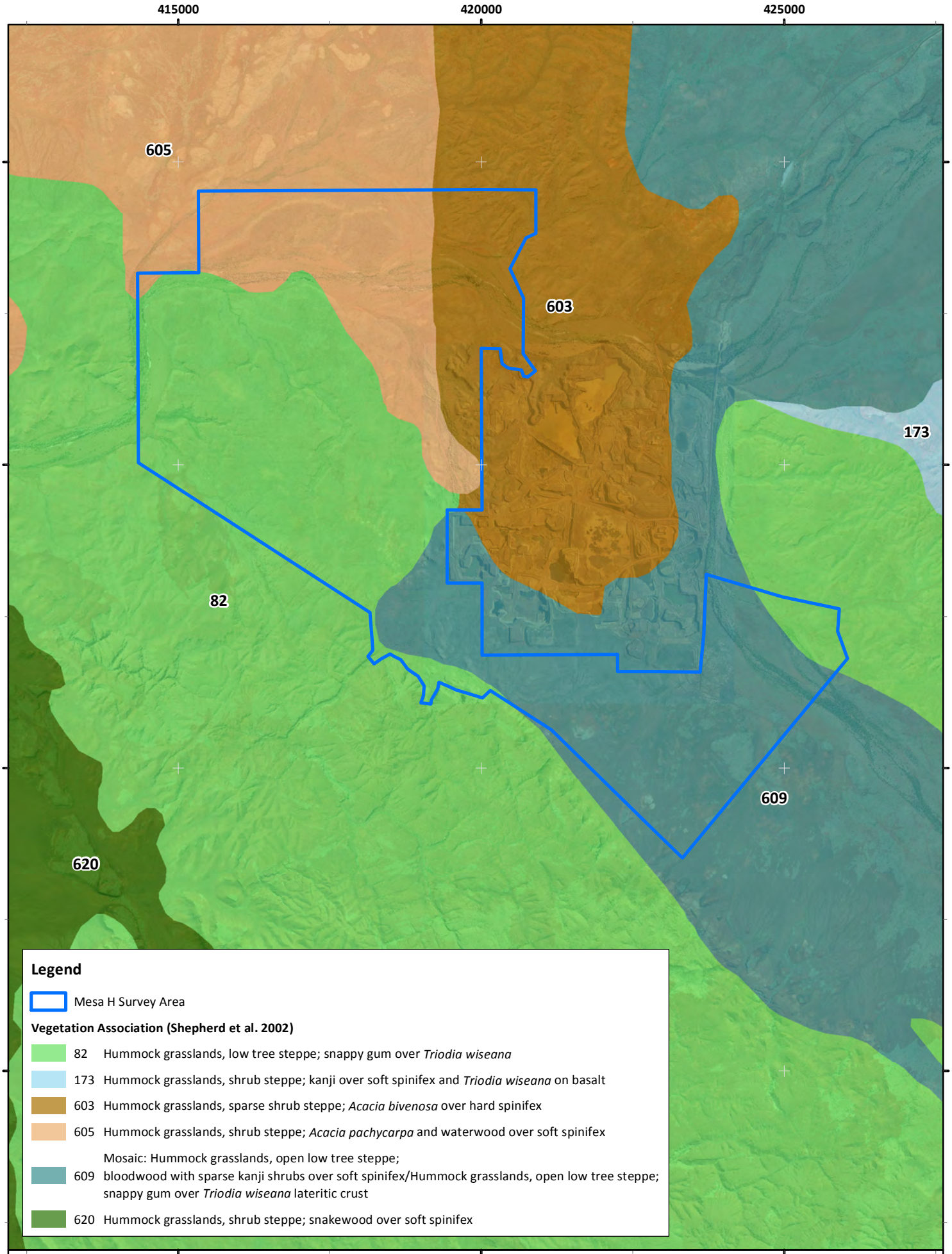
Author: D. Roocke	Date: 09-08-2017	Datum: GDA 1994 - Projection: MGA Zone 50
Drawn: T. Pedersen	Figure Ref: 14269-16-BIDR-2Rev1_170809_FigA2_LandSys	0 1 2 3 Km

N



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Mesa H – Level 2 Vegetation and Flora Assessment, May 2016

Figure A.3: Pre-European Vegetation of the Mesa H Survey Area

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Author: D. Roocke	Date: 09-08-2017
Drawn: T. Pedersen	Figure Ref: 14269-16-BIDR-2Rev1_170809_FigA3_PreEuroVeg

Datum: GDA 1994 - Projection: MGA Zone 50

0 1 2 3 Km

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Appendix B: Conservation Categories for Flora, Fauna and Ecological Communities, and Categories for Introduced Flora

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Table B.1: Categories and definitions for EPBC Act listed flora and fauna species listed under the *Environment Protection and Biodiversity Conservation Act 1999*.

Conservation category	Definition
Extinct	Taxa with no reasonable doubt that the last member of the species has died.
Extinct in the wild	Taxa known to survive only in cultivation, in captivity or as a naturalized population well outside its past range; or it has not been recorded in its known and/or expected habitat, at appropriated seasons, anywhere in its past range, despite exhaustive surveys over a time frame appropriate to its life cycle and form.
Critically endangered (CR)	Taxa facing an extremely high risk of extinction in the wild in the immediate future, as determined in accordance with the prescribed criteria.
Endangered (E)	Taxa are not critically endangered; and are facing a very high risk of extinction in the wild in the near future, as determined in accordance with the prescribed criteria.
Vulnerable (V)	Taxa are not critically endangered or endangered; and are facing a high risk of extinction in the wild in the medium-term future, as determined in accordance with the prescribed criteria.
Conservation dependent (CD)	Taxa are the focus of a specific conservation program the cessation of which would result in the species becoming vulnerable, endangered or critically endangered; or the following subparagraphs are satisfied: i) the taxa is a species of fish; ii) the taxa is the focus of a management plan that provides management actions necessary to stop the decline of, and support the recovery of, the taxa so that its chances of long term survival in nature are maximized; iii) the management plan is in force under a law of the Commonwealth or of a State or Territory; iv) Cessation of the management plan would adversely affect the conservation status of the taxa Fish includes all taxa of bony fish, sharks, rays, crustaceans, molluscs and other marine organisms, but does not include marine mammals/reptiles.

Three categories exist for listing threatened ecological communities under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).

Table B.2: Definitions and criteria for threatened ecological communities listed under the *Environment Protection and Biodiversity Conservation Act 1999*.

Categories of ecological communities	
Critically endangered	If, at that time, it is facing an extremely high risk of extinction in the wild in the immediate future, as determined in accordance with the prescribed criteria.
Endangered	If, at that time, it is not critically endangered and is facing a very high risk of extinction in the wild in the near future, as determined in accordance with the prescribed criteria.
Vulnerable	If, at that time, it is not critically endangered or endangered, and is facing a high risk of extinction in the wild in the medium-term future, as determined in accordance with the prescribed criteria.

Table B.3: Categories of threatened ecological communities (Department of Parks and Wildlife 2016b).

PD: Presumed Destroyed
An ecological community that has been adequately searched for but for which no representative occurrences have been located. The community has been found to be totally destroyed or so extensively modified throughout its range that no occurrence of it is likely to recover its species composition and/or structure in the foreseeable future. An ecological community will be listed as presumed totally destroyed if there are no recent records of the community being extant **and either** of the following applies (A or B): A) Records within the last 50 years have not been confirmed despite thorough searches of known or likely habitats **or** B) All occurrences recorded within the last 50 years have since been destroyed.
CR : Critically Endangered
An ecological community that has been adequately surveyed and found to have been subject to a major contraction in area and/or that was originally of limited distribution and is facing severe modification or destruction throughout its range in the immediate future, or is already severely degraded throughout its range but capable of being substantially restored or rehabilitated. An ecological community will be listed as **Critically Endangered** when it has been adequately surveyed and is found to be facing an extremely high risk of total destruction in the immediate future. This will be determined on the basis of the best available information, by it meeting **any one or more of** the following criteria (A, B or C): A) The estimated geographic range, and/or total area occupied, and/or number of discrete occurrences since European settlement have been reduced by at least 90% **and either or both** of the following apply (i or ii): i) geographic range, and/or total area occupied and/or number of discrete occurrences are continuing to decline such that total destruction of the community is imminent (within approximately 10 years); ii) modification throughout its range is continuing such that in the immediate future (within approximately 10 years) the community is unlikely to be capable of being substantially rehabilitated. B) Current distribution is limited, **and one or more** of the following apply (i, ii or iii): i) geographic range and/or number of discrete occurrences, and/or area occupied is highly restricted and the community is currently subject to known threatening processes which are likely to result in total destruction throughout its range in the immediate future (within approximately 10 years); ii) there are very few occurrences, each of which is small and/or isolated and extremely vulnerable to known threatening processes; iii) there may be many occurrences but total area is very small and each occurrence is small and/or isolated and extremely vulnerable to known threatening processes. C) The ecological community exists only as highly modified occurrences that may be capable of being rehabilitated if such work begins in the immediate future (within approximately 10 years).

En: Endangered

An ecological community that has been adequately surveyed and found to have been subject to a major contraction in area and/or was originally of limited distribution and is in danger of significant modification throughout its range or severe modification or destruction over most of its range in the near future.

An ecological community will be listed as **Endangered** when it has been adequately surveyed and is not Critically Endangered but is facing a very high risk of total destruction in the near future. This will be determined on the basis of the best available information by it meeting **any one or more** of the following criteria (A, B, or C):

A) The geographic range, and/or total area occupied, and/or number of discrete occurrences have been reduced by at least 70% since European settlement **and either or both** of the following apply (i or ii):

i) the estimated geographic range, and/or total area occupied and/or number of discrete occurrences are continuing to decline such that total destruction of the community is likely in the short term future (within approximately 20 years);

ii) modification throughout its range is continuing such that in the short term future (within approximately 20 years) the community is unlikely to be capable of being substantially restored or rehabilitated.

B) Current distribution is limited, **and one or more** of the following apply (i, ii or iii):

i) geographic range and/or number of discrete occurrences, and/or area occupied is highly restricted and the community is currently subject to known threatening processes which are likely to result in total destruction throughout its range in the short term future (within approximately 20 years);

ii) there are few occurrences, each of which is small and/or isolated and all or most occurrences are very vulnerable to known threatening processes;

iii) there may be many occurrences but total area is small and all or most occurrences are small and/or isolated and very vulnerable to known threatening processes.

C) The ecological community exists only as very modified occurrences that may be capable of being substantially restored or rehabilitated if such work begins in the short-term future (within approximately 20 years).

VU: Vulnerable

An ecological community that has been adequately surveyed and is found to be declining and/or has declined in distribution and/or condition and whose ultimate security has not yet been assured and/or a community that is still widespread but is believed likely to move into a category of higher threat in the near future if threatening processes continue or begin operating throughout its range.

An ecological community will be listed as **Vulnerable** when it has been adequately surveyed and is not Critically Endangered or Endangered but is facing a high risk of total destruction or significant modification in the medium to long-term future. This will be determined on the basis of the best available information by it meeting **any one or more of** the following criteria (A, B or C):

A) The ecological community exists largely as modified occurrences that are likely to be capable of being substantially restored or rehabilitated.

B) The ecological community may already be modified and would be vulnerable to threatening processes, is restricted in area and/or range and/or is only found at a few locations.

C) The ecological community may be still widespread but is believed likely to move into a category of higher threat in the medium to long term future because of existing or impending threatening processes.

Possible threatened ecological communities that do not meet survey criteria or that are not adequately defined are added to the Priority Ecological Community Lists under Priorities 1, 2 and 3. Ecological Communities that are adequately known, and are rare but not threatened or meet criteria for Near Threatened, or that have been recently removed from the threatened list, are placed in Priority 4. These ecological communities require regular monitoring. Conservation Dependent ecological communities are placed in Priority 5.

Table B.4: Definitions and criteria for priority ecological communities (Department of Parks and Wildlife 2016b).

P1: Priority One – Poorly-known ecological communities
Ecological communities that are known from very few occurrences with a very restricted distribution (generally ≤5 occurrences or a total area of ≤ 100ha). Occurrences are believed to be under threat either due to limited extent, or being on lands under immediate threat (e.g. within agricultural or pastoral lands, urban areas, active mineral leases) or for which current threats exist. May include communities with occurrences on protected lands. Communities may be included if they are comparatively well-known from one or more localities but do not meet adequacy of survey requirements, and/or are not well defined, and appear to be under immediate threat from known threatening processes across their range.
P2: Priority Two – Poorly-Known ecological communities
Communities that are known from few occurrences with a restricted distribution (generally ≤10 occurrences or a total area of ≤200ha). At least some occurrences are not believed to be under immediate threat of destruction or degradation. Communities may be included if they are comparatively well known from one or more localities but do not meet adequacy of survey requirements, and/or are not well defined, and appear to be under threat from known threatening processes.
P3: Priority Three – Poorly-Known ecological communities
(i) Communities that are known from several to many occurrences, a significant number or area of which are not under threat of habitat destruction or degradation or: (ii) communities known from a few widespread occurrences, which are either large or with significant remaining areas of habitat in which other occurrences may occur, much of it not under imminent threat, or; (iii) communities made up of large, and/or widespread occurrences, that may or may not be represented in the reserve system, but are under threat of modification across much of their range from processes such as grazing by domestic and/or feral stock, and inappropriate fire regimes. Communities may be included if they are comparatively well known from several localities but do not meet adequacy of survey requirements and/or are not well defined, and known threatening processes exist that could affect them.
P4: Priority Four
Ecological communities that are adequately known, rare but not threatened or meet criteria for Near Threatened, or that have been recently removed from the threatened list. These communities require regular monitoring. (i) Rare. Ecological communities known from few occurrences that are considered to have been adequately surveyed, or for which sufficient knowledge is available, and that are considered not currently threatened or in need of special protection, but could be if present circumstances change. These communities are usually represented on conservation lands. (ii) Near Threatened. Ecological communities that are considered to have been adequately surveyed and that do not qualify for Conservation Dependent, but that are close to qualifying for Vulnerable. (iii) Ecological communities that have been removed from the list of threatened communities during the past five years.
P5: Priority Five – Conservation dependent ecological communities
Ecological communities that are not threatened but are subject to a specific conservation program, the cessation of which would result in the community becoming threatened within five years.

Table B.5: Conservation codes for Western Australian flora and fauna under the *Wildlife Conservation Act 1950*.

Code	Conservation category	Definition
S1	Schedule 1 of the Wildlife Conservation (Specially Protected Fauna) Notice and Wildlife Conservation (Rare Flora) Notice under the *Wildlife Conservation Act 1950*.	Taxa that is rare or likely to become extinct, as critically endangered taxa.
S2	Schedule 2 of the Wildlife Conservation (Specially Protected Fauna) Notice and Wildlife Conservation (Rare Flora) Notice under the *Wildlife Conservation Act 1950*.	Taxa that is rare or likely to become extinct, as endangered taxa.
S3	Schedule 3 of the Wildlife Conservation (Specially Protected Fauna) Notice and Wildlife Conservation (Rare Flora) Notice under the *Wildlife Conservation Act 1950*.	Taxa that is rare or likely to become extinct, as vulnerable taxa.
S4	Schedule 4 of the Wildlife Conservation (Specially Protected Fauna) Notice and Wildlife Conservation (Rare Flora) Notice under the *Wildlife Conservation Act 1950*.	Taxa that is presumed to be extinct.
S5	Schedule 5 of the Wildlife Conservation (Specially Protected Fauna) Notice under the *Wildlife Conservation Act 1950*.	Birds that are subject to international agreements relating to the protection of migratory birds.
S6	Schedule 6 of the Wildlife Conservation (Specially Protected Fauna) Notice under the *Wildlife Conservation Act 1950*.	Fauna that are of special conservation need being species dependent on ongoing conservation intervention.
S7	Schedule 7 of the Wildlife Conservation (Specially Protected Fauna) Notice under the *Wildlife Conservation Act 1950*.	Declared to be fauna that is in need of special protection, otherwise than for the reasons mentioned.

Note: Schedules 5, 6, and 7 are only related to conservation significant fauna.

Threatened fauna and flora (Schedule 1) are further ranked by the Department according to their level of threat using IUCN Red List criteria:

- CR: Critically Endangered - considered to be facing an extremely high risk of extinction in the wild.
- EN: Endangered - considered to be facing a very high risk of extinction in the wild.
- VU: Vulnerable - considered to be facing a high risk of extinction in the wild.

Taxa that have not yet been adequately surveyed to be listed under Schedule 1 or 2 are added to the Priority Flora and Priority Fauna Lists under Priorities 1, 2 or 3. These three categories are ranked in order of priority for survey and evaluation of conservation status so that consideration can be given to their declaration as threatened flora or fauna. Taxa that are adequately known, are rare but not threatened, or meet criteria for Near Threatened, or that have been recently removed from the threatened list for other than taxonomic reasons, are placed in Priority 4. These taxa require regular monitoring. Conservation Dependent species are placed in Priority 5.

Table B.6: Priority species under Western Australian *Wildlife Conservation Act 1950*.

P1: Priority One – Poorly known taxa
Taxa that are known from one or a few collections or sight records (generally five or less) which are potentially at risk. All occurrences are either: very small; or on lands not managed for conservation, e.g. agricultural or pastoral lands, urban areas, road and rail reserves, gravel reserves, and active mineral leases; or otherwise under threat of habitat destruction or degradation. Taxa may be included if they are comparatively well known from one or more localities but do not meet adequacy of survey requirements and appear to be under immediate threat from known threatening processes. Such taxa are in urgent need of further survey.
P2: Priority Two – Poorly known taxa
Taxa that are known from one or a few collections (generally five or less), some of which are on lands managed primarily for nature conservation, e.g. national parks, conservation parks, nature reserves, and other lands with secure tenure being managed for conservation. Taxa may be included if they are comparatively well known from one or more localities but do not meet adequacy of survey requirements and appear to be under threat from known threatening processes. Such taxa are in urgent need of further survey.
P3: Priority Three – Poorly known taxa
Taxa that are known from several localities and does not appear under imminent threat, or from few but widespread localities with either large population size or significant remaining areas of apparently suitable habitat, much of it not under imminent threat. Taxa may be included if they are comparatively well known from several localities but do not meet adequacy of survey requirements and known threatening processes exist that could affect them. Such taxa are in urgent need of further survey.
P4: Priority Four: Rare, near threatened and other taxa in need of monitoring
(a) Rare. Taxa that are considered to have been adequately surveyed, or for which sufficient knowledge is available, and that are considered not currently threatened or in need of special protection, but could be if present circumstances change. These taxa are usually represented on conservation lands. (b) Near Threatened. Taxa that are considered to have been adequately surveyed and that do not qualify for Conservation Dependent, but that are close to qualifying for Vulnerable. (c) Taxa that have been removed from the list of threatened species during the past five years for reasons other than taxonomy.
P5: Priority Five: Conservation dependent taxa
Taxa that are not threatened but are subject to a specific conservation program, the cessation of which would result in the taxa becoming threatened within five years.

The management of introduced flora species in Western Australia is regulated through the *Biosecurity and Agriculture Management Act 2007* (BAM Act). A list of declared pests, including 'pest' plants is provided under the BAM Act, which has been updated to incorporate a number of other Acts that are administered by DAFWA (2016). Declared pests can fall into two categories: one that relates to the prevention of introducing the species or eradicating it; and the other relates to managing the species and whether it can be kept (i.e. for scientific purposes, education or other purpose).

The threat and risk posed to site-specific biodiversity values, influences to rehabilitation success, primary production, infrastructure assets or human health will differ depending on the unique characteristics of each site and the associated land management practice or operation. Therefore site or project specific weed assessments and priorities should be reviewed for each project.

As per introduced flora species, the BAM Act seeks to establish a modern biosecurity regulatory scheme to prevent serious animal pests from entering the State and becoming established, and to minimise the spread and impact of any that are already present within the State. Declared animal pests fall into three categories as Gazetted under the BAM Act (DAFWA 2016). These categories are outlined in Table B.7.

Table B.7: Declared pests categories as gazetted under the *Biosecurity and Agriculture Management Act 2007* (Department of Agriculture and Food 2016).

Category	Description
C1 (Exclusion)	Pests will be assigned to this category if they are not established in Western Australia and control measures are to be taken, including border checks, in order to prevent them entering and establishing in the State.
C2 (Eradication)	Pests will be assigned to this category if they are present in Western Australia in low enough numbers or in sufficiently limited areas that their eradication is still a possibility.
C3 (Management)	Pests will be assigned to this category if they are established in Western Australia but it is feasible, or desirable, to manage them in order to limit their damage. Control measures can prevent a C3 pest from increasing in population size or density or moving from an area in which it is established into an area which currently is free of that pest.

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Appendix C: Database Searches

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Government of Western Australia
Department of Parks and Wildlife

Your Ref: **14269-15**
Our Ref: **40-0915FL**
Enquiries: Jessica Donaldson
Phone: (08) 9219 8760
Email: flora.data@dpaw.wa.gov.au

Astron Environmental Services
129 Royal Street
East Perth WA 6004

Attention: Natalie Cadd

Dear Natalie Cadd,

REQUEST FOR THREATENED AND PRIORITY FLORA INFORMATION

I refer to your request of 14 September 2015 for Threatened (Declared Rare) and Priority Flora information in the Pannawonica area. The search was conducted within the area of the coordinates you submitted with an additional 20km buffer.

A search was undertaken for this area of **(1)** the Department's *Threatened (Declared Rare) and Priority Flora* database (for results, see "TPFL" – coordinates are GDA94), **(2)** the *Western Australian Herbarium Specimen* database for Threatened and Priority flora species opportunistically collected in the area of interest (for results, see "WAHERB"- coordinates are GDA94 – see condition number 4 in the attached 'Conditions in Respect of Supply') and **(3)**, the Department's *Threatened and Priority Flora List* [this list is searched using 'place names'. This list, which may also be used as a species target list, contains species that are declared rare (Conservation Code R or X for those presumed to be extinct), poorly known (Conservation Codes 1, 2 or 3), or require monitoring (Conservation Code 4) – for results, *if any*, see "TP List"]. The results are attached electronically to this email.

Attached also are the conditions under which this information has been supplied. Your attention is specifically drawn to the ninth point, which refers to the requirement to undertake field investigations for the accurate determination of Threatened and Priority flora occurrence at a site. *The information supplied should be regarded as an indication only of the Threatened and Priority flora that may be present and may be used as a target list in any surveys undertaken.*

The information provided does not preclude you from obtaining and complying with, where necessary, land clearing approvals from other agencies.

An invoice for $ 300 (plus GST) to supply this information will be forwarded.

It would be appreciated if any populations of Threatened and Priority flora you encounter in the area could be reported to this Department to ensure their ongoing management.

If you require any further details, or wish to discuss Threatened and Priority flora management, please contact Dr Ken Atkins, Manager, Species and Communities Branch, on (08) 9334 0455.

Yours faithfully

Jessica Donaldson
.....
THREATENED FLORA DATABASE OFFICER
for the Director General

29 September 2015

Species and Communities Branch
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www.dpaw.wa.gov.au

Government of **Western Australia**
Department of **Parks and Wildlife**

THREATENED AND PRIORITY FLORA INFORMATION

Conditions with Respect to the Supply of Information

- The data supplied may not be provided to any other organisations, nor be used for any purpose other than for the project for which it has been originally provided for; without the prior consent of the Executive Director, Department of Parks and Wildlife.
- Specific locality information for threatened flora is regarded as confidential, and should be treated as such by receiving organisations. Specific locality information for threatened flora may not be used in reports without the written permission of the Executive Director, Department of Parks and Wildlife. Reports may only show generalised locations at a low resolution or, where necessary, show specific locations without identifying species. Species and Communities Branch is to be contacted for guidance on the presentation of threatened flora information.
- The Department of Parks and Wildlife respects the privacy of private landowners who may have threatened and priority flora on their property. Threatened and priority flora locations identified in the data as being on private property should be treated in confidence, and contact with property owners must only be made through the Department of Parks and Wildlife.
- The development of the Perth Herbarium database was not originally intended for electronic mapping (eg. GIS ArcView). The latitude and longitude coordinates for each entry are not verified prior to being data based. It is only in recent times that collections have been submitted with GPS coordinates. Therefore, be aware when using this data in ArcView that some records may not plot to the locality description given with each collection.
- Acknowledgment of the Department of Parks and Wildlife as the source of data is to be made in any published material and cited as Parks and Wildlife (2015) Threatened and Priority Flora Database Search for [search area] accessed on the [date of search]. Prepared by the Species and Communities Branch for [Requesters name and company] for [purpose of search].
- Copies of all such publications are to be forwarded to the Department of Parks and Wildlife, Attention; the Manager, Species and Communities Branch.

Disclaimers with Respect to the Supply of Information

- Receiving organisations should note that while every effort has been made to prevent errors and omissions in the data, they may be present. The Department of Parks and Wildlife accepts no responsibility for this.
- Receiving organisations must also recognise that the database is subject to continual updating and amendment, and such considerations should be taken into account by the user.
- It should be noted that the supplied data does not necessarily represent a comprehensive listing of the threatened flora of the area in question. Its comprehensiveness is dependent on the amount of surveys carried out within a specified area. The receiving organisation should consider engaging a botanist, if required, to undertake a survey of the area under consideration.

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Department of Parks and Wildlife

ABBREVIATIONS USED IN THREATENED AND PRIORITY FLORA DATABASE

VESTING

AAP	Aboriginal Planning Authority
AGR	Chief Executive, Dep. of Agriculture
ALT	Aboriginal Land Trust
APB	Agricultural Protection Board of WA
BGP	Botanical Gardens & Parks Authority
BSA	Boy Scouts Association
CC	Conservation Commission – NPNCA - LFC
CGT	Crown Grant in Trust
COM	Commonwealth of Australia
CRO	Crown Freehold-Govt Ownership
CRW	Crown
DAG	Dep. of Agriculture
DOW	Dep. of Water
DPI	Dep. of Planning
EXD	Exec Direc CALM
FES	Fire and Emergency Services Aust.
HOW	Dep. of Housing/State Housing Commission
ILD	Industrial Lands Develop. Auth
LAC	LandCorp
LGA	Shire/LGA
MAG	Minister for Agriculture
MCB	Metropolitan Cemeteries Board
MED	Ministry of Education
MHE	Minister for Health
MIN	Minister for Mines
MPL	Ministry for Planning
MPR	Minister for Prisons
MRD	Main Roads WA
MTR	Minister for Transport
MWA	Minister for Water Resources
MWO	Minister for Works
NAT	Natural Trust of Australia WA
NON	Not Vested
PLB	Pastoral Lands Board
PRI	Private/Freehold
RAI	Public Transport Authority
REL	Religious Organisation
SPC	State Planning Commission
SYN	Synergy (ex Western Power)
SWA	State of Western Australia
TEL	Telstra
UNK	Unknown
WAT	Water Corporation
WEL	Minister Community Welfare
WRC	Water & Rivers Commission
XPL	Ex-Pastoral Lease

PURPOSES

ABR	Aboriginal Reserve
ACC	Access Track
AER	Aerodrome
AIR	Airport
ARS	Agricultural Research Station
BAP	Baptist Union of WA
CAM	Camping
CAR	Caravan park
CEM	Cemetery
CFA	Conservation of Fauna
CFF	Conservation Of Flora & Fauna
CFL	Conservation of Flora
CHU	Church
CMN	Communications
COM	Common
CON	Conservation Park
CPK	Car Park
CRM	Conservation & Resource Management
DEF	Defence
DRA	Drain
EDE	Educational Endowment
EDU	Educational purposes
UWA	
ENE	Enjoyment of Natural Environ.
EPL	Ex-pastoral Lease (Sect 33(2) CALM Act)
EPS	Explosives
EXC	Excepted from sale
EXL	Exploration Lease
EXP	Experimental Farm
FIR	Firing Range
FOR	State Forest
FP	Foreshore Purposes
GE	General Lease
GHA	Grain Handling
GOL	Golf
GRA	Gravel Pit
GVT	Government Requirements
HAR	Harbour Purposes
HEP	Heritage Purposes
HER	Heritage trail
HOS	Hospital
KEN	Kennels
LGA	LGA/Shire Requirements
LPR	Landscape Protection
MIN	Mining lease
MUN	Municipal Purposes
NPK	National Park
NRE	Nature Reserve
OTH	Other
PAR	Parkland (& Recreation)
PAS	Pastoral lease
PCR	Proposed for Conservation
PFF	Protection of Flora & Fauna
PFL	Protection of Flora
PIC	Picnic ground
PLA	Plantation
PMC	Protection of Meteorite Crater
POS	Public Open Space
PPA	Public parkland
PRS	Prison site
PUR	Purchase Lease
PUT	Public Utility
QUA	Quarry
RAC	Racecourse
RAD	Radio Station
REC	Recreation
REH	Rehabilitation/Re-establish Native Plants
RRE	Railway Reserve
RUB	Rubbish
SAL	Saleyards
SAN	Sand
SCH	School-site
SET	Settlers requirements
SHO	Showgrounds
SNN	Sanitary
SOI	Soil Conservation
STO	Stopping place
STK	Stock Route
TIM	Timber
TOU	Tourism
TOW	Town-site
TRA	Training Ground
TRI	Trig station
UCL	Unallocated Crown Land
UNK	Unknown
VER	Road Verge
VPF	Vermin Proof Fence
WAT	Water
WLS	Wildlife Sanctuary
WOO	Firewood

ABBREVIATIONS USED IN THE WESTERN AUSTRALIAN HERBARIUM DATABASE

Geocode Method - The method that was used to record the latitude and longitude.

Auto - Indicates that the coordinate data in the record was created automatically (i.e. by software), usually by creating a coordinate from information provided in the Nearest Named Place or Locality textual description fields.

GAP - Acronym for "Generalised Arbitrary Point" as used in HISPID. GAP indicates that the coordinate data was obtained manually from the Nearest Named Place or Locality textual description fields.

GPS - Acronym for "Global Positioning System". GPS indicates that the coordinate data in the record was obtained from a GPS unit by the collector of the specimen.

MAN - Shorthand for manual. MAN indicates that the coordinate data was created by hand using some method not allowed for by one of the other manual Geocode Method values, in particular, TOPO, GAP, or GPS.

TOPO - Shorthand for topographic map. TOPO indicates that the coordinate data was obtained by plotting textual locality details against a topographic map.

None - Indicates that no coordinate data has been supplied by the collector.

Unknown - Indicates that there is no known method for determining the coordinate data. Should be used if the collector provided no indication of how they sampled the specimen's coordinate data.

PREC (Precision) - precision ratings for coordinates.

Precision 1: Absolutely precise (to nearest 100m or nearest second) and must be GPS determined. For example 35°26'42"S 123°40'26"E

Precision 2: Falling within a diameter of 3km (ca 2 minutes) or if no GPS mentioned in collecting notes. (The location must be able to be pinpointed on a 1:250 000 map, a spot locality. For example 35°26'42"S 123°40'26"E

Precision 3: Falling within a diameter of 10km (ca 7 minutes) or for degrees and minutes, where seconds have not been given. For example 35°26'_"S 123°40'_"E

Precision 4: Falling within a diameter of ca 50km (30 minutes). For example 35°26'_"S 123°40'_"E

Precision 5: Where a location is a prescribed large geographical area within a state or only the state is given. Diameter is greater than 50km. For example 35°_'_"S 123°_'_"E

Precision 6: used when localities are New Holland, Eastern Australia or Not given. Fields will be left blank.

Department of Parks and Wildlife

CONSERVATION CODES

For Western Australian Flora and Fauna

T Threatened species

Listed as Specially Protected under the *Wildlife Conservation Act 1950,* published under Schedule 1 of the Wildlife Conservation (Specially Protected Fauna) Notice for Threatened Fauna and Wildlife Conservation (Rare Flora) Notice for Threatened Flora (which may also be referred to as Declared Rare Flora).

- Fauna that is rare or likely to become extinct are declared to be fauna that is in need of special protection
- Flora that are extant and considered likely to become extinct, or rare and therefore in need of special protection, are declared to be rare flora

Species* which have been adequately searched for and are deemed to be, in the wild, either rare, at risk of extinction, or otherwise in need of special protection, and have been gazetted as such.
The assessment of the conservation status of these species is based on their national extent.

X Presumed extinct species

Listed as Specially Protected under the *Wildlife Conservation Act 1950,* published under Schedule 2 of the Wildlife Conservation (Specially Protected Fauna) Notice for Presumed Extinct Fauna and Wildlife Conservation (Rare Flora) Notice for Presumed Extinct Flora (which may also be referred to as Declared Rare Flora).

Species which have been adequately searched for and there is no reasonable doubt that the last individual has died, and have been gazetted as such.

IA Migratory birds protected under an international agreement

Listed as Specially Protected under the *Wildlife Conservation Act 1950,* listed under Schedule 3 of the Wildlife Conservation (Specially Protected Fauna) Notice.

Birds that are subject to an agreement between the government of Australia and the governments of Japan (JAMBA), China (CAMBA) and The Republic of Korea (ROKAMBA), relating to the protection of migratory birds.

S Other specially protected fauna

Listed as Specially Protected under the *Wildlife Conservation Act 1950.* Fauna declared to be in need of special protection, otherwise than for the reasons mentioned for Schedules 1, 2 or 3, are published under Schedule 4 of the Wildlife Conservation (Specially Protected Fauna) Notice.

Threatened Fauna and Flora are ranked according to their level of threat using IUCN Red List categories and criteria. *For example:* Carnaby's Cockatoo (*Calyptorynchus latirostris*) is listed as 'Specially Protected' under the *Wildlife Conservation Act 1950,* published under Schedule 1, and referred to as a 'Threatened' species with a ranking of 'Endangered'.

CR Critically Endangered - considered to be facing an extremely high risk of extinction in the wild.

EN Endangered - considered to be facing a very high risk of extinction in the wild.

VU Vulnerable - considered to be facing a high risk of extinction in the wild.

A list of the current rankings can be downloaded from the Parks and Wildlife Threatened Species and Communities webpage at http://dpaw.wa.gov.au/plants-and-animals/threatened-species-and-communities/

P Priority species

Species that maybe threatened or near threatened but are data deficient, have not yet been adequately surveyed to be listed under the Schedules of the Wildlife Conservation (Specially Protected Fauna) Notice or the Wildlife Conservation (Rare Flora) Notice, are added to the Priority Fauna or Priority Flora Lists under Priorities 1, 2 or 3. These three categories are ranked in order of priority for survey and evaluation of conservation status so that consideration can be given to their declaration as threatened flora or fauna. Species that are adequately known, are rare but not threatened, or meet criteria for near threatened, or that have been recently removed from the threatened list for other than taxonomic reasons, are placed in Priority 4. These species require regular monitoring. Conservation dependent species that are subject to a specific conservation program are placed in Priority 5.

Assessment of Priority codes is based on the Western Australian distribution of the species, unless the distribution in WA is part of a contiguous population extending into adjacent States, as defined by the known spread of locations.

1: Priority One: Poorly-known species

Species that are known from one or a few locations (generally five or less) which are potentially at risk. All occurrences are either: very small; or on lands not managed for conservation, e.g. agricultural or pastoral lands, urban areas, road and rail reserves, gravel reserves and active mineral leases; or otherwise under threat of habitat destruction or degradation. Species may be included if they are comparatively well known from one or more locations but do not meet adequacy of survey requirements and appear to be under immediate threat from known threatening processes. Such species are in urgent need of further survey.

2: Priority Two: Poorly-known species

Species that are known from one or a few locations (generally five or less), some of which are on lands managed primarily for nature conservation, e.g. national parks, conservation parks, nature reserves and other lands with secure tenure being managed for conservation. Species may be included if they are comparatively well known from one or more locations but do not meet adequacy of survey requirements and appear to be under threat from known threatening processes. Such species are in urgent need of further survey.

3: Priority Three: Poorly-known species

Species that are known from several locations, and the species does not appear to be under imminent threat, or from few but widespread locations with either large population size or significant remaining areas of apparently suitable habitat, much of it not under imminent threat. Species may be included if they are comparatively well known from several locations but do not meet adequacy of survey requirements and known threatening processes exist that could affect them. Such species are in need of further survey.

4: Priority Four: Rare, Near Threatened and other species in need of monitoring

(a) Rare. Species that are considered to have been adequately surveyed, or for which sufficient knowledge is available, and that are considered not currently threatened or in need of special protection, but could be if present circumstances change. These species are usually represented on conservation lands.
(b) Near Threatened. Species that are considered to have been adequately surveyed and that do not qualify for Conservation Dependent, but that are close to qualifying for Vulnerable.
(c) Species that have been removed from the list of threatened species during the past five years for reasons other than taxonomy.

5: Priority Five: Conservation Dependent species

Species that are not threatened but are subject to a specific conservation program, the cessation of which would result in the species becoming threatened within five years.

*Species includes all taxa (plural of taxon - a classificatory group of any taxonomic rank, e.g. a family, genus, species or any infraspecific category i.e. subspecies, variety or forma).

DEPARTMENT OF ENVIRONMENT AND CONSERVATION

THREATENED AND PRIORITY ECOLOGICAL COMMUNITIES INFORMATION

CONDITIONS IN RESPECT OF SUPPLY OF INFORMATION

1. All requests for data are to be made in writing to the Director General, Department of Environment and Conservation Attention: Species and Communities Branch

2. The data supplied may not be supplied to other organisations, nor be used for any purpose other than for the project for which they have been provided, without the prior written consent of the data custodian (Val English), Species and Communities Branch.

3. Specific locality information for threatened and priority ecological communities (TECs/PECs) is regarded as confidential, and should be treated as such by receiving organisations. Specific locality information for TECs/PECs may not be used in public reports without the written permission of the Director General, Department of Environment and Conservation. Publicly available reports may only show generalised locations (ie buffer locations). The TEC database manager is to be contacted for guidance on the presentation of TEC/PEC information.

4. Note that the Department of Environment and Conservation respects the privacy of private landowners who may have threatened and priority ecological communities on their property. Locations of TECs/PECs identified in the data as being on private property should be treated in confidence, and contact with property owners made through the Department of Environment and Conservation.

5. Receiving organisations should note that while every effort has been made to prevent errors and omissions in the data provided, they may be present. The Department of Environment and Conservation accepts no responsibility for this.

6. Receiving organisations must also recognise that the Threatened Ecological Communities database is subject to continual updating and amendment, and such considerations should be taken into account by the user.

7. It should be noted that the supplied data do not necessarily represent a comprehensive listing of the threatened and priority ecological communities of the area in question. Its comprehensiveness is dependant on the amount of survey carried out within the specified area. Private property has been relatively little surveyed. The receiving organisation should employ a consultant, if there is any likelihood of the presence of any threatened or priority ecological community, to undertake a survey of the area under consideration.

8. Acknowledgment of the Department of Environment and Conservation as source of the data is to be made in any published material. Copies of all such publications are to be forwarded to the Department of Environment and Conservation, Attention: Manager, Species and Communities Branch.

Threatened and Priority Ecological Community buffers in WA

UNDER NO CIRCUMSTANCES IS THIS DATA TO BE PROVIDED TO ANY THIRD PARTIES, for more details see conditions for the supply of this information.

Citation

Title: Threatened and Priority Ecological Community buffers in WA

Custodian: Department of Environment & Conservation

Description

Abstract: Ecological communities throughout WA that are "Presumed Totally Destroyed", "Critically Endangered", "Endangered", "Vulnerable", "Priority 1-5", "Lower Risk" and "Not evaluated". Communities are based on various life-forms including plants, invertebrates and micro-organisms.

Geographical Bounding Box

North: -14.788854

South: -35.005719

East: 128.870214

West: 113.765525

Data Currency and Status

Beginning Date: 1/1/94

Ending Date: current

Maintenance/Update: As requested

Access

Stored Data Format: ESRI shapefile

Coordinate System: GCS_GDA_1994

Access Constraints:	**Digital data is only available with written permission of the custodian. In addition, some occurrence data eg. location of sites on private land, is password restricted.**

Data Quality

Positional Accuracy:	**Point location data within occurrences usually from GPS fix, usually within 100 metres. Some digitized from hard copy.**
Attribute Accuracy:	**Not documented.**
Logical Consistency:	**Not documented.**
Completeness:	**Information on specific communities was obtained from regional, subregional or specific habitat surveys of floristic communities, invertebrate communities, wetland assemblages and communities of micro-organisms.**

Attributes List:

Name	Description
BDY_ID	Associated boundary polygon unique identifier
OCC_UNIQUE	Unique occurrence identifier
COM_ID	Shortened community name identifier
COM_NAME	Community name
CT_DESC	State listed Category of Threat
S_ID_COUNT	Number of Site IDs within a buffer
FIRST_S_ID	First site identifier
LAST_S_ID	Last site identifier
BUFFER	Buffer radius from site ID or boundary in metres

General Information:

Priority Ecological Communities

- There are 284 known PECs and subtypes , 271 (~95%) of these on the TEC/PEC database
- The location of priority communities is good, but not complete across the state
- There is a formal list of PECs at http://www.dec.wa.gov.au/content/view/849/2017/
- Many PECs are awaiting endorsement as TECs

buffers

- The buffer radius around each occurrence of a TEC or PEC is included to help ensure that developments with potential to impact groundwater or surface water are picked up.
- For wetland TEC or PECs we seek to include an area within the buffer zone that is intended to help protect groundwater and surface water. The area required to protect different types of wetlands from a variety of hydrological impacts will, of course, differ.

- For upland TEC or PECs that are believed not to be groundwater dependent, the buffer area radius encompasses the TEC or PEC site location recorded in the TEC database, and extends at least to the furthest point in the occurrence. This is to ensure that the 'buffer' area encompasses at least the entire TEC or PEC. This means that some linear occurrences may need a larger buffer radius to encompass the entire occurrence.
- Occurrences with a buffer distance of 0 are no longer extant.

Contact Information

Contact Organisation:	**Department of Environment & Conservation**
Contact Position:	**TEC Database Administrator - Species and Communities Branch**
Mail Address:	**Locked Bag 104, Bentley Delivery Centre**
Suburb/Locality:	**Kensington**
Country/State:	**WA**
Postcode:	**6983**
Telephone:	**(08) 9334 0116**
Fax:	**(08) 9334 0300**
Email:	**communities.data@dec.wa.gov.au**

Metadata Information

Metadata Date: **current**

NatureMap
Mapping Western Australia's biodiversity

NatureMap Species Report

Created By Guest user on 25/07/2016

Kingdom Plantae
Current Names Only Yes
Core Datasets Only Yes
Method 'By Circle'
Centre 116° 11' 50" E,21° 44' 11" S
Buffer 40km
Group By Family

Family	Species	Records
Acanthaceae	1	1
Aizoaceae	3	7
Amaranthaceae	26	73
Apiaceae	1	1
Araliaceae	3	6
Arecaceae	1	4
Asphodelaceae	1	1
Asteraceae	20	39
Boraginaceae	7	11
Brassicaceae	1	1
Campanulaceae	2	4
Capparaceae	1	4
Caryophyllaceae	4	15
Celastraceae	2	2
Chenopodiaceae	9	13
Cleomaceae	1	5
Combretaceae	3	5
Convolvulaceae	6	10
Cucurbitaceae	3	8
Cyperaceae	23	51
Dilleniaceae	2	2
Droseraceae	1	1
Euphorbiaceae	15	35
Fabaceae	86	256
Frankeniaceae	1	1
Gentianaceae	1	2
Goodeniaceae	14	31
Haloragaceae	3	6
Hydrocharitaceae	5	15
Lamiaceae	4	8
Lauraceae	1	2
Lentibulariaceae	1	1
Loranthaceae	4	5
Lythraceae	4	13
Malvaceae	58	174
Marsileaceae	3	3
Menispermaceae	1	2
Molluginaceae	3	7
Moraceae	2	4
Myrtaceae	15	36
Nyctaginaceae	5	12
Oleaceae	1	4
Onagraceae	1	3
Oxalidaceae	1	1
Papaveraceae	1	1
Pedaliaceae	1	1
Phrymaceae	2	2
Phyllanthaceae	5	8
Plantaginaceae	1	1
Poaceae	74	183
Portulacaceae	6	12
Potamogetonaceae	3	7
Proteaceae	7	9
Pteridaceae	4	10
Rubiaceae	5	6
Ruppiaceae	1	1
Sapindaceae	1	1
Scrophulariaceae	5	8
Solanaceae	16	38
Stylidiaceae	2	2
Surianaceae	1	1
Thymelaeaceae	1	1
Violaceae	1	2
Zygophyllaceae	8	24
TOTAL	**495**	**1203**

Name ID	Species Name	Naturalised	Conservation Code	[1]Endemic To Query Area

	Name ID	Species Name	Naturalised	Conservation Code	[1]Endemic To Query Area
Acanthaceae					
1.	12088	*Rostellularia adscendens var. clementii*			
Aizoaceae					
2.	44241	*Trianthema glossostigmum*			
3.	44305	*Trianthema pilosum*			
4.	44362	*Trianthema triquetrum*			
Amaranthaceae					
5.	2647	*Alternanthera angustifolia*			
6.	2651	*Alternanthera nana (Hairy Joyweed)*			
7.	2653	*Alternanthera pungens (Khaki Weed)*	Y		
8.	31076	*Amaranthus cochleitepalus*			
9.	2660	*Amaranthus cuspidifolius*			
10.	2663	*Amaranthus interruptus (Native Amaranth)*			
11.	2666	*Amaranthus mitchellii (Boggabri Weed)*			
12.		*Amaranthus sp.*			
13.	20018	*Amaranthus undulatus*			
14.	18361	*Gomphrena affinis subsp. pilbarensis*			
15.	2680	*Gomphrena cunninghamii*			
16.	2690	*Ptilotus aervoides*			
17.	2694	*Ptilotus appendiculatus*			
18.	2696	*Ptilotus astrolasius*			
19.	2698	*Ptilotus auriculifolius*			
20.	2699	*Ptilotus axillaris (Mat Mulla Mulla)*			
21.	2704	*Ptilotus calostachyus (Weeping Mulla Mulla)*			
22.	2711	*Ptilotus clementii (Tassel Top)*			
23.	2725	*Ptilotus fusiformis*			
24.	2728	*Ptilotus gomphrenoides*			
25.	2734	*Ptilotus incanus*			
26.	2738	*Ptilotus latifolius (Tangled Mulla Mulla)*			
27.	41001	*Ptilotus nobilis subsp. nobilis (Yellow Tails)*			
28.	2747	*Ptilotus obovatus (Cotton Bush)*			
29.		*Ptilotus sp.*			
30.	2766	*Ptilotus villosiflorus*			
Apiaceae					
31.	6218	*Daucus glochidiatus (Australian Carrot)*			
Araliaceae					
32.	6202	*Astrotricha hamptonii (Ironplant)*			
33.	6278	*Trachymene oleracea*			
34.	19043	*Trachymene oleracea subsp. oleracea*			
Arecaceae					
35.	1042	*Phoenix dactylifera (Date Palm)*	Y		
Asphodelaceae					
36.	1364	*Asphodelus fistulosus (Onion Weed)*	Y		
Asteraceae					
37.	7822	*Angianthus acrohyalinus (Hook-leaf Angianthus)*			
38.	7866	*Blumea tenella*			
39.	14090	*Calocephalus beardii*			
40.	7893	*Calocephalus knappii*			
41.	7899	*Calotis breviradiata*			
42.	7906	*Calotis plumulifera*			
43.	19762	*Centipeda minima subsp. macrocephala*			
44.	35558	*Flaveria trinervia (Speedy Weed)*	Y		
45.	29594	*Helichrysum luteoalbum (Jersey Cudweed)*			
46.	13494	*Pentalepis trichodesmoides*			
47.	42160	*Pentalepis trichodesmoides subsp. trichodesmoides*			
48.	17817	*Pluchea dunlopii*			
49.	17816	*Pluchea ferdinandi-muelleri*			
50.	43944	*Pluchea longiseta*			
51.	8168	*Pluchea rubelliflora*			
52.	8192	*Pterocaulon sphacelatum (Apple Bush)*			
53.	8193	*Pterocaulon sphaeranthoides*			
54.	13310	*Rhodanthe margarethae*			
55.	8238	*Streptoglossa liatroides*			
56.	8240	*Streptoglossa odora*			
Boraginaceae					
57.	6706	*Heliotropium cunninghamii*			

	Name ID	Species Name	Naturalised	Conservation Code	[1]Endemic To Query Area
58.	6712	*Heliotropium heteranthum*			
59.	6713	*Heliotropium ovalifolium*			
60.	17309	*Heliotropium pachyphyllum*			
61.		*Heliotropium sp.*			
62.	17031	*Heliotropium transforme*			
63.	11750	*Trichodesma zeylanicum var. zeylanicum*			
Brassicaceae					
64.	3037	*Lepidium phlebopetalum (Veined Peppercress)*			
Campanulaceae					
65.	37480	*Lobelia arnhemiaca*			
66.	36880	*Lobelia heterophylla subsp. pilbarensis*			
Capparaceae					
67.	11670	*Capparis spinosa var. nummularia (Coastal Caper)*			
Caryophyllaceae					
68.	2898	*Polycarpaea corymbosa*			
69.	12075	*Polycarpaea corymbosa var. corymbosa*			
70.	2901	*Polycarpaea holtzei*			
71.	2903	*Polycarpaea longiflora*			
Celastraceae					
72.	4731	*Stackhousia intermedia*			
73.	18405	*Stackhousia sp. swollen gynophore (W.R. Barker 2041)*			
Chenopodiaceae					
74.	11632	*Dysphania glomulifera subsp. eremaea*			
75.	2544	*Maireana georgei (Satiny Bluebush)*			
76.	2551	*Maireana melanocoma (Pussy Bluebush)*			
77.	2604	*Sclerolaena costata*			
78.	2607	*Sclerolaena densiflora*			
79.	2611	*Sclerolaena eriacantha (Tall Bindii)*			
80.	2638	*Suaeda arbusculoides*			
81.	31616	*Tecticornia auriculata*			
82.	33220	*Tecticornia pterygosperma subsp. denticulata*			
Cleomaceae					
83.	2988	*Cleome viscosa (Tickweed, Tjinduwadhu)*			
Combretaceae					
84.	5300	*Terminalia canescens (Joolal)*			
85.	45698	*Terminalia circumalata*			
86.	5313	*Terminalia supranitifolia*		P3	
Convolvulaceae					
87.	6608	*Bonamia pannosa*			
88.	44782	*Bonamia pilbarensis*			
89.	6633	*Ipomoea muelleri (Poison Morning Glory, Yumbu)*			
90.	11312	*Ipomoea pes-caprae subsp. brasiliensis*			
91.	6637	*Ipomoea polymorpha*			
92.		*Polymeria sp.*			
Cucurbitaceae					
93.	7369	*Citrullus colocynthis*	Y		
94.	41721	*Cucumis variabilis*			
95.	7381	*Trichosanthes cucumerina*			
Cyperaceae					
96.	750	*Bulbostylis barbata*			
97.	774	*Cyperus bifax (Downs Nutgrass)*			
98.	786	*Cyperus cunninghamii*			
99.	12811	*Cyperus cunninghamii subsp. cunninghamii*			
100.	788	*Cyperus dactylotes*			
101.	789	*Cyperus difformis (Rice Sedge)*			
102.	12808	*Cyperus hesperius*			
103.	798	*Cyperus iria*			
104.	799	*Cyperus ixiocarpus*			
105.	12807	*Cyperus microcephalus subsp. microcephalus*			
106.	810	*Cyperus rotundus (Nut Grass)*	Y		
107.	814	*Cyperus squarrosus*			
108.	818	*Cyperus vaginatus (Stiffleaf Sedge)*			
109.	823	*Eleocharis atropurpurea*			
110.	826	*Eleocharis dulcis (Chinese Water Chestnut)*			
111.	827	*Eleocharis geniculata*			

	Name ID	Species Name	Naturalised	Conservation Code	[1]Endemic To Query Area
112.	831	*Eleocharis sphacelata (Tall Spikerush, Djabren)*			
113.	851	*Fimbristylis dichotoma (Eight Day Grass)*			
114.	862	*Fimbristylis microcarya*			
115.	12159	*Fimbristylis simulans*			
116.	963	*Schoenoplectus laevis*			
117.	964	*Schoenoplectus lateriflorus*			
118.	16257	*Schoenoplectus subulatus*			
Dilleniaceae					
119.	5135	*Hibbertia hypericoides (Yellow Buttercups)*			
120.	5146	*Hibbertia montana*		P4	
Droseraceae					
121.	43544	*Drosera finlaysoniana*			
Euphorbiaceae					
122.	17422	*Adriana tomentosa var. tomentosa*			
123.	4617	*Euphorbia australis (Namana)*			
124.	42843	*Euphorbia australis var. glabra*		P2	
125.	35303	*Euphorbia australis var. subtomentosa*			
126.	4620	*Euphorbia boophthona (Gascoyne Spurge)*			
127.	9048	*Euphorbia careyi*			
128.	4629	*Euphorbia hirta (Asthma Plant)*	Y		
129.		*Euphorbia sp.*			
130.	4647	*Euphorbia tannensis*			
131.	12097	*Euphorbia tannensis subsp. eremophila (Desert Spurge)*			
132.	42879	*Euphorbia trigonosperma*			
133.	13281	*Euphorbia vaccaria*			
134.	42877	*Euphorbia vaccaria var. erucoides*			
135.	42876	*Euphorbia vaccaria var. vaccaria*			
136.	4650	*Euphorbia wheeleri*			
Fabaceae					
137.	3209	*Acacia ampliceps*			
138.	44586	*Acacia ampliceps x sclerosperma subsp. sclerosperma*			
139.	3214	*Acacia ancistrocarpa (Fitzroy Wattle)*			
140.	37260	*Acacia aptaneura*			
141.	3223	*Acacia arida*			
142.	3228	*Acacia atkinsiana*			
143.	3241	*Acacia bivenosa*			
144.	3260	*Acacia citrinoviridis*			
145.	17013	*Acacia colei var. colei*			
146.	17014	*Acacia colei var. ileocarpa*			
147.	3300	*Acacia dictyophleba (Sandhill Wattle, Ngarkalya)*			
148.	16174	*Acacia elachantha*			
149.	3360	*Acacia hamersleyensis*			
150.	3377	*Acacia inaequilatera (Baderi)*			
151.	3419	*Acacia ligulata (Umbrella Bush, Watarka)*			
152.	3471	*Acacia orthocarpa (Needleleaf Wattle)*			
153.	3500	*Acacia pruinocarpa (Gidgee)*			
154.	3501	*Acacia ptychophylla*			
155.	3506	*Acacia pyrifolia (Ranji Bush, Kandji)*			
156.	29016	*Acacia pyrifolia var. morrisonii*			
157.	29015	*Acacia pyrifolia var. pyrifolia*			
158.	3519	*Acacia rhodophloia*			
159.	13078	*Acacia sclerosperma subsp. sclerosperma*			
160.	29135	*Acacia sericophylla*			
161.		*Acacia sp.*			
162.	3553	*Acacia spondylophylla*			
163.	13070	*Acacia synchronicia*			
164.	3577	*Acacia tetragonophylla (Kurara, Wakalpuka)*			
165.	3579	*Acacia trachycarpa (Minni Ritchi, Balgali)*			
166.	23521	*Acacia trudgeniana*			
167.	3585	*Acacia tumida (Pindan Wattle, Walgali)*			
168.	20319	*Acacia tumida var. pilbarensis*			
169.	3598	*Acacia wanyu*			
170.	3606	*Acacia xiphophylla*			
171.	3680	*Aeschynomene indica (Budda Pea)*			
172.	17147	*Alysicarpus muelleri*			
173.	11055	*Cajanus cinereus*			
174.	3783	*Crotalaria medicaginea*			
175.	11231	*Crotalaria novae-hollandiae subsp. novae-hollandiae*			

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176.	17439	*Cullen lachnostachys*			
177.	17118	*Cullen leucanthum*			
178.	17119	*Cullen leucochaites*			
179.	17120	*Cullen pogonocarpum*			
180.	3871	*Erythrina vespertilio (Yulbah)*			
181.	3971	*Indigofera boviperda*			
182.	17113	*Indigofera boviperda subsp. boviperda*			
183.	45436	*Indigofera chamaeclada subsp. pubens*			
184.	3973	*Indigofera colutea (Sticky Indigo)*			
185.	45473	*Indigofera fractiflexa subsp. fractiflexa*			
186.	3980	*Indigofera linifolia*			
187.	3982	*Indigofera monophylla*			
188.	3985	*Indigofera rugosa*			
189.	20317	*Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)*		P3	
190.	3987	*Indigofera trita*			
191.	3989	*Isotropis atropurpurea (Poison Sage)*			
192.	4061	*Lotus cruentus (Redflower Lotus)*			
193.	4105	*Mirbelia viminalis*			
194.	3675	*Petalostylis labicheoides (Slender Petalostylis)*			
195.	20862	*Rhynchosia bungarensis*		P4	
196.	4191	*Rhynchosia minima (Rhynchosia)*			
197.	12280	*Senna artemisioides subsp. oligophylla*			
198.	12305	*Senna glutinosa subsp. chatelainiana*			
199.	12307	*Senna glutinosa subsp. glutinosa*			
200.	12309	*Senna glutinosa subsp. pruinosa*			
201.	12308	*Senna glutinosa subsp. x luerssenii*			
202.	12312	*Senna notabilis*			
203.		*Senna sp.*			
204.	12319	*Senna venusta*			
205.	4198	*Sesbania formosa (White Dragon Tree)*			
206.	13596	*Swainsona complanata*			
207.	12356	*Swainsona formosa*			
208.	4234	*Swainsona maccullochiana (Ashburton Pea)*			
209.	4280	*Tephrosia rosea (Flinders River Poison, Bungoo'dah)*			
210.	41825	*Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)*			
211.		*Tephrosia sp.*			
212.	15947	*Tephrosia sp. B Kimberley Flora (C.A. Gardner 7300)*			
213.	17768	*Tephrosia sp. Bungaroo Creek (M.E. Trudgen 11601)*			
214.	41811	*Tephrosia sp. Fortescue (A.A. Mitchell 606)*			
215.	42442	*Tephrosia sp. NW Eremaean (S. van Leeuwen et al. PBS 0356)*			
216.	40060	*Tephrosia sp. clay soils (S. van Leeuwen et al. PBS 0273)*			
217.	4285	*Tephrosia supina*			
218.	4286	*Tephrosia uniovulata*			
219.	4287	*Tephrosia virens*			
220.		*Vigna benthamii*			
221.	4323	*Vigna lanceolata (Maloga Vigna, Wega)*			
222.	11576	*Vigna lanceolata var. lanceolata*			
Frankeniaceae					
223.	5188	*Frankenia ambita*			
Gentianaceae					
224.	41646	*Schenkia clementii*			
Goodeniaceae					
225.	7424	*Dampiera candicans*			
226.	7490	*Goodenia armitiana*			
227.	7509	*Goodenia forrestii*			
228.	7521	*Goodenia lamprosperma*			
229.	7526	*Goodenia microptera*			
230.	12552	*Goodenia muelleriana*			
231.	7530	*Goodenia nuda*		P4	
232.	7544	*Goodenia ramelii*			
233.		*Goodenia sp.*			
234.	10982	*Goodenia stobbsiana*			
235.	7556	*Goodenia tenuiloba*			
236.	7644	*Scaevola spinescens (Currant Bush, Maroon)*			
237.	7654	*Velleia connata (Cup Velleia)*			
238.	7658	*Velleia discophora (Cabbage Poison)*			
Haloragaceae					
239.	6174	*Haloragis gossei*			

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240.	23464	*Haloragis gossei var. inflata*			
241.	6201	*Myriophyllum verrucosum (Red Water Milfoil)*			
Hydrocharitaceae					
242.	17955	*Najas graminea var. graminea*			
243.	138	*Najas marina (Prickly Water Nymph)*			
244.	139	*Najas tenuifolia (Water Nymph)*			
245.	17868	*Vallisneria nana*			
246.		*Vallisneria sp.*			
Lamiaceae					
247.	6830	*Basilicum polystachyon*			
248.	13692	*Clerodendrum floribundum var. angustifolium*			
249.	13691	*Clerodendrum floribundum var. ovatum*			
250.	6907	*Ocimum basilicum (Basil)*	Y		
Lauraceae					
251.	2949	*Cassytha capillaris*			
Lentibulariaceae					
252.	7125	*Utricularia australis*			
Loranthaceae					
253.	13700	*Amyema bifurcata*			
254.	2383	*Amyema preissii (Wireleaf Mistletoe)*			
255.	2385	*Amyema sanguinea*			
256.	2396	*Lysiana casuarinae*			
Lythraceae					
257.	5276	*Ammannia auriculata*			
258.	5277	*Ammannia baccifera*			
259.	5285	*Rotala diandra*			
260.	5286	*Rotala mexicana*			
Malvaceae					
261.	4891	*Abutilon fraseri (Lantern Bush)*			
262.	16919	*Abutilon hannii*			
263.	4895	*Abutilon lepidum*			
264.	4898	*Abutilon macrum*			
265.	4901	*Abutilon otocarpum (Desert Chinese Lantern)*			
266.	4902	*Abutilon oxycarpum (Flannel Weed)*			
267.		*Abutilon sp.*			
268.	42920	*Abutilon sp. Dioicum (A.A. Mitchell PRP 1618)*			
269.		*Abutilon sp. Dioicum (A.A.Mitchell PRP 1618)*			
270.	14113	*Abutilon sp. Pilbara (W.R. Barker 2025)*			
271.	13659	*Corchorus laniflorus*			
272.	18408	*Corchorus lasiocarpus subsp. parvus*			
273.	4862	*Corchorus parviflorus*			
274.	4864	*Corchorus sidoides (Flannel Weed)*			
275.	18415	*Corchorus sidoides subsp. sidoides*			
276.	18414	*Corchorus sidoides subsp. vermicularis*			
277.		*Corchorus sp.*			
278.	20242	*Corchorus sp. Hamersley Range hilltops (S. van Leeuwen 3826)*			
279.	17661	*Corchorus tectus*			
280.	4865	*Corchorus tridens*			
281.	4910	*Gossypium australe (Native Cotton)*			
282.	4918	*Gossypium robinsonii (Wild Cotton)*			
283.		*Gynatrix pulchella*			
284.	29317	*Hibiscus austrinus var. austrinus*			
285.	4922	*Hibiscus brachychlaenus*			
286.	4925	*Hibiscus coatesii*			
287.	4930	*Hibiscus goldsworthii*			
288.	4933	*Hibiscus leptocladus*			
289.	4941	*Hibiscus solanifolius*			
290.	11651	*Hibiscus sturtii var. campylochlamys*			
291.	11385	*Hibiscus sturtii var. grandiflorus*			
292.	11477	*Hibiscus sturtii var. platychlamys*			
293.	5024	*Keraudrenia nephrosperma*			
294.	5051	*Melhania oblongifolia*			
295.		*Melhania sp.*			
296.	5053	*Melochia pyramidata*	Y		
297.	31758	*Sida arsiniata*			
298.	4971	*Sida cardiophylla*			
299.	4972	*Sida clementii*			

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300.	4976	*Sida echinocarpa*			
301.	4977	*Sida fibulifera (Silver Sida)*			
302.	4988	*Sida rohlenae*			
303.	18149	*Sida rohlenae subsp. rohlenae*			
304.		*Sida sp.*			
305.	31859	*Sida sp. Articulation below (A.A. Mitchell PRP 1605)*			
306.	33698	*Sida sp. Pilbara (A.A. Mitchell PRP 1543)*			
307.		*Sida sp. Pilbara (A.A.Mitchell PRP1543)*			
308.	31852	*Sida sp. Supplejack Station (T.S. Henshall 2345)*			
309.	16617	*Sida sp. spiciform panicles (E. Leyland s.n. 14/8/90)*			
310.	16948	*Sida sp. verrucose glands (F.H. Mollemans 2423)*			
311.	4989	*Sida spinosa (Spiny Sida)*			
312.	4875	*Triumfetta chaetocarpa (Urchins)*			
313.	14694	*Triumfetta clementii*			
314.	4878	*Triumfetta johnstonii*			
315.	14942	*Triumfetta maconochieana*			
316.		*Triumfetta sp.*			
317.	17529	*Triumfetta tenuiseta*			
318.	5106	*Waltheria indica*			
Marsileaceae					
319.	74	*Marsilea drummondii (Common Nardoo)*			
320.	76	*Marsilea hirsuta (Nardoo)*			
321.		*Marsilea sp.*			
Menispermaceae					
322.	2942	*Tinospora smilacina (Snakevine, Oondala)*			
Molluginaceae					
323.	2835	*Glinus lotoides (Hairy Carpet Weed)*			
324.	2836	*Glinus oppositifolius*			
325.	29851	*Mollugo molluginea*			
Moraceae					
326.	31578	*Ficus aculeata var. indecora (Ranji)*			
327.	19648	*Ficus brachypoda*			
Myrtaceae					
328.	16783	*Corymbia candida*			
329.	16782	*Corymbia candida subsp. candida*			
330.	16780	*Corymbia candida subsp. dipsodes*			
331.	17077	*Corymbia ferriticola*			
332.	17093	*Corymbia hamersleyana*			
333.		*Corymbia terminalis*			
334.	17084	*Corymbia zygophylla*			
335.	5580	*Eucalyptus camaldulensis (River Gum, Yabalinyba)*			
336.	35345	*Eucalyptus camaldulensis subsp. obtusa (Blunt-budded River Red Gum)*			
337.	35343	*Eucalyptus camaldulensis subsp. refulgens*			
338.	18088	*Eucalyptus leucophloia subsp. leucophloia*			
339.	5875	*Melaleuca argentea (Silver Cadjeput, Bandaran)*			
340.	5879	*Melaleuca bracteata (River Teatree)*			
341.	5915	*Melaleuca glomerata*			
342.	6081	*Verticordia forrestii (Forrest's Featherflower)*			
Nyctaginaceae					
343.	2769	*Boerhavia burbidgeana*			
344.	2770	*Boerhavia coccinea (Tar Vine, Wituka)*			
345.	2772	*Boerhavia gardneri*			
346.	2774	*Boerhavia repleta*			
347.	2775	*Boerhavia schomburgkiana*			
Oleaceae					
348.	12059	*Jasminum didymum subsp. lineare (Desert Jasmine)*			
Onagraceae					
349.	6136	*Ludwigia perennis*			
Oxalidaceae					
350.	4349	*Oxalis corniculata (Yellow Wood Sorrel)*	Y		
Papaveraceae					
351.	17797	*Argemone ochroleuca subsp. ochroleuca*	Y		
Pedaliaceae					
352.	43521	*Josephinia sp. Style-topped fruit (M. Maier BES MM 1017)*			Y

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Phrymaceae					
353.	7060	*Glossostigma diandrum*			
354.	12486	*Peplidium aithocheilum*			
Phyllanthaceae					
355.	12013	*Flueggea virosa subsp. melanthesoides (Dogwood, Guwal)*			
356.	9056	*Phyllanthus baccatus*			
357.	17626	*Phyllanthus erwinii*			
358.	4680	*Phyllanthus maderaspatensis*			
359.		*Phyllanthus sp.*			
Plantaginaceae					
360.	7098	*Stemodia grossa (Marsh Stemodia, Mindjaara)*			
Poaceae					
361.	172	*Acrachne racemosa*			
362.	204	*Aristida burbidgeae*			
363.	207	*Aristida contorta (Bunched Kerosene Grass)*			
364.	210	*Aristida holathera*			
365.	12063	*Aristida holathera var. holathera*			
366.	213	*Aristida ingrata*			
367.	215	*Aristida latifolia (Feathertop Wiregrass)*			
368.	217	*Aristida nitidula (Flat-awned Threeawn)*			
369.		*Aristida sp.*			
370.	239	*Bothriochloa bladhii (Forest Bluegrass)*			
371.	16355	*Bothriochloa decipiens var. cloncurrensis*		P1	
372.	241	*Brachyachne convergens (Spider Grass)*			
373.	258	*Cenchrus ciliaris (Buffel Grass)*	Y		
374.	259	*Cenchrus echinatus (Burrgrass)*	Y		
375.	29721	*Cenchrus setiger (Birdwood Grass)*	Y		
376.	266	*Chloris barbata (Purpletop Chloris)*	Y		
377.	270	*Chloris pumilio*			
378.	279	*Cymbopogon ambiguus (Scentgrass)*			
379.		*Cymbopogon sp.*			
380.	283	*Cynodon dactylon (Couch)*	Y		
381.	290	*Dactyloctenium radulans (Button Grass)*			
382.	303	*Dichanthium fecundum (Curly Bluegrass)*			
383.	13741	*Dichanthium sericeum subsp. humilius*			
384.	310	*Digitaria brownii (Cotton Panic Grass)*			
385.	313	*Digitaria ctenantha (Comb Finger Grass)*			
386.	328	*Echinochloa colona (Awnless Barnyard Grass)*	Y		
387.	355	*Elytrophorus spicatus (Spikegrass)*			
388.	357	*Enneapogon caerulescens (Limestone Grass)*			
389.		*Enneapogon sp.*			
390.	375	*Eragrostis cumingii (Cuming's Love Grass)*			
391.	378	*Eragrostis dielsii (Mallee Lovegrass)*			
392.	380	*Eragrostis eriopoda (Woollybutt Grass, Wangurnu)*			
393.	16731	*Eragrostis exigua*			
394.	381	*Eragrostis falcata (Sickle Lovegrass)*			
395.	388	*Eragrostis leptocarpa (Drooping Lovegrass)*			
396.	38505	*Eragrostis surreyana*		P3	
397.	398	*Eragrostis tenellula (Delicate Lovegrass)*			
398.	399	*Eragrostis xerophila (Knotty-butt Neverfail)*			
399.	400	*Eriachne aristidea*			
400.	403	*Eriachne benthamii (Swamp Wanderrie)*			
401.	407	*Eriachne festucacea (Plains Wandarrie Grass)*			
402.	411	*Eriachne helmsii (Buck Wanderrie Grass)*			
403.	413	*Eriachne mucronata (Mountain Wanderrie Grass)*			
404.	16485	*Eriachne pulchella subsp. dominii*			
405.	16486	*Eriachne pulchella subsp. pulchella*			
406.	421	*Eriachne tenuiculmis*			
407.	426	*Eriochloa pseudoacrotricha (Perennial Cupgrass)*			
408.	11011	*Eulalia aurea*			
409.	443	*Heteropogon contortus (Bunch Speargrass)*			
410.	464	*Iseilema membranaceum (Small Flinders Grass)*			
411.	471	*Leptochloa digitata (Whorled Cane Grass)*			
412.	19061	*Leptochloa fusca*			
413.	505	*Panicum laevinode*			
414.	518	*Paspalidium clementii (Clements Paspalidium)*			
415.	519	*Paspalidium constrictum (Knottybutt Grass)*			
416.	523	*Paspalidium rarum (Rare Paspalidium)*			
417.	525	*Paspalidium tabulatum*			

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418.	606	*Setaria dielsii (Diels' Pigeon Grass)*			
419.	629	*Sporobolus australasicus (Fairy Grass)*			
420.	17819	*Themeda sp. Mt Barricade (M.E. Trudgen 2471)*			
421.	673	*Themeda triandra*			
422.	679	*Triodia angusta*			
423.	13131	*Triodia epactia*			
424.	17877	*Triodia melvillei*			
425.		*Triodia sp.*			
426.	45373	*Triodia sp. Pannawonica (B.M. Anderson & M.D. Barrett BMA 89)*		P1	Y
427.	43220	*Triodia sp. Peedamulla (A.A. Mitchell PRP 1636)*			
428.	35843	*Triodia sp. Robe River (M.E. Trudgen et al. MET 12367)*		P3	
429.	704	*Triodia wiseana (Limestone Spinifex)*			
430.	717	*Urochloa piligera*			
431.	729	*Xerochloa barbata (Rice Grass)*			
432.	730	*Xerochloa imberbis (Rice Grass)*			
433.	732	*Yakirra australiensis*			
434.	11894	*Yakirra australiensis var. australiensis*			
Portulacaceae					
435.	2864	*Calandrinia ptychosperma*			
436.	2878	*Portulaca conspicua*			
437.	2882	*Portulaca intraterranea*			
438.	2884	*Portulaca oleracea (Purslane, Wakati)*			
439.	2886	*Portulaca pilosa (Djanggara)*	Y		
440.		*Portulaca sp.*			
Potamogetonaceae					
441.		*Potamogeton sp.*			
442.	20426	*Potamogeton tepperi*			
443.	113	*Potamogeton tricarinatus (Floating Pondweed)*			
Proteaceae					
444.	19570	*Grevillea pyramidalis subsp. leucadendron*			
445.	2121	*Grevillea wickhamii (Wickham's Grevillea)*			
446.	13440	*Grevillea wickhamii subsp. aprica*			
447.	19478	*Grevillea wickhamii subsp. hispidula*			
448.	19074	*Grevillea wickhamii subsp. macrodonta*			
449.	2138	*Hakea chordophylla*			
450.	19137	*Hakea lorea subsp. lorea*			
Pteridaceae					
451.	30	*Ceratopteris thalictroides*			
452.	32	*Cheilanthes brownii*			
453.	37	*Cheilanthes lasiophylla (Woolly Cloak Fern)*			
454.	12818	*Cheilanthes sieberi subsp. sieberi*			
Rubiaceae					
455.	7338	*Oldenlandia crouchiana*			
456.	7339	*Oldenlandia galioides*			
457.		*Oldenlandia sp.*			
458.	12964	*Pomax rupestris*			
459.	13339	*Synaptantha tillaeacea var. tillaeacea*			
Ruppiaceae					
460.		*Ruppia sp.*			
Sapindaceae					
461.	4759	*Dodonaea coriacea*			
Scrophulariaceae					
462.	7192	*Eremophila cuneifolia (Pinyuru, T'iranju)*			
463.	15052	*Eremophila forrestii subsp. forrestii*			
464.	16696	*Eremophila fraseri subsp. fraseri*			
465.	7234	*Eremophila longifolia (Berrigan, Tulypurpa)*			
466.	23997	*Eremophila tietkensii*			
Solanaceae					
467.	6971	*Nicotiana benthamiana (Tjuntiwari)*			
468.	11331	*Nicotiana occidentalis subsp. obliqua*			
469.	11856	*Nicotiana occidentalis subsp. occidentalis*			
470.		*Nicotiana sp.*			
471.	20652	*Physalis angulata*	Y		
472.	6989	*Solanum ashbyae*			
473.	6995	*Solanum centrale (Desert Raisin, Kampurarpa)*			
474.	6998	*Solanum cleistogamum*			

	Name ID	Species Name	Naturalised	Conservation Code	[1]Endemic To Query Area
475.	7002	*Solanum diversiflorum*			
476.	7009	*Solanum gabrielae*			
477.	7014	*Solanum horridum*			
478.	7018	*Solanum lasiophyllum (Flannel Bush, Mindjulu)*			
479.	7022	*Solanum nigrum (Black Berry Nightshade)*	Y		
480.	7029	*Solanum phlomoides*			
481.		*Solanum sp.*			
482.	7036	*Solanum sturtianum (Thargomindah Nightshade)*			
Stylidiaceae					
483.	7729	*Stylidium fluminense*			
484.	18123	*Stylidium weeliwolli*		P2	
Surianaceae					
485.	3182	*Stylobasium spathulatum (Pebble Bush)*			
Thymelaeaceae					
486.	5230	*Pimelea ammocharis*			
Violaceae					
487.	5215	*Hybanthus aurantiacus*			
Zygophyllaceae					
488.	4368	*Tribulopis angustifolia*			
489.	4374	*Tribulus astrocarpus*			
490.	4377	*Tribulus hirsutus*			
491.	4379	*Tribulus macrocarpus*			
492.	4380	*Tribulus occidentalis (Perennial Caltrop)*			
493.	4381	*Tribulus platypterus (Cork Hopbush)*			
494.		*Tribulus sp.*			
495.	4383	*Tribulus terrestris (Caltrop)*	Y		

Conservation Codes
T - Rare or likely to become extinct
X - Presumed extinct
IA - Protected under international agreement
S - Other specially protected fauna
1 - Priority 1
2 - Priority 2
3 - Priority 3
4 - Priority 4
5 - Priority 5

[1] For NatureMap's purposes, species flagged as endemic are those whose records are wholely contained within the search area. Note that only those records complying with the search criterion are included in the calculation. For example, if you limit records to those from a specific datasource, only records from that datasource are used to determine if a species is restricted to the query area.

Australian Government

Department of the Environment

EPBC Act Protected Matters Report

This report provides general guidance on matters of national environmental significance and other matters protected by the EPBC Act in the area you have selected.

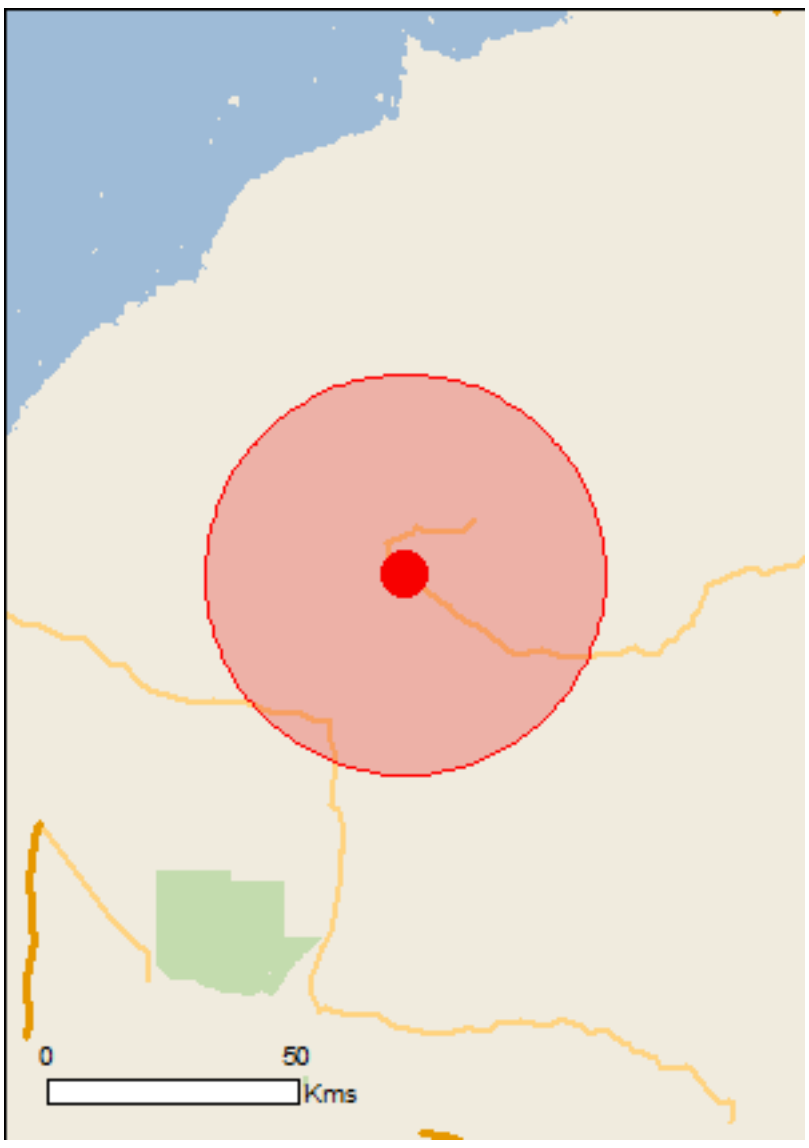
Information on the coverage of this report and qualifications on data supporting this report are contained in the caveat at the end of the report.

Information is available about Environment Assessments and the EPBC Act including significance guidelines, forms and application process details.

Report created: 25/07/16 16:03:50

Summary
Details
- Matters of NES
- Other Matters Protected by the EPBC Act
- Extra Information

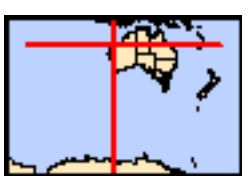
Caveat
Acknowledgements



This map may contain data which are ©Commonwealth of Australia (Geoscience Australia), ©PSMA 2010

Coordinates

Buffer: 40.0Km



Summary

Matters of National Environmental Significance

This part of the report summarises the matters of national environmental significance that may occur in, or may relate to, the area you nominated. Further information is available in the detail part of the report, which can be accessed by scrolling or following the links below. If you are proposing to undertake an activity that may have a significant impact on one or more matters of national environmental significance then you should consider the Administrative Guidelines on Significance.

World Heritage Properties:	None
National Heritage Places:	None
Wetlands of International Importance:	None
Great Barrier Reef Marine Park:	None
Commonwealth Marine Area:	None
Listed Threatened Ecological Communities:	None
Listed Threatened Species:	8
Listed Migratory Species:	7

Other Matters Protected by the EPBC Act

This part of the report summarises other matters protected under the Act that may relate to the area you nominated. Approval may be required for a proposed activity that significantly affects the environment on Commonwealth land, when the action is outside the Commonwealth land, or the environment anywhere when the action is taken on Commonwealth land. Approval may also be required for the Commonwealth or Commonwealth agencies proposing to take an action that is likely to have a significant impact on the environment anywhere.

The EPBC Act protects the environment on Commonwealth land, the environment from the actions taken on Commonwealth land, and the environment from actions taken by Commonwealth agencies. As heritage values of a place are part of the 'environment', these aspects of the EPBC Act protect the Commonwealth Heritage values of a Commonwealth Heritage place. Information on the new heritage laws can be found at http://www.environment.gov.au/heritage

A permit may be required for activities in or on a Commonwealth area that may affect a member of a listed threatened species or ecological community, a member of a listed migratory species, whales and other cetaceans, or a member of a listed marine species.

Commonwealth Land:	None
Commonwealth Heritage Places:	None
Listed Marine Species:	12
Whales and Other Cetaceans:	None
Critical Habitats:	None
Commonwealth Reserves Terrestrial:	None
Commonwealth Reserves Marine:	None

Extra Information

This part of the report provides information that may also be relevant to the area you have nominated.

State and Territory Reserves:	None
Regional Forest Agreements:	None
Invasive Species:	10
Nationally Important Wetlands:	None
Key Ecological Features (Marine)	None

Details

Matters of National Environmental Significance

Listed Threatened Species		[Resource Information]
Name	Status	Type of Presence
Birds		
Pezoporus occidentalis Night Parrot [59350]	Endangered	Species or species habitat may occur within area
Rostratula australis Australian Painted Snipe [77037]	Endangered	Species or species habitat may occur within area
Mammals		
Dasyurus hallucatus Northern Quoll, Digul [331]	Endangered	Species or species habitat known to occur within area
Macroderma gigas Ghost Bat [174]	Vulnerable	Species or species habitat likely to occur within area
Macrotis lagotis Greater Bilby [282]	Vulnerable	Species or species habitat likely to occur within area
Rhinonicteris aurantia (Pilbara form) Pilbara Leaf-nosed Bat [82790]	Vulnerable	Roosting known to occur within area
Plants		
Lepidium catapycnon Hamersley Lepidium, Hamersley Catapycnon [9397]	Vulnerable	Species or species habitat likely to occur within area
Reptiles		
Liasis olivaceus barroni Olive Python (Pilbara subspecies) [66699]	Vulnerable	Species or species habitat known to occur within area

Listed Migratory Species		[Resource Information]
* Species is listed under a different scientific name on the EPBC Act - Threatened Species list.		
Name	Threatened	Type of Presence
Migratory Marine Birds		
Apus pacificus Fork-tailed Swift [678]		Species or species habitat likely to occur within area
Migratory Terrestrial Species		
Hirundo rustica Barn Swallow [662]		Species or species habitat may occur within area

Name	Threatened	Type of Presence
[Motacilla cinerea](#)		
Grey Wagtail [642]		Species or species habitat may occur within area
[Motacilla flava](#)		
Yellow Wagtail [644]		Species or species habitat may occur within area
Migratory Wetlands Species		
[Charadrius veredus](#)		
Oriental Plover, Oriental Dotterel [882]		Species or species habitat may occur within area
[Glareola maldivarum](#)		
Oriental Pratincole [840]		Species or species habitat may occur within area
[Pandion haliaetus](#)		
Osprey [952]		Species or species habitat known to occur within area

Other Matters Protected by the EPBC Act

Listed Marine Species [Resource Information]

* Species is listed under a different scientific name on the EPBC Act - Threatened Species list.

Name	Threatened	Type of Presence
Birds		
[Apus pacificus](#)		
Fork-tailed Swift [678]		Species or species habitat likely to occur within area
[Ardea alba](#)		
Great Egret, White Egret [59541]		Species or species habitat known to occur within area
[Ardea ibis](#)		
Cattle Egret [59542]		Species or species habitat may occur within area
[Charadrius veredus](#)		
Oriental Plover, Oriental Dotterel [882]		Species or species habitat may occur within area
[Glareola maldivarum](#)		
Oriental Pratincole [840]		Species or species habitat may occur within area
[Haliaeetus leucogaster](#)		
White-bellied Sea-Eagle [943]		Species or species habitat likely to occur within area
[Hirundo rustica](#)		
Barn Swallow [662]		Species or species habitat may occur within area
[Merops ornatus](#)		
Rainbow Bee-eater [670]		Species or species habitat may occur within area
[Motacilla cinerea](#)		
Grey Wagtail [642]		Species or species habitat may occur within area
[Motacilla flava](#)		
Yellow Wagtail [644]		Species or species habitat may occur within area

Name	Threatened	Type of Presence
Pandion haliaetus		
Osprey [952]		Species or species habitat known to occur within area
Rostratula benghalensis (sensu lato)		
Painted Snipe [889]	Endangered*	Species or species habitat may occur within area

Extra Information

Invasive Species [Resource Information]

Weeds reported here are the 20 species of national significance (WoNS), along with other introduced plants that are considered by the States and Territories to pose a particularly significant threat to biodiversity. The following feral animals are reported: Goat, Red Fox, Cat, Rabbit, Pig, Water Buffalo and Cane Toad. Maps from Landscape Health Project, National Land and Water Resouces Audit, 2001.

Name	Status	Type of Presence
Birds		
Columba livia		
Rock Pigeon, Rock Dove, Domestic Pigeon [803]		Species or species habitat likely to occur within area
Mammals		
Capra hircus		
Goat [2]		Species or species habitat likely to occur within area
Equus asinus		
Donkey, Ass [4]		Species or species habitat likely to occur within area
Felis catus		
Cat, House Cat, Domestic Cat [19]		Species or species habitat likely to occur within area
Mus musculus		
House Mouse [120]		Species or species habitat likely to occur within area
Oryctolagus cuniculus		
Rabbit, European Rabbit [128]		Species or species habitat likely to occur within area
Vulpes vulpes		
Red Fox, Fox [18]		Species or species habitat likely to occur within area
Plants		
Cenchrus ciliaris		
Buffel-grass, Black Buffel-grass [20213]		Species or species habitat likely to occur within area
Parkinsonia aculeata		
Parkinsonia, Jerusalem Thorn, Jelly Bean Tree, Horse Bean [12301]		Species or species habitat likely to occur within area
Prosopis spp.		
Mesquite, Algaroba [68407]		Species or species

Name	Status	Type of Presence
		habitat likely to occur within area

Caveat

The information presented in this report has been provided by a range of data sources as acknowledged at the end of the report.

This report is designed to assist in identifying the locations of places which may be relevant in determining obligations under the Environment Protection and Biodiversity Conservation Act 1999. It holds mapped locations of World and National Heritage properties, Wetlands of International and National Importance, Commonwealth and State/Territory reserves, listed threatened, migratory and marine species and listed threatened ecological communities. Mapping of Commonwealth land is not complete at this stage. Maps have been collated from a range of sources at various resolutions.

Not all species listed under the EPBC Act have been mapped (see below) and therefore a report is a general guide only. Where available data supports mapping, the type of presence that can be determined from the data is indicated in general terms. People using this information in making a referral may need to consider the qualifications below and may need to seek and consider other information sources.

For threatened ecological communities where the distribution is well known, maps are derived from recovery plans, State vegetation maps, remote sensing imagery and other sources. Where threatened ecological community distributions are less well known, existing vegetation maps and point location data are used to produce indicative distribution maps.

For species where the distributions are well known, maps are digitised from sources such as recovery plans and detailed habitat studies. Where appropriate, core breeding, foraging and roosting areas are indicated under 'type of presence'. For species whose distributions are less well known, point locations are collated from government wildlife authorities, museums, and non-government organisations; bioclimatic distribution models are generated and these validated by experts. In some cases, the distribution maps are based solely on expert knowledge.

Only selected species covered by the following provisions of the EPBC Act have been mapped:

- migratory and
- marine

The following species and ecological communities have not been mapped and do not appear in reports produced from this database:

- threatened species listed as extinct or considered as vagrants
- some species and ecological communities that have only recently been listed
- some terrestrial species that overfly the Commonwealth marine area
- migratory species that are very widespread, vagrant, or only occur in small numbers

The following groups have been mapped, but may not cover the complete distribution of the species:

- non-threatened seabirds which have only been mapped for recorded breeding sites
- seals which have only been mapped for breeding sites near the Australian continent

Such breeding sites may be important for the protection of the Commonwealth Marine environment.

Coordinates

-21.73639 116.19722

Acknowledgements

This database has been compiled from a range of data sources. The department acknowledges the following custodians who have contributed valuable data and advice:

-Office of Environment and Heritage, New South Wales
-Department of Environment and Primary Industries, Victoria
-Department of Primary Industries, Parks, Water and Environment, Tasmania
-Department of Environment, Water and Natural Resources, South Australia
-Parks and Wildlife Commission NT, Northern Territory Government
-Department of Environmental and Heritage Protection, Queensland
-Department of Parks and Wildlife, Western Australia
-Environment and Planning Directorate, ACT
-Birdlife Australia
-Australian Bird and Bat Banding Scheme
-Australian National Wildlife Collection
-Natural history museums of Australia
-Museum Victoria
-Australian Museum
-South Australian Museum
-Queensland Museum
-Online Zoological Collections of Australian Museums
-Queensland Herbarium
-National Herbarium of NSW
-Royal Botanic Gardens and National Herbarium of Victoria
-Tasmanian Herbarium
-State Herbarium of South Australia
-Northern Territory Herbarium
-Western Australian Herbarium
-Australian National Herbarium, Atherton and Canberra
-University of New England
-Ocean Biogeographic Information System
-Australian Government, Department of Defence
Forestry Corporation, NSW
-Geoscience Australia
-CSIRO
-Other groups and individuals

The Department is extremely grateful to the many organisations and individuals who provided expert advice and information on numerous draft distributions.

Please feel free to provide feedback via the Contact Us page.

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Appendix D: Previous Survey Area Locations

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412000 414000 416000 418000 420000 422000 424000 426000 428000

7600000 7598000 7596000 7594000 7592000 7590000 7588000

Legend

- Mesa H Survey Area
- Astron (2016a)
- Astron (2016b)
- Astron (2011)
- Rio Tinto (2014)
- Biota (2012)
- Biota (2011)
- Biota (2007)
- Biota (2006)
- Biota (2003)

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Mesa H – Level 2 Vegetation and Flora Assessment, May 2016

Figure D.1: Previous Surveys Conducted Over the Mesa H Survey Area

Datum: GDA 1994 - Projection: MGA Zone 50

0 500 1,000 1,500 2,000 metres

N

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Appendix E: Vegetation Classification and Condition Scales

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Table E.1: Vegetation Classification System (Specht 1970) as modified by Aplin (1979).

Stratum	70-100% cover	30-70% cover	10-30% cover	2-10% cover	<2% cover
Trees > 30 m	Tall closed forest	Tall open Forest	Tall woodland	Tall open woodland	Scattered tall trees
Trees 10-30 m	Closed forest	Open forest	Woodland	Open woodland	Scattered trees
Trees < 10 m	Low closed forest	Low open forest	Low woodland	Low open woodland	Scattered low trees
Shrubs > 2 m	Tall closed scrub	Tall open scrub	Tall shrubland	Tall open shrubland	Scattered tall shrubs
Shrubs 1-2 m	Closed heath	Open heath	Shrubland	Open shrubland	Scattered shrubs
Shrubs < 1 m	Low closed heath	Low open heath	Low shrubland	Low open shrubland	Scattered low shrubs
Hummock grasses	Closed hummock grassland	Hummock grassland	Open hummock grassland	Very open hummock grassland	Scattered hummock grasses
Grasses, sedges, herbs	Closed tussock grassland/ sedgeland/ herbland	Tussock grassland/ sedgeland/ herbland	Open tussock grassland/ sedgeland/ herbland	Very open tussock grassland/ sedgeland/ herbland	Scattered tussock grasses/ sedges/ herbs

Table E.2: Summary of vegetation condition scale, as adapted from Trudgen (1988).

Vegetation condition	Condition description
Excellent	Pristine or nearly so, no obvious signs of damage caused by human activities since European settlement.
Very Good	Some relatively slight signs of damage caused by human activities since European settlement. For example, some signs of damage to tree trunks caused by repeated fire, the presence of some relatively non-aggressive weeds, or occasional vehicle tracks.
Good	More obvious signs of damage caused by human activity since European settlement, including some obvious impact on the vegetation structure such as that caused by low levels of grazing or slightly aggressive weeds.
Poor	Still retains basic vegetation structure or ability to regenerate to it after very obvious impacts of human activities since European settlement, such as grazing, partial clearing, frequent fires or aggressive weeds.
Very Poor	Severely impacted by grazing, very frequent fires, clearing or a combination of these activities. Scope for some regeneration but not to a state approaching good condition without intensive management. Usually with a number of weed species present including very aggressive species.
Completely Degraded	Areas that are completely or almost completely without native species in the structure of their vegetation; i.e. areas that are cleared or 'parkland cleared' with their flora comprising weed or crop species with isolated native trees or shrubs.

Appendix F: Current (this Report) and Previous Sampling Locations

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412000 414000 416000 418000 420000 422000 424000 426000 428000

7600000 7598000 7596000 7594000 7592000 7590000 7588000

Robe River

Jimmawurrada Creek

Millstream - Yarraloola Rd

Legend

- Main Road
- Railway
- River/Creek
- Mesa H Survey Area

Sampling Sites

- Quadrat Astron 1 phase
- Relevé Astron 1 phase
- Quadrat Astron 2 phases
- Relevé Astron 2 phases
- Quadrat Biota 1 phase
- Relevé Biota 1 phase
- Quadrat Biota 2 phases

Robe River Mining Co. Pty Ltd

Mesa H – Level 2 Vegetation and Flora Assessment, May 2016

Figure F.1: Current Survey and Previous Surveys Sampling Locations

Datum: GDA 1994 - Projection: MGA Zone 50

0 500 1,000 1,500 2,000 metres

N

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Appendix G: Priority Ecological Communities of the Mesa H Survey Area

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400000 410000 420000 430000 440000 450000

7610000 7600000 7590000 7580000

Wona Land System

PANNAWONICA

Pannawonica - Millstream Rd

Pannawonica Rd

Robe River

Jimmawurrada Creek

Millstream - Yarraloola Rd

Triodia sp. Robe River Assemblages

Legend

- Towns
- Main Road
- Railway
- River/Creek
- Mesa H Survey Area

Priority Ecological Community (Department of Parks and Wildlife 2015)

- Wona Land System (P1): Four plant assemblages of the Wona Land System (previously 'Cracking clays of the Chichester and Mungaroona Range')
- *Triodia* sp. Robe River Assemblages (P3): *Triodia* sp. Robe River assemblages of mesas of the West Pilbara

Robe River Mining Co. Pty Ltd

Mesa H – Level 2 Vegetation and Flora Assessment, May 2016

Figure G.1: Priority Ecological Communities of the Mesa H Survey Area

Datum: GDA 1994 - Projection: MGA Zone 50

0 2 4 6 8 10 km

N

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Appendix H: Threatened and Priority Flora Species Likelihood of Occurrence within the Survey Area

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Table H.1: Likelihood of occurrence of Threatened and Priority flora recorded within 20 km of the survey area (NatureMap (Department of Parks and Wildlife 2016a), TPFL (Department of Parks and Wildlife 2016c), TP List (Department of Parks and Wildlife 2016d), WAHerb (Department of Parks and Wildlife 2016e)). The TP List database is searched using place names. As a result, many of the records obtained from this database may occur beyond 50 km of the survey area.

Species	Habit and flowering information	Life Form	Habitat	Likelihood of occurrence	
				Pre-survey	Post-survey
Threatened					
Thyrptomene wittwerii	Spreading or rounded shrub, 0.5 m to 1.5 (-2.1) m high. White-cream flowers in April or July or August.	Perennial	Skeletal red stony soils. Breakaways, stony creek beds.	Unlikely	Unlikely
Priority 1					
Bothriochloa decipiens var. *cloncurrensis*	Herbaceous grass, to 1.4 m high.	Perennial	Seasonally damp depression. Stony clay plain.	Potential	Unlikely
Triodia sp. Pannawonica (B.M. Anderson & M.D. Barrett BMA 89)	Hummock grass.	Perennial	Shale	Potential	Potential
Priority 2					
Dicladanthera glabra	Spreading herb or shrub, to 0.6 (-1) m high.	Perennial	Alluvium. Along watercourses, near rock pools.	Potential	Unlikely
Euphorbia australis var. *glabra*	Herb	Annual	Creek banks. Red brown loam, some pebbles.	Potential	Potential
Pentalepis trichodesmoides subsp. *hispida*	Multi-stemmed shrub to 0.8 m high. Flowers July to October.	Perennial	Summits of ridges, cobbled slopes, outcrops, banks of creeks and edges of basalt screes.	Potential	Unlikely
Stylidium weeliwolli	Herb, 0.1 m to 0.25 m high, throat appendages 4, rod-shaped. Pink and red flowers from August to September.	Annual	Gritty sand soil, sandy clay. Edge of watercourses.	Likely	Potential

Species	Habit and flowering information	Life Form	Habitat	Likelihood of occurrence	
				Pre-survey	Post-survey
Priority 3					
Eragrostis surreyana	Grass. Culms erect or decumbent, 5-8 (-13) cm tall. Panicle linear, 9 cm to 13 cm long; 0.5 cm to 1.3 cm wide.	Annual	Soak area. Red-brown sandy clay.	Potential	Potential
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	Shrub or herb 0.2 m to 2 m high. May to July.	Perennial	Drainage lines, creeks in hills or plains. Brown silty loam.	Potential	Recorded
Pleurocarpaea gracilis	Rounded shrub to 0.5 m. June to October.	Perennial	Summit of rounded hill, slopes, skeletal red gritty soil over massive Brockman Iron Formation rock.	Potential	Unlikely
Solanum albostellatum	Low herb or shrub to 0.2 m high. March.	Perennial	Floodplains, slight bedrock outcrops. Red brown silty clay loam. Cracking clay.	Potential	Unlikely
Terminalia supranitifolia	Spreading tangled tree or shrub to 3 m high.	Perennial	Sandy soils or among basalt rocks.	Potential	Unlikely
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367)	Hummock grass. June, July, September.	Perennial	Mesa tops and edges; breakaways; hillsides and hilltops.	Likely	Recorded
Priority 4					
Goodenia nuda	Erect to ascending herb to 0.5 m high. Yellow flowers, April to August.	Short-lived perennial	Alluvial soils over ironstone, floodplains, valleys, watercourses, orange-brown alluvial sand over ironstone.	Potential	Unlikely
Rhynchosia bungarensis	Compact, prostrate shrub, to 0.5 m high. May to November.	Short-lived perennial	Pebbly, shingly coarse sand amongst boulders. Banks of flow line in the mouth of a gully in a valley wall.	Likely	Recorded

Appendix I: Vegetation Association Mapping

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414000 415000 416000 417000 418000 419000 420000 421000

7600000 7599000 7598000 7597000 7596000

Legend

- Survey Site
- Railway
- Main Road
- River/Creek
- Mesa H Survey Area

I.1A
I.1B
I.1C

MH358 MH310 MH336 MH331 MH400 MH309r MH333r MH306 MH368 MH307 MH343 MH308 MH395 MH361 MH359 MH21 MH20 MH05 MH06 MH100 MH22 MH31 MH39 MH40 MH203 MH200 MH32 MH363 MH342 MH204 MH397 MH337r MH398 MH324 MH354 MH305 MH01 MH345 MH325 MH329 MH327 MH399r MH29 MH346 MH326 MH300 MH332 MH02 MH328 MH26 MH330 MH353 MH335 MH370 MH321 MH313 MH318 MH41 MH18 MH19 MH44 MH311r MH43 MH38 MH360r MH07 MH316

Robe River Mining Co. Pty Ltd
Mesa H – Level 2 Vegetation and Flora Assessment, May 2016

Figure I.1A: Vegetation Association Mapping

Datum: GDA 1994 - Projection: MGA Zone 50

0 200 400 600 800 1,000 metres

N

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414000 415000 416000 417000 418000 419000 420000 421000

7596000 7595000 7594000 7593000 7592000 7591000

I.1A I.1B I.1C

Legend

- Survey Site
- Railway
- Main Road
- River/Creek
- Mesa H Survey Area

Robe River Mining Co. Pty Ltd

Mesa H – Level 2 Vegetation and Flora Assessment, May 2016

Figure I.1B: Vegetation Association Mapping

Datum: GDA 1994 - Projection: MGA Zone 50

0 200 400 600 800 1,000 metres

N

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Author: D. Roocke | Drawn: T. Pedersen | Date: 09-08-2017 | Figure Ref: 14269-16-BIDR-2Rev1_170809_FigI1_VegAsso

421000 422000 423000 424000 425000 426000 427000 428000

7593000 7592000 7591000 7590000 7589000

I.1A I.1B I.1C

MH344 MH338 MH393 MH401 MH392 MH371 MH373 MH409 MH408 MH407 MH350 MH402 MH348 MH403 MH406 MH404 MH405 MH339

BA32 BA21 BA07 BA18 BA22 BA111 BA10 BA219 BA42A BA210 BA209 BADR05 BAKM15 BUN06 GBR23

AqAbTwTspR AiAqAbTw ChAtuTw AxTe AsTe AxTw AbTw AptTw EcEvAtrApyPTw EvAtrTwEspp ChAbTwTe ChAtuTe ChAtuTw ChAlAbTw AoTeTw ElAlAbTw ChAppGbGsppPStTeTw Disturbed Mosaic of AiAqAbTw/ChAtuTw

Legend

- Survey Site
- Railway
- Main Road
- River/Creek
- Mesa H Survey Area

Robe River Mining Co. Pty Ltd

Mesa H – Level 2 Vegetation and Flora Assessment, May 2016

Figure I.1C: Vegetation Association Mapping

Datum: GDA 1994 - Projection: MGA Zone 50

0 200 400 600 800 1,000 metres

N

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Author: D. Roocke | Drawn: T. Pedersen | Date: 09-08-2017 | Figure Ref: 14269-16-BIDR-2Rev1_170809_FigI1_VegAsso

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Appendix J: Sample Site Data

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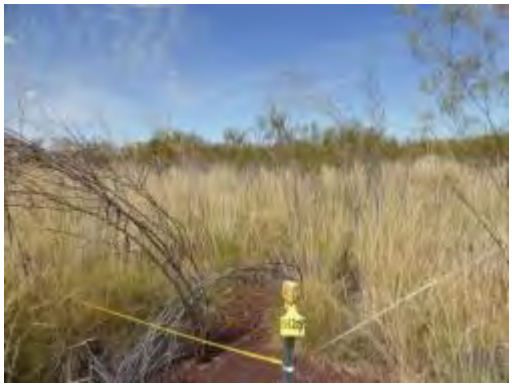
Site: BA209
Location: Map 10 **Type:** 50x50m Quadrat
Date: 2016-05-02 **Described by:** JA/KMc
MGA Zone: 50 **Easting:** 422677 **Northing:** 7590737
Habitat: Plain
Soil: Reddish brown silty clay loam
Rock type: Ironstone
Vegetation: *Acacia ancistrocarpa* tall shrubland over *Triodia wiseana* and *T. epactia* hummock grassland.
Veg Condition: Very Good
Fire Age: 5-10 years



Species List

Name	Cover (%)	Height (m)
Acacia ancistrocarpa	12	2.5
Acacia inaequilatera	0.5	3.5
Acacia tumida var. *pilbarensis*	0.5	0.2
Bonamia erecta	0.5	0.3
Corchorus lasiocarpus subsp. *parvus*	0.5	0.2
Corymbia hamersleyana	0.5	3.0
Dysphania rhadinostachya subsp. *rhadinostachya*	0.5	0.1
Euphorbia australis	0.5	0.1
Euphorbia boophthona	0.5	0.45
Goodenia microptera	0.5	0.4
Hakea lorea subsp. *lorea*	0.5	0.6
Hibiscus sturtii var. *campylochlamys*	0.5	0.2
Jasminum didymum subsp. *lineare*	0.5	1.0
Mollugo molluginea	0.5	0.05
Paspalidium tabulatum	0.5	0.1
Phyllanthus maderaspatensis	0.5	0.2
Ptilotus astrolasius	0.5	0.4
Ptilotus axillaris	0.5	0.2
Ptilotus calostachyus	0.5	0.15
Ptilotus fusiformis	0.5	0.5
Ptilotus nobilis subsp. *nobilis*	0.5	0.4
Rhynchosia minima	0.5	0.3
Senna notabilis	0.5	0.4
Solanum diversiflorum	0.5	0.4
Sporobolus australasicus	0.5	0.1

Name	Cover (%)	Height (m)
Tephrosia sp. Bungaroo Creek (M.E. Trudgen 11601)	0.5	0.01
Trachymene oleracea subsp. *oleracea*	0.5	0.7
Trichodesma zeylanicum var. *zeylanicum*	0.5	1.4
Triodia epactia	12	0.4
Triodia wiseana	25	0.6

* denotes weed species
? denotes unconfirmed ID

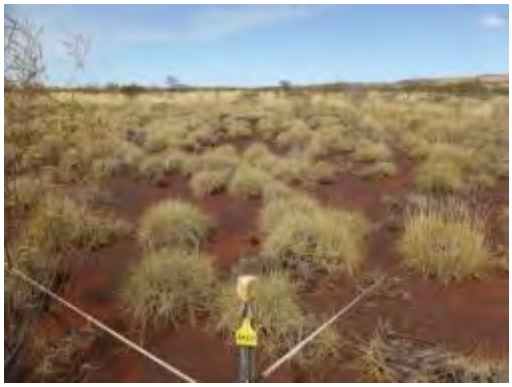
Site: BA210
Location: Map10 **Type:** 50x50m Quadrat
Date: 2016-05-12 **Described by:** KMc/LV
MGA Zone: 50 **Easting:** 421815 **Northing:** 7590790
Habitat: Hillcrest
Soil: Red brown silty clay loam
Rock type: Ironstone
Vegetation: *Acacia bivenosa* open shrubland over *Triodia wiseana* hummock grassland.
Veg Condition: Excellent
Fire Age: 5-10 years

Species List

Name	Cover (%)	Height (m)
Acacia ancistrocarpa	0.5	0.45
Acacia bivenosa	3	1.4
Acacia inaequilatera	0.5	2.1
Acacia ptychophylla	0.5	0.55
Corymbia hamersleyana	0.5	2.3
Dysphania rhadinostachya subsp. *rhadinostachya*	0.5	0.25
Goodenia stobbsiana	0.5	0.15
Hakea chordophylla	0.5	2.5
Indigofera monophylla	0.5	0.4
Jasminum didymum subsp. *lineare*	0.5	0.06
Polycarpaea holtzei	0.5	0.01
Ptilotus aervoides	0.5	0.02
Ptilotus fusiformis	0.5	0.35
Ptilotus nobilis subsp. *nobilis*	0.5	0.35
Stemodia grossa	0.5	0.15
Triodia wiseana	45	0.35

* denotes weed species
? denotes unconfirmed ID

Site: BA219
Location: SE corner of survey area **Type:** 50x50m Quadrat
Date: 2016-05-02 **Described by:** DR/LV
MGA Zone: 50 **Easting:** 422621 **Northing:** 7591000
Habitat: Plain
Soil: Red brown sandy clay loam
Rock type: Ironstone
Vegetation: *Acacia ancistrocarpa* and *A. synchronicia* tall open shrubland over *A. bivenosa* scattered shrubs over *Triodia epactia* and *T. wiseana* hummock grassland.
Veg Condition: Very Good
Fire Age: 5-10 years



Species List

Name	Cover (%)	Height (m)
Abutilon sp. Dioicum (A.A. Mitchell PRP 1618)	0.5	0.25
Acacia ancistrocarpa	1	2.2
Acacia bivenosa	1	1.6
Acacia inaequilatera	0.5	3.0
Acacia synchronicia	1	2.5
Bonamia erecta	0.5	0.4
Cleome viscosa	0.5	0.3
Cucumis variabilis	0.5	
Dysphania kalpari	0.5	0.1
Dysphania rhadinostachya subsp. *rhadinostachya*	0.5	0.1
Euphorbia australis	0.5	0.05
Euphorbia boophthona	0.5	0.25
Goodenia microptera	0.5	0.25
Gossypium australe	0.5	0.1
Mollugo molluginea	0.5	0.1
Pterocaulon sp.	0.5	0.01
Ptilotus astrolasius	0.5	0.1
Ptilotus axillaris	0.5	0.1
Ptilotus fusiformis	0.5	0.5
Ptilotus nobilis subsp. *nobilis*	0.5	0.7
Senna artemisioides subsp. *oligophylla*	0.5	1.1
Senna notabilis	0.5	0.1
Sida cardiophylla	0.5	0.1
Solanum diversiflorum	0.5	0.3
Streptoglossa bubakii	0.5	0.4

Name	Cover (%)	Height (m)
Stylobasium spathulatum	0.5	1.6
Tribulus macrocarpus	0.5	0.05
Triodia epactia	18	0.5
Triodia wiseana	22	0.5

* denotes weed species
? denotes unconfirmed ID

Site: MH01
Location: Map 3 **Type:** 50x50m Quadrat
Date: 2016-05-07 **Described by:** DR
MGA Zone: 50 **Easting:** 415563 **Northing:** 7597703
Habitat: Hillcrest
Soil: Red brown clay loam
Rock type: Ironstone
Vegetation: *Acacia acradenia* tall shrubland over *Triodia wiseana* open hummock grassland.
Veg Condition: Excellent
Fire Age: No fire evident

Species List

Name	Cover (%)	Height (m)
Acacia acradenia	12	2.5
Acacia bivenosa	0.5	1.7
Acacia trachycarpa	0.5	1.5
Cassytha capillaris	0.5	0.5
Grevillea wickhamii	0.5	2.9
Hakea chordophylla	0.5	2.0
Keraudrenia velutina subsp. *elliptica*	0.5	0.9
Ptilotus calostachyus	0.5	0.5
Triodia wiseana	22	0.6

* denotes weed species
? denotes unconfirmed ID

Site: MH02
Location: Map 3 on edge of Mesa **Type:** 50x50m Quadrat
Date: 2016-05-07 **Described by:** KMc/LV
MGA Zone: 50 **Easting:** 415152 **Northing:** 7596909
Habitat: Hillslope
Soil: Reddish brown silty clay loam
Rock type: Ironstone
Vegetation: *Acacia acradenia* and *Grevillea wickhamii* tall shrubland over *Triodia wiseana* and *T.* sp. Robe River (M.E. Trudgen et al. MET 12367) P3 open hummock grassland.
Veg Condition: Excellent
Fire Age: >10 years

Species List

Name	Cover (%)	Height (m)
Acacia acradenia	15	2.5
Bonamia pilbarensis	0.5	0.15
Cassytha capillaris	0.5	
Grevillea wickhamii	2	3.0
Ptilotus astrolasius	0.5	0.3
Solanum horridum	0.5	0.2
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	2	0.4
Triodia wiseana	25	0.4
Triumfetta maconochieana	0.5	0.5

* denotes weed species
? denotes unconfirmed ID

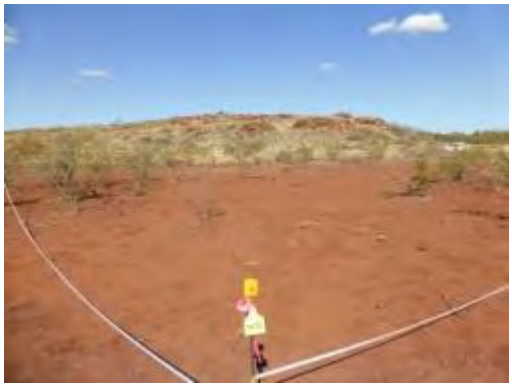
Site: MH05
Location: NW corner of survey area **Type:** 50x50m Quadrat
Date: 2016-05-01 **Described by:** JA/KMc
MGA Zone: 50 **Easting:** 415428 **Northing:** 7598709
Habitat: Plain
Soil: Red brown silty clay loam
Rock type: Ironstone
Vegetation: *Acacia synchronicia* tall open shrubland over *A. bivenosa* scattered shrubs over *Triodia wiseana* very open hummock grassland with **Cenchrus ciliaris* scattered tussock grasses.
Veg Condition: Poor
Fire Age: >10 years

Species List

Name	Cover (%)	Height (m)
**Cenchrus ciliaris*	1	0.3
**Cenchrus setiger*	0.5	0.2
Acacia bivenosa	1	1.6
Acacia sclerosperma subsp. *sclerosperma*	0.5	1.3
Acacia synchronicia	4	2.2
Acacia trachycarpa	0.5	2.6
Corchorus lasiocarpus subsp. *parvus*	0.5	0.1
Evolvulus alsinoides var. *villosicalyx*	0.5	0.1
Gossypium australe	0.5	0.5
Gossypium robinsonii	0.5	0.5
Hibiscus sturtii var. *campylochlamys*	0.5	0.1
Petalostylis labicheoides	0.5	2.4
Ptilotus nobilis subsp. *nobilis*	0.5	0.05
Sclerolaena costata	0.5	0.1
Stylobasium spathulatum	0.5	1.0
Trianthema triquetrum	0.5	0.05
Tribulus macrocarpus	0.5	0.05
Triodia epactia	0.5	0.3
Triodia wiseana	2	0.4

* denotes weed species
? denotes unconfirmed ID

Site: MH06
Location: NW corner of survey area **Type:** 50x50m Quadrat
Date: 2016-05-01 **Described by:** JA/KMc
MGA Zone: 50 **Easting:** 415345 **Northing:** 7598609
Habitat: Plain
Soil: Brown silty clay loam
Rock type: NA
Vegetation: *Petalostylis labicheoides* and *Acacia synchronicia* scattered tall shrubs to tall open shrubland over *Triodia wiseana* scattered hummocks to very open hummock grassland.
Veg Condition: Poor
Fire Age: >10 years



Species List

Name	Cover (%)	Height (m)
**Cenchrus ciliaris*	2	0.3
**Cenchrus setiger*	0.5	0.25
**Vachellia farnesiana*	0.5	1.7
Acacia bivenosa	0.5	1.6
Acacia synchronicia	1	2.3
Acacia trachycarpa	0.5	3.0
Gossypium robinsonii	0.5	1.1
Hibiscus sturtii var. *campylochlamys*	0.5	0.15
Petalostylis labicheoides	1	2.8
Pterocaulon sphaeranthoides	0.5	0.3
Sclerolaena costata	0.5	0.1
Senna notabilis	0.5	0.4
Stylobasium spathulatum	0.5	1.8
Tribulus macrocarpus	0.5	0.1
Triodia epactia	0.5	0.4
Triodia wiseana	2	0.6

* denotes weed species
? denotes unconfirmed ID

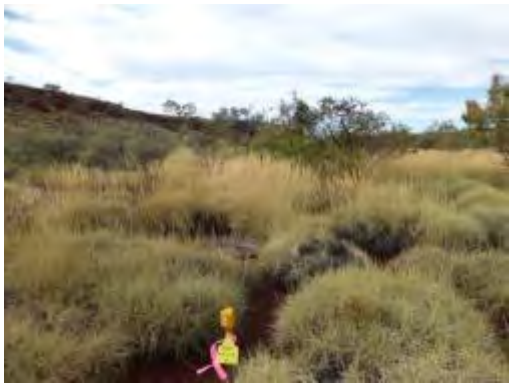
Site: MH07
Location: Map 7 **Type:** 50x50m Quadrat
Date: 2016-05-07 **Described by:** DR
MGA Zone: 50 **Easting:** 417440 **Northing:** 7595897
Habitat: Footslope
Soil: Brown clay loam
Rock type: Ironstone
Vegetation: *Corymbia hamersleyana* low open woodland over *Acacia inaequilatera* scattered tall shrubs over *Triodia wiseana* open hummock grassland.
Veg Condition: Excellent
Fire Age: 5-10 years

Species List

Name	Cover (%)	Height (m)
Acacia ancistrocarpa	0.5	2.8
Acacia bivenosa	0.5	1.4
Acacia inaequilatera	1	2.9
Corchorus lasiocarpus subsp. *parvus*	0.5	0.9
Corymbia hamersleyana	3	6.0
Gossypium australe	0.5	0.3
Gossypium robinsonii	0.5	0.9
Hibiscus sturtii var. *campylochlamys*	0.5	0.5
Lysiana casuarinae	0.5	1.8
Ptilotus astrolasius	0.5	0.1
Senna glutinosa subsp. *glutinosa*	0.5	1.2
Sida sp. Pilbara (A.A. Mitchell PRP 1543)	0.5	0.5
Tephrosia uniovulata	0.5	0.5
Triodia wiseana	25	0.5

* denotes weed species
? denotes unconfirmed ID

Site: MH09
Location: Map 6 **Type:** 50x50m Quadrat
Date: 2016-05-07 **Described by:** DR
MGA Zone: 50 **Easting:** 417168 **Northing:** 7594275
Habitat: Footslope
Soil: Reddish brown clay loam
Rock type: Ironstone
Vegetation: *Corymbia hamersleyana* scattered low trees over *Acacia inaequilatera* tall open shrubland over *A. bivenosa* and *Senna artemisioides* subsp. *oligophylla* open shrubland over *Triodia wiseana* hummock grassland.
Veg Condition: Excellent
Fire Age: 5-10 years

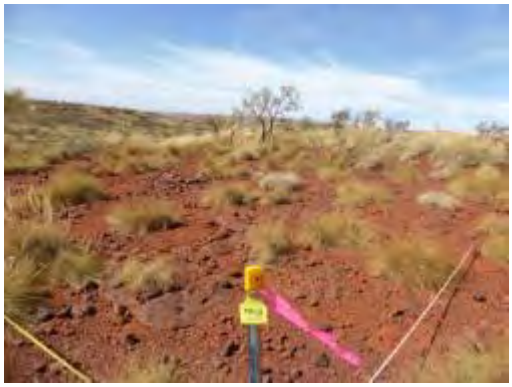


Species List

Name	Cover (%)	Height (m)
Acacia ancistrocarpa	0.5	2.9
Acacia bivenosa	1	1.9
Acacia inaequilatera	3	2.8
Acacia pyrifolia var. *pyrifolia*	0.5	1.2
Clerodendrum floribundum var. *angustifolium*	0.5	2.0
Corymbia hamersleyana	1	5.0
Cucumis variabilis	0.5	0.1
Gossypium australe	0.5	0.5
Grevillea wickhamii	0.5	0.9
Indigofera monophylla	0.5	0.5
Lysiana casuarinae	0.5	2.0
Pterocaulon sp.	0.5	0.2
Senna artemisioides subsp. *oligophylla*	1	1.9
Stylobasium spathulatum	0.5	2.0
Trichodesma zeylanicum var. *zeylanicum*	0.5	0.5
Triodia wiseana	40	0.6

* denotes weed species
? denotes unconfirmed ID

Site: MH10
Location: South of Mesa J **Type:** 60x40m Quadrat
Date: 2016-04-30 **Described by:** JA/KMc
MGA Zone: 50 **Easting:** 418548 **Northing:** 7593981
Habitat: Hillcrest
Soil: Red brown sandy clay loam
Rock type: Ironstone
Vegetation: *Acacia inaequilatera* and *Grevillea pyramidalis* subsp. *leucadendron* tall open shrubland over *Triodia wiseana* and *T.* sp. Robe River (M.E. Trudgen et al. MET 12367) P3, open hummock grassland.
Veg Condition: Very Good
Fire Age: >10 years



Species List

Name	Cover (%)	Height (m)
Acacia ancistrocarpa	0.5	1.2
Acacia bivenosa	0.5	1.4
Acacia inaequilatera	2	2.2
Cassytha capillaris	0.5	
Eriachne mucronata	0.5	
Eriachne pulchella subsp. *pulchella*	0.5	0.1
Goodenia stobbsiana	0.5	
Grevillea pyramidalis subsp. *leucadendron*	2	2.1
Oldenlandia crouchiana	0.5	0.1
Tephrosia uniovulata	0.5	0.4
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	7	0.4
Triodia wiseana	20	0.4

* denotes weed species
? denotes unconfirmed ID

Site: MH11
Location: Map 7 Mesa H **Type:** 50x50m Quadrat
Date: 2016-04-30 **Described by:** JA/KMc
MGA Zone: 50 **Easting:** 418166 **Northing:** 7594621
Habitat: Hillcrest
Soil: Red brown silty clay loam
Rock type: CID
Vegetation: *Acacia inaequilatera* scattered tall shrubs over *Triodia* sp. Robe River (M.E. Trudgen et al. MET 12367) P3 and *T. wiseana* open hummock grassland.
Veg Condition: Excellent
Fire Age: >10 years

Species List

Name	Cover (%)	Height (m)
Acacia ancistrocarpa	0.5	2.0
Acacia bivenosa	0.5	2.1
Acacia inaequilatera	1	2.8
Amyema preissii	0.5	
Cassytha capillaris	0.5	
Eriachne mucronata	0.5	
Eriachne pulchella subsp. *pulchella*	0.5	0.1
Euphorbia australis var. *subtomentosa*	0.5	0.1
Goodenia stobbsiana	0.5	0.2
Grevillea wickhamii	0.5	2.2
Hakea chordophylla	0.5	2.8
Oldenlandia crouchiana	0.5	0.1
Ptilotus calostachyus	0.5	
Ptilotus nobilis subsp. *nobilis*	0.5	0.1
Solanum horridum	0.5	0.3
Trachymene oleracea subsp. *oleracea*	0.5	0.1
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	11	0.4
Triodia wiseana	10	0.6

* denotes weed species
? denotes unconfirmed ID

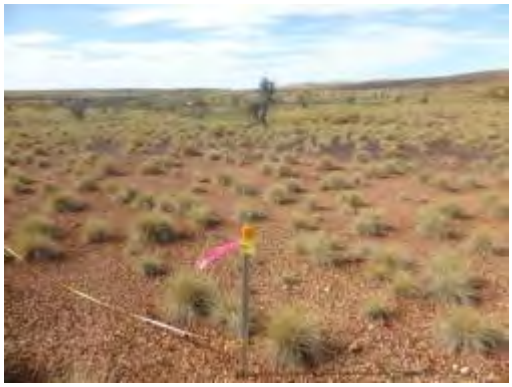
Site: MH12
Location: Top of Mesa **Type:** 50x50m Quadrat
Date: 2016-04-30 **Described by:** DR/LV
MGA Zone: 50 **Easting:** 418228 **Northing:** 7594335
Habitat: Hillcrest
Soil: Red brown clay loam
Rock type: Ironstone
Vegetation: *Acacia pruinocarpa* tall open shrubland over *Triodia wiseana* and *T.* sp. Robe River (M.E. Trudgen et al. MET 12367) P3 open hummock grassland.
Veg Condition: Excellent
Fire Age: No fire evident

Species List

Name	Cover (%)	Height (m)
Acacia inaequilatera	0.5	1.9
Acacia pruinocarpa	6	2.8
Acacia tumida var. *pilbarensis*	0.5	1.3
Cassytha capillaris	0.5	0.2
Eriachne mucronata	0.5	0.3
Eucalyptus leucophloia subsp. *leucophloia*	0.5	1.0
Jasminum didymum subsp. *lineare*	0.5	0.5
Oldenlandia crouchiana	0.5	0.05
Ptilotus auriculifolius	0.5	0.1
Senna stricta	0.5	0.8
Trichodesma zeylanicum var. *zeylanicum*	0.5	0.2
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	5	0.4
Triodia wiseana	12	0.5

* denotes weed species
? denotes unconfirmed ID

Site: MH17
Location: Map 7 **Type:** 50x50m Quadrat
Date: 2016-05-07 **Described by:** LV
MGA Zone: 50 **Easting:** 416719 **Northing:** 7594779
Habitat: Hillslope
Soil: Brown clay loam
Rock type: Calcrete
Vegetation: *Triodia wiseana* open hummock grassland.
Veg Condition: Excellent
Fire Age: 2-5 years



Species List

Name	Cover (%)	Height (m)
Acacia bivenosa	0.5	0.5
Acacia inaequilatera	0.5	2.5
Acacia tumida var. *pilbarensis*	0.5	0.6
Bonamia pilbarensis	0.5	0.1
Corchorus lasiocarpus subsp. *parvus*	0.5	0.5
Grevillea wickhamii	0.5	0.4
Hakea chordophylla	0.5	2.1
Ptilotus calostachyus	0.5	0.4
Sida sp. Pilbara (A.A. Mitchell PRP 1543)	0.5	0.12
Triodia wiseana	20	

* denotes weed species
? denotes unconfirmed ID

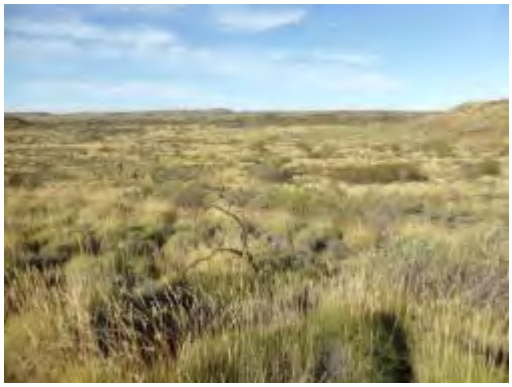
Site: MH18
Location: Map 4 NE end of Mesa H **Type:** 25x100m Quadrat
Date: 2016-05-12 **Described by:** KMc
MGA Zone: 50 **Easting:** 417905 **Northing:** 7596681
Habitat: Gully
Soil: Red brown clay loam
Rock type: Ironstone
Vegetation: *Corymbia hamersleyana* low open woodland over *Acacia tumida* var. *pilbarensis* tall shrubland over *Triodia wiseana* and *T.* sp Robe River (M.E. Trudgen et al. MET 12367) P3 open hummock grassland.
Veg Condition: Excellent
Fire Age: >10 years

Species List

Name	Cover (%)	Height (m)
Abutilon sp. Dioicum (A.A. Mitchell PRP 1618)	0.5	1.2
Acacia ancistrocarpa	0.5	2.1
Acacia bivenosa	0.5	1.6
Acacia tumida var. *pilbarensis*	15	4.0
Cassytha capillaris	0.5	0.4
Corymbia hamersleyana	5	6.0
Cymbopogon ambiguus	0.5	0.6
Duperreya commixta	0.5	1.2
Eriachne mucronata	0.5	0.3
Ficus aculeata var. *indecora*	0.5	0.8
Grevillea wickhamii	0.5	3.5
Hybanthus aurantiacus	0.5	0.1
Paraneurachne muelleri	0.5	0.2
Petalostylis labicheoides	0.5	1.7
Ptilotus calostachyus	0.5	0.8
Ptilotus incanus	0.5	0.2
Ptilotus nobilis subsp. *nobilis*	0.5	0.1
Rhynchosia minima	0.5	0.3
Solanum cleistogamum	0.5	0.25
Tephrosia uniovulata	0.5	0.6
Themeda triandra	0.5	0.8
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	6	0.5
Triodia wiseana	8	0.5
Vigna lanceolata var. *lanceolata*	0.5	0.2

* denotes weed species
? denotes unconfirmed ID

Site: MH19
Location: Map 4 **Type:** 50x50m Relevé
Date: 2016-05-12 **Described by:** LV
MGA Zone: NA **Easting:** 418207 **Northing:** 7596618
Habitat: Breakaway
Soil: Red brown silty clay loam
Rock type: Ironstone
Vegetation: *Acacia bivenosa* and *A. inaequilatera* open shrubland over *Triodia wiseana* hummock grassland.
Veg Condition: Excellent
Fire Age: >10 years

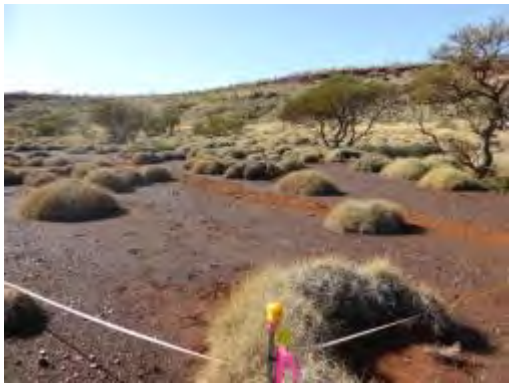


Species List

Name	Cover (%)	Height (m)
Acacia bivenosa	3	1.8
Acacia inaequilatera	1	2.0
Cassytha capillaris	0.5	0.5
Lysiana casuarinae	0.5	1.5
Triodia wiseana	60	0.4

* denotes weed species
? denotes unconfirmed ID

Site: MH20
Location: Map 3 **Type:** 50x50m Quadrat
Date: 2016-05-01 **Described by:** DR/LV
MGA Zone: 50 **Easting:** 415767 **Northing:** 7598751
Habitat: Valley flat
Soil: Red brown sandy loam
Rock type: Ironstone
Vegetation: *Acacia xiphophylla* tall open shrubland over *Triodia wiseana* open hummock grassland.
Veg Condition: Very Good
Fire Age: >10 years

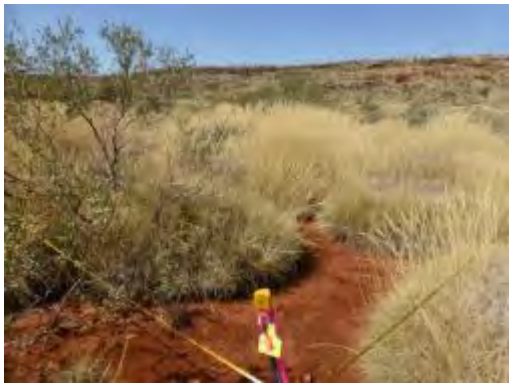


Species List

Name	Cover (%)	Height (m)
**Cenchrus setiger*	0.5	0.25
Acacia bivenosa	0.5	1.2
Acacia synchronicia	0.5	0.5
Acacia xiphophylla	4	4.0
Maireana melanocoma	0.5	0.25
Ptilotus auriculifolius	0.5	0.5
Senna glutinosa subsp. *x luerssenii*	0.5	0.45
Triodia wiseana	23	0.5

* denotes weed species
? denotes unconfirmed ID

Site: MH21
Location: Map 3 **Type:** 50x50m Quadrat
Date: 2016-05-01 **Described by:** DR/LV
MGA Zone: 50 **Easting:** 415589 **Northing:** 7598719
Habitat: Plain
Soil: Red brown sandy loam
Rock type: Ironstone
Vegetation: *Acacia synchronicia* tall open shrubland over *Triodia wiseana* open hummock grassland.
Veg Condition: Excellent
Fire Age: >10 years

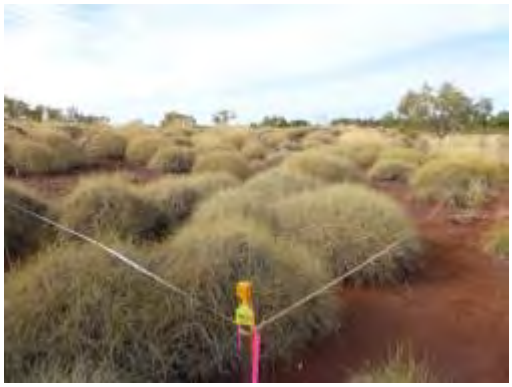


Species List

Name	Cover (%)	Height (m)
**Cenchrus setiger*	0.5	0.25
Acacia synchronicia	4	2.4
Ptilotus auriculifolius	0.5	0.02
Triodia wiseana	20	1.2

* denotes weed species
? denotes unconfirmed ID

Site: MH22
Location: Map 5 just south of rail crossing near main track **Type:** 50x50m Quadrat
Date: 2016-05-02 **Described by:** JA/KMc
MGA Zone: 50 **Easting:** 418686 **Northing:** 7598675
Habitat: Plain
Soil: Brown sandy clay loam
Rock type: Ironstone
Vegetation: *Corymbia hamersleyana* scattered low trees to low open woodland over *Triodia wiseana* hummock grassland.
Veg Condition: Very Good
Fire Age: >10 years



Species List

Name	Cover (%)	Height (m)
**Cenchrus ciliaris*	0.5	
Acacia ancistrocarpa	0.5	1.1
Acacia bivenosa	0.5	1.6
Acacia inaequilatera	0.5	1.4
Acacia synchronicia	0.5	1.8
Aristida contorta	0.5	0.05
Corymbia hamersleyana	2	4.0
Eragrostis eriopoda	0.5	0.4
Eriachne sp.	0.5	0.4
Evolvulus alsinoides var. *villosicalyx*	0.5	0.1
Goodenia forrestii	0.5	0.05
Goodenia microptera	0.5	0.05
Hakea chordophylla	0.5	1.0
Ptilotus astrolasius	0.5	0.1
Ptilotus calostachyus	0.5	0.1
Ptilotus nobilis subsp. *nobilis*	0.5	0.02
Senna glutinosa subsp. *glutinosa*	0.5	1.0
Sida echinocarpa	0.5	0.8
Triodia epactia	0.5	0.7
Triodia wiseana	35	0.8

* denotes weed species
? denotes unconfirmed ID

Site: MH24
Location: NA **Type:** 50x50m Quadrat
Date: 2016-05-08 **Described by:** JA
MGA Zone: 50 **Easting:** 418765 **Northing:** 7592306
Habitat: Floodplain
Soil: Brown sandy loam
Rock type: NA
Vegetation: *Acacia pyrifolia* var. *pyrifolia*, *Grevillea wickhamii, Gossypium robinsonii* tall open shrubland over *Triodia epactia* open hummock grassland.
Veg Condition: Very Good
Fire Age: >10 years

Species List

Name	Cover (%)	Height (m)
**Argemone ochroleuca* subsp. *ochroleuca*	0.5	0.1
**Cenchrus ciliaris*	0.5	0.2
**Setaria verticillata*	0.5	0.3
**Tribulus terrestris*	0.5	0.05
Acacia bivenosa	0.5	0.5
Acacia pyrifolia var. *pyrifolia*	4	2.3
Boerhavia coccinea	0.5	0.1
Cleome viscosa	0.5	0.25
Clerodendrum floribundum var. *angustifolium*	0.5	0.4
Corchorus lasiocarpus subsp. *parvus*	0.5	0.2
Cucumis variabilis	0.5	
Eremophila longifolia	0.5	3.0
Euphorbia biconvexa	0.5	0.4
Euphorbia boophthona	0.5	0.3
Evolvulus alsinoides var. *villosicalyx*	0.5	0.45
Gomphrena cunninghamii	0.5	0.1
Gossypium robinsonii	1	2.5
Grevillea pyramidalis subsp. *leucadendron*	0.5	2.5
Grevillea wickhamii	2	4.5
Hybanthus aurantiacus	0.5	0.4
Indigofera monophylla	0.5	0.4
Ipomoea muelleri	0.5	
Jasminum didymum subsp. *lineare*	0.5	1.4
Mollugo molluginea	0.5	0.1
Notoleptopus decaisnei var. Orbicularis (A.B. Craig 428)	0.5	0.15

Name	Cover (%)	Height (m)
Pentalepis trichodesmoides	0.5	0.9
Petalostylis labicheoides	0.5	2.2
Phyllanthus erwinii	0.5	0.1
Phyllanthus maderaspatensis	0.5	0.2
Polycarpaea longiflora	0.5	0.2
Pterocaulon sphacelatum	0.5	0.4
Pterocaulon sphaeranthoides	0.5	0.3
Ptilotus incanus	0.5	0.3
Senna artemisioides subsp. *oligophylla*	0.5	0.5
Sida echinocarpa	0.5	0.6
Solanum horridum	0.5	0.3
Stemodia grossa	0.5	0.2
Stylobasium spathulatum	0.5	3.5
Swainsona formosa	0.5	0.2
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	0.5	0.3
Trichodesma zeylanicum var. *zeylanicum*	0.5	0.7
Triodia epactia	25	0.5
Triodia wiseana	0.5	0.4
Waltheria indica	0.5	0.5

* denotes weed species
? denotes unconfirmed ID

Site: MH25
Location: mao 9 **Type:** 50x50m Quadrat
Date: 2016-05-09 **Described by:** LV
MGA Zone: NA **Easting:** 419125 **Northing:** 7592892
Habitat: Plain
Soil: Red brown sandy clay loam
Rock type: Ironstone
Vegetation: *Corymbia hamersleyana* low woodland over *Acacia inaequilatera* scattered tall shrubs over *Triodia epactia* and *T. wiseana* hummock grassland.
Veg Condition: Good
Fire Age: >10 years

Species List

Name	Cover (%)	Height (m)
Acacia bivenosa	0.5	1.3
Acacia inaequilatera	1	2.3
Acacia synchronicia	0.5	2.3
Aristida holathera var. *holathera*	0.5	0.4
Corchorus lasiocarpus subsp. *parvus*	0.5	0.35
Corymbia hamersleyana	12	4.0
Cucumis variabilis	0.5	0.1
Cynanchum floribundum	0.5	0.02
Euphorbia boopthona/tannensis	0.5	0.35
Goodenia stobbsiana	0.5	0.35
Gossypium australe	0.5	1.5
Grevillea pyramidalis subsp. *leucadendron*	0.5	1.2
Hakea chordophylla	0.5	1.9
Hibiscus leptocladus	0.5	0.4
Jasminum didymum subsp. *lineare*	0.5	1.0
Lysiana casuarinae	0.5	1.8
Mollugo molluginea	0.5	0.1
Pterocaulon sp.	0.5	0.1
Ptilotus astrolasius	0.5	0.25
Ptilotus nobilis subsp. *nobilis*	0.5	0.03
Rhynchosia minima	0.5	0.15
Scaevola spinescens	0.5	0.4
Senna artemisioides subsp. *oligophylla*	0.5	1.3
Senna notabilis	0.5	0.3
Solanum cleistogamum	0.5	0.1

Name	Cover (%)	Height (m)
Stylobasium spathulatum	0.5	1.7
Tribulus platypterus	0.5	0.1
Triodia epactia	40	0.5
Triodia wiseana	5	0.5

* denotes weed species
? denotes unconfirmed ID

Site: MH26
Location: NA **Type:** 50x50m Quadrat
Date: 2016-05-09 **Described by:** DR
MGA Zone: 50 **Easting:** 416341 **Northing:** 7596965
Habitat: Footslope
Soil: Red brown silty clay loam
Rock type: Ironstone
Vegetation: *Corymbia hamersleyana* scattered low trees over *Acacia inaequilatera* tall open shrubland over *A. bivenosa* scattered shrubs over *Triodia wiseana* hummock grassland.
Veg Condition: Excellent
Fire Age: >10 years

Species List

Name	Cover (%)	Height (m)
Acacia bivenosa	1	1.6
Acacia inaequilatera	4	3.0
Cassytha capillaris	0.5	0.3
Corymbia hamersleyana	1	5.0
Euphorbia australis var. *hispidula*	0.5	0.1
Lysiana casuarinae	0.5	1.5
Pterocaulon sp.	0.5	0.4
Ptilotus calostachyus	0.5	0.4
Senna glutinosa subsp. *glutinosa*	0.5	1.0
Solanum horridum	0.5	0.1
Triodia wiseana	32	0.6

* denotes weed species
? denotes unconfirmed ID

Site: MH27
Location: Map 6 in drainage gully on Mesa **Type:** 25x100m Quadrat
Date: 2016-05-07 **Described by:** KMc/LV
MGA Zone: 50 **Easting:** 415627 **Northing:** 7595215
Habitat: Minor creek
Soil: Reddish brown sandy clay loam
Rock type: Ironstone
Vegetation: *Acacia tumida* var. *pilbarensis* and *Grevillea wickhamii*, tall open scrub over *Petalostylis labicheoides* scattered shrubs over *Triodia wiseana* hummock grassland.
Veg Condition: Excellent
Fire Age: >10 years

Species List

Name	Cover (%)	Height (m)
Acacia tumida var. *pilbarensis*	35	5.0
Cassytha capillaris	0.5	
Corchorus lasiocarpus subsp. *parvus*	0.5	0.4
Cucumis variabilis	0.5	0.2
Dodonaea coriacea	0.5	0.35
Eucalyptus leucophloia subsp. *leucophloia*	0.5	5.0
Goodenia stobbsiana	0.5	0.4
Grevillea wickhamii	1	4.0
Hibiscus sturtii var. *campylochlamys*	0.5	0.25
Indigofera monophylla	0.5	0.8
Jasminum didymum subsp. *lineare*	0.5	1.0
Petalostylis labicheoides	1	1.7
Ptilotus astrolasius	0.5	0.35
Ptilotus calostachyus	0.5	0.4
Sida sp. Pilbara (A.A. Mitchell PRP 1543)	0.5	0.2
Solanum cleistogamum	0.5	0.3
Trichodesma zeylanicum var. *zeylanicum*	0.5	1.8
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	0.5	0.5
Triodia wiseana	35	0.6
Triumfetta maconochieana	0.5	0.8

* denotes weed species
? denotes unconfirmed ID

Site: MH28
Location: On Map 9 **Type:** 10x250m Quadrat
Date: 2016-05-08 **Described by:** KMc
MGA Zone: 50 **Easting:** 419157 **Northing:** 7592299
Habitat: Minor creek
Soil: Reddish brown silty clay loam
Rock type: Ironstone
Vegetation: *Acacia tumida* var. *pilbarensis, Grevillea wickhamii* and *Gossypium robinsonii* tall shrubland over *Corchorus lasiocarpus* subsp. *parvus* and *Indigofera monophylla* low open shrubland over *Triodia wiseana* and *T.* sp. Robe River (M.E. Trudgen et al. MET 12367) P3 open hummock grassland.
Veg Condition: Very Good
Fire Age: 2-5 years

Species List

Name	Cover (%)	Height (m)
Acacia ancistrocarpa	0.5	0.8
Acacia inaequilatera	0.5	1.3
Acacia maitlandii	0.5	0.6
Acacia ptychophylla	0.5	0.3
Acacia tumida var. *pilbarensis*	9	3.0
Aristida holathera var. *holathera*	0.5	0.4
Bonamia pilbarensis	0.5	0.1
Corchorus lasiocarpus subsp. *parvus*	1	0.4
Cymbopogon ambiguus	0.5	0.6
Gossypium australe	0.5	1.4
Gossypium robinsonii	2	3.0
Grevillea wickhamii	2	2.2
Hibiscus sturtii var. *campylochlamys*	0.5	0.4
Hybanthus aurantiacus	0.5	0.2
Indigofera monophylla	1	0.6
Keraudrenia velutina subsp. *elliptica*	0.5	0.4
Paraneurachne muelleri	0.5	0.7
Petalostylis labicheoides	2	2.1
Ptilotus astrolasius	0.5	0.4
Ptilotus calostachyus	0.5	1.5
Ptilotus fusiformis	0.5	0.4
Sida arsiniata	0.5	0.4
Sida sp. Pilbara (A.A. Mitchell PRP 1543)	0.5	0.7
Tephrosia virens	0.5	0.6

Name	Cover (%)	Height (m)
Trichodesma zeylanicum var. *zeylanicum*	0.5	0.7
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	5	0.4
Triodia wiseana	10	0.5
Triumfetta johnstonii	0.5	0.6

* denotes weed species
? denotes unconfirmed ID

Site: MH29
Location: NA **Type:** 20x125m Quadrat
Date: 2016-05-09 **Described by:** JA
MGA Zone: 50 **Easting:** 415340 **Northing:** 7597256
Habitat: Gully
Soil: Red brown clay loam
Rock type: Ironstone
Vegetation: *Acacia tumida* var. *pilbarensis* and *Grevillea wickhamii* tall shrubland over *Triodia wiseana* and *T.* sp. Robe River (M.E. Trudgen et al. MET 12367) P3 very open hummock grassland.
Veg Condition: Excellent
Fire Age: >10 years

Species List

Name	Cover (%)	Height (m)
Acacia acradenia	0.5	2.8
Acacia bivenosa	0.5	2.6
Acacia inaequilatera	0.5	1.8
Acacia tumida var. *pilbarensis*	25	4.5
Bonamia pilbarensis	0.5	0.85
Goodenia stobbsiana	0.5	0.3
Grevillea wickhamii	1	3.0
Hibiscus coatesii	0.5	1.1
Jasminum didymum subsp. *lineare*	0.5	1.3
Petalostylis labicheoides	0.5	2.5
Ptilotus calostachyus	0.5	0.4
Solanum horridum	0.5	0.15
Tephrosia uniovulata	0.5	0.4
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	1	0.5
Triodia wiseana	6	0.5

* denotes weed species
? denotes unconfirmed ID

Site: MH30
Location: Map 9 **Type:** 50x50m Quadrat
Date: 2016-05-08 **Described by:** LV
MGA Zone: NA **Easting:** 418971 **Northing:** 7592378
Habitat: Floodplain
Soil: Red brown silty clay loam
Rock type: Ironstone
Vegetation: *Gossypium robinsonii* and *Grevillea wickhamii* tall open shrubland over *Stylobasium spathulatum, Pentalepis trichodesmoides* and *Acacia pyrifolia* var. *pyrifolia* open shrubland over *Triodia epactia* open hummock grassland with **Cenchrus ciliaris* very open tussock grassland.
Veg Condition: Good
Fire Age: >10 years

Species List

Name	Cover (%)	Height (m)
**Cenchrus ciliaris*	2	0.15
**Cenchrus setiger*	0.5	0.15
Abutilon sp.	0.5	0.06
Acacia pyrifolia var. *pyrifolia*	1	1.5
Cleome viscosa	0.5	0.1
Corchorus lasiocarpus subsp. *parvus*	0.5	0.6
Cucumis variabilis	0.5	0.4
Euphorbia biconvexa	0.5	0.1
Evolvulus alsinoides var. *villosicalyx*	0.5	0.25
Flueggea virosa subsp. *melanthesoides*	0.5	1.1
Gossypium australe	0.5	0.35
Gossypium robinsonii	2	2.5
Grevillea pyramidalis subsp. *leucadendron*	0.5	2.3
Grevillea wickhamii	1	2.3
Hybanthus aurantiacus	0.5	0.15
Indigofera monophylla	0.5	0.5
Ipomoea muelleri	0.5	0.06
Jasminum didymum subsp. *lineare*	0.5	0.6
Mollugo molluginea	0.5	0.2
Notoleptopus decaisnei var. Orbicularis (A.B. Craig 428)	0.5	0.1
Paspalidium ?clementii	0.5	0.03
Pentalepis trichodesmoides	1	1.0
Phyllanthus maderaspatensis	0.5	0.25
Pterocaulon sp.	0.5	0.25

Name	Cover (%)	Height (m)
Ptilotus axillaris	0.5	0.02
Ptilotus nobilis subsp. *nobilis*	0.5	0.15
Senna artemisioides subsp. *oligophylla*	0.5	0.6
Stylobasium spathulatum	1	1.5
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	0.5	0.07
Trichodesma zeylanicum var. *zeylanicum*	0.5	1.2
Triodia epactia	15	0.6

* denotes weed species
? denotes unconfirmed ID

Site: MH31
Location: Map 4 **Type:** 60x40m Quadrat
Date: 2016-05-03 **Described by:** DR/KMc
MGA Zone: 50 **Easting:** 417691 **Northing:** 7598571
Habitat: Hillslope
Soil: Red brown clay loam
Rock type: Ironstone
Vegetation: *Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Acacia bivenosa* open shrubland over *Triodia wiseana* hummock grassland.
Veg Condition: Excellent
Fire Age: >10 years

Species List

Name	Cover (%)	Height (m)
Abutilon sp. Dioicum (A.A. Mitchell PRP 1618)	0.5	0.5
Acacia acradenia	0.5	2.2
Acacia bivenosa	5	1.9
Acacia inaequilatera	0.5	2.0
Acacia synchronicia	0.5	1.6
Acacia trachycarpa	0.5	1.4
Acacia tumida var. *pilbarensis*	0.5	2.3
Cassytha capillaris	0.5	0.3
Corymbia hamersleyana	0.5	5.5
Cymbopogon ambiguus	0.5	0.4
Dodonaea coriacea	0.5	1.0
Eriachne mucronata	0.5	0.3
Eucalyptus leucophloia subsp. *leucophloia*	1	6.0
Grevillea wickhamii	0.5	1.4
Hakea chordophylla	0.5	2.0
Hibiscus sturtii var. *campylochlamys*	0.5	0.3
Indigofera monophylla	0.5	0.3
Jasminum didymum subsp. *lineare*	0.5	1.5
Ptilotus astrolasius	0.5	0.3
Ptilotus calostachyus	0.5	0.1
Senna glutinosa subsp. *x luerssenii*	0.5	1.0
Triodia wiseana	40	0.9

* denotes weed species
? denotes unconfirmed ID

Site: MH32
Location: Map 3 **Type:** 50x50m Quadrat
Date: 2016-05-01 **Described by:** DR/LV
MGA Zone: 50 **Easting:** 415534 **Northing:** 7598428
Habitat: Hillslope
Soil: Red brown sandy loam
Rock type: CID
Vegetation: *Acacia bivenosa, A. acradenia* tall open shrubland over *Triodia wiseana* and *T.* sp. Robe River (M.E. Trudgen et al. MET 12367) P3 hummock grassland.
Veg Condition: Excellent
Fire Age: >10 years

Species List

Name	Cover (%)	Height (m)
Acacia acradenia	3	2.5
Acacia bivenosa	6	2.2
Acacia sp.	0.5	0.35
Clerodendrum sp.	0.5	0.7
Corymbia hamersleyana	0.5	1.7
Eriachne mucronata	0.5	0.2
Grevillea pyramidalis subsp. *leucadendron*	0.5	1.2
Hakea chordophylla	0.5	1.0
Mollugo molluginea	0.5	0.1
Paraneurachne muelleri	0.5	0.1
Ptilotus calostachyus	0.5	0.2
Senna glutinosa subsp. *x luerssenii*	0.5	1.0
Solanum horridum	0.5	0.15
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	1	0.6
Triodia wiseana	45	1.3

* denotes weed species
? denotes unconfirmed ID

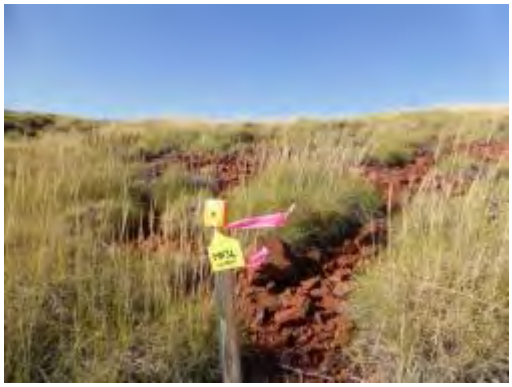
Site: MH33
Location: Cnr of Map 6 **Type:** 50x50m Quadrat
Date: 2016-05-11 **Described by:** KMc
MGA Zone: 50 **Easting:** 414471 **Northing:** 7595007
Habitat: Hillslope
Soil: Light reddish brown silty clay loam
Rock type: Basalt
Vegetation: *Acacia ptychophylla* scattered low shrubs over *Triodia wiseana* open hummock grassland.
Veg Condition: Excellent
Fire Age: No fire evident

Species List

Name	Cover (%)	Height (m)
Acacia inaequilatera	0.5	3.0
Acacia ptychophylla	1	0.4
Bonamia pilbarensis	0.5	0.1
Bulbostylis barbata	0.5	0.1
Dampiera candicans	0.5	0.4
Grevillea wickhamii	0.5	4.0
Hakea chordophylla	0.5	2.7
Indigofera monophylla	0.5	0.25
Polycarpaea longiflora	0.5	0.1
Ptilotus astrolasius	0.5	0.2
Solanum horridum	0.5	0.1
Trachymene oleracea subsp. *oleracea*	0.5	0.6
Trichodesma zeylanicum var. *zeylanicum*	0.5	0.2
Triodia wiseana	25	0.6
Triumfetta appendiculata	0.5	0.1
Triumfetta clementii	0.5	0.4

* denotes weed species
? denotes unconfirmed ID

Site: MH34
Location: Cnr of Map 6 **Type:** 50x50m Quadrat
Date: 2016-05-11 **Described by:** KMc
MGA Zone: 50 **Easting:** 414362 **Northing:** 7595092
Habitat: Hillslope
Soil: Light reddish brown silty clay loam
Rock type: Basalt
Vegetation: *Triodia wiseana* open hummock grassland.
Veg Condition: Excellent
Fire Age: No fire evident



Species List

Name	Cover (%)	Height (m)
Acacia ptychophylla	0.5	0.4
Cleome viscosa	0.5	0.5
Corchorus lasiocarpus subsp. *parvus*	0.5	0.6
Dampiera candicans	0.5	0.5
Eriachne mucronata	0.5	0.2
Fimbristylis dichotoma	0.5	0.05
Indigofera monophylla	0.5	0.3
Mollugo molluginea	0.5	0.2
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	0.5	0.6
Trachymene oleracea subsp. *oleracea*	0.5	0.5
Triodia wiseana	20	0.4
Triumfetta appendiculata	0.5	0.5

* denotes weed species
? denotes unconfirmed ID

Site: MH35
Location: Map 7 on edge of Mesa and gully **Type:** 50x50m Quadrat
Date: 2016-05-07 **Described by:** KMc
MGA Zone: 50 **Easting:** 417219 **Northing:** 7595183
Habitat: Hillslope
Soil: Brown silty clay loam
Rock type: Ironstone
Vegetation: *Eucalyptus leucophloia* scattered low trees over *Acacia inaequilatera* scattered tall shrubs over *Triodia wiseana* open hummock grassland.
Veg Condition: Very Good
Fire Age: No fire evident

Species List

Name	Cover (%)	Height (m)
Acacia bivenosa	0.5	2.1
Acacia inaequilatera	1	2.5
Cassytha capillaris	0.5	
Corchorus lasiocarpus subsp. *parvus*	0.5	0.3
Dysphania sp.	0.5	0.05
Eucalyptus leucophloia subsp. *leucophloia*	2	8.0
Sida sp. Pilbara (A.A. Mitchell PRP 1543)	0.5	0.4
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	0.5	0.4
Triodia wiseana	20	0.4

* denotes weed species
? denotes unconfirmed ID

Site: MH36
Location: Map 6 edge of Mesa h **Type:** 10x250m Quadrat
Date: 2016-05-11 **Described by:** KMc
MGA Zone: 50 **Easting:** 415408 **Northing:** 7594986
Habitat: Breakaway
Soil: Red brown silty clay loam
Rock type: CID
Vegetation: *Eucalyptus leucophloia* subsp. *leucophloia* low open woodland over *Triodia wiseana* very open hummock grassland.
Veg Condition: Excellent
Fire Age: 2-5 years

Species List

Name	Cover (%)	Height (m)
Abutilon sp. Dioicum (A.A. Mitchell PRP 1618)	0.5	2.0
Acacia bivenosa	0.5	1.8
Acacia tumida var. *pilbarensis*	0.5	1.5
Cleome viscosa	0.5	0.4
Corchorus lasiocarpus subsp. *parvus*	0.5	0.6
Cucumis variabilis	0.5	0.4
Cymbopogon ambiguus	0.5	0.8
Cyperus cunninghamii subsp. *cunninghamii*	0.5	0.25
Eriachne mucronata	0.5	0.4
Eucalyptus leucophloia subsp. *leucophloia*	4	6.0
Flueggea virosa subsp. *melanthesoides*	0.5	2.5
Gossypium australe	0.5	1.2
Grevillea wickhamii	0.5	1.0
Hibiscus sturtii var. *campylochlamys*	0.5	0.9
Jasminum didymum subsp. *lineare*	0.5	2.5
Rhynchosia minima	0.5	0.4
Solanum horridum	0.5	0.1
Stylobasium spathulatum	0.5	1.8
Trichodesma zeylanicum var. *zeylanicum*	0.5	0.4
Triodia wiseana	8	0.35
Triumfetta appendiculata	0.5	0.8
Triumfetta maconochieana	0.5	0.4

* denotes weed species
? denotes unconfirmed ID

Site: MH37
Location: On breakaway slope **Type:** 25x100m Relevé
Date: 2016-04-30 **Described by:** JA/KMc
MGA Zone: 50 **Easting:** 417793 **Northing:** 7595468
Habitat: Breakaway
Soil: Brown silty clay loam
Rock type: Ironstone
Vegetation: *Acacia tumida* var. *pilbarensis* tall open shrubland over *Triodia wiseana* open hummock grassland.
Veg Condition: Excellent
Fire Age: 5-10 years

Species List

Name	Cover (%)	Height (m)
Acacia ancistrocarpa	0.5	0.5
Acacia inaequilatera	0.5	0.6
Acacia tumida var. *pilbarensis*	3	2.2
Bonamia pilbarensis	0.5	0.005
Cassytha capillaris	0.5	
Clerodendrum floribundum var. *angustifolium*	0.5	0.5
Corchorus lasiocarpus subsp. *parvus*	0.5	0.9
Corymbia hamersleyana	0.5	1.8
Eriachne mucronata	0.5	0.3
Eucalyptus leucophloia subsp. *leucophloia*	0.5	4.0
Euphorbia sp.	0.5	0.15
Gossypium australe	0.5	0.5
Hakea chordophylla	0.5	0.2
Hibiscus sturtii var. *campylochlamys*	0.5	0.4
Jasminum didymum subsp. *lineare*	0.5	1.2
Petalostylis labicheoides	0.5	1.5
Senna glutinosa subsp. *glutinosa*	0.5	1.3
Sida sp. Articulation below (A.A. Mitchell PRP 1605)	0.5	0.25
Solanum horridum	0.5	0.15
Tephrosia uniovulata	0.5	0.6
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	0.5	0.4
Triodia wiseana	15	0.4

* denotes weed species
? denotes unconfirmed ID

Site: MH38
Location: Map 4 **Type:** 25x100m Quadrat
Date: 2016-05-04 **Described by:** JA/LV
MGA Zone: 50 **Easting:** 418405 **Northing:** 7596289
Habitat: Minor creek
Soil: Brown sandy loam
Rock type: Ironstone
Vegetation: *Corymbia hamersleyana* low open woodland over *Acacia tumida* var. *pilbarensis* and *A. ancistrocarpa* tall open shrubland over *A. bivenosa* and *Petalostylis labicheoides* open shrubland over *Triodia wiseana* open hummock grassland.
Veg Condition: Excellent
Fire Age: >10 years

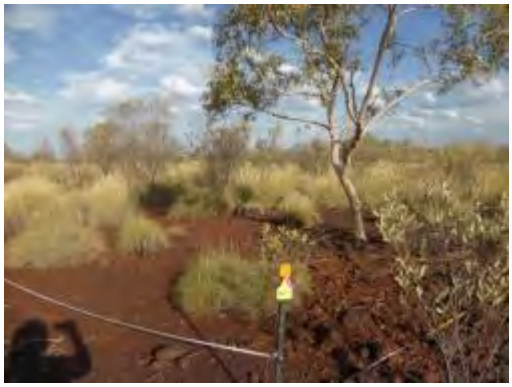
Species List

Name	Cover (%)	Height (m)
Acacia ancistrocarpa	1	2.5
Acacia bivenosa	7	1.5
Acacia inaequilatera	0.5	2.6
Acacia ptychophylla	0.5	1.3
Acacia trachycarpa	0.5	1.5
Acacia tumida var. *pilbarensis*	2	3.0
Bonamia pilbarensis	0.5	0.1
Cassytha capillaris	0.5	0.1
Cleome viscosa	0.5	0.15
Corymbia hamersleyana	9	6.0
Cymbopogon ambiguus	0.5	0.4
Cyperus vaginatus	0.5	0.4
Eriachne mucronata	0.5	0.3
Eucalyptus leucophloia subsp. *leucophloia*	0.5	4.5
Gossypium robinsonii	0.5	1.8
Grevillea wickhamii	0.5	1.0
Hybanthus aurantiacus	0.5	0.4
Indigofera monophylla	0.5	0.35
Petalostylis labicheoides	1	2.0
Phyllanthus maderaspatensis	0.5	0.02
Ptilotus fusiformis	0.5	0.4
Solanum horridum	0.5	0.01
Stylobasium spathulatum	0.5	1.2
Themeda triandra	0.5	0.4

Name	Cover (%)	Height (m)
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	0.5	
Triodia wiseana	25	0.4

* denotes weed species
? denotes unconfirmed ID

Site: MH39
Location: Northwest Mesa **Type:** 50x50m Quadrat
Date: 2016-05-03 **Described by:** JA/LV
MGA Zone: 50 **Easting:** 416106 **Northing:** 7598544
Habitat: Hillcrest
Soil: Light reddish brown silty clay loam
Rock type: Ironstone
Vegetation: *Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Acacia acradenia, Grevillea wickhamii* and *A. tumida* var. *pilbarensis* tall open shrubland over *Triodia wiseana* open hummock grassland.
Veg Condition: Excellent
Fire Age: >10 years

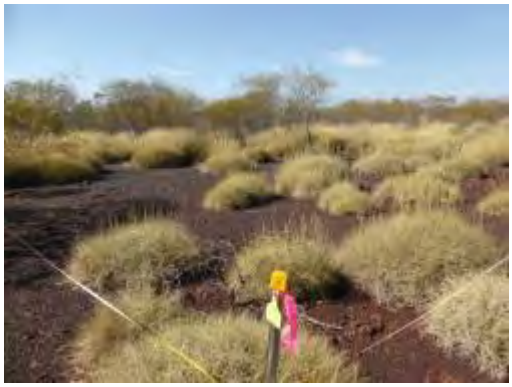


Species List

Name	Cover (%)	Height (m)
Acacia acradenia	3	2.4
Acacia tumida var. *pilbarensis*	1	4.0
Eucalyptus leucophloia subsp. *leucophloia*	1	4.5
Grevillea wickhamii	2	3.5
Petalostylis labicheoides	0.5	1.4
Tephrosia uniovulata	0.5	0.6
Triodia wiseana	15	0.6

* denotes weed species
? denotes unconfirmed ID

Site: MH40
Location: NA **Type:** 50x50m Quadrat
Date: 2016-05-03 **Described by:** DR/KMc
MGA Zone: 50 **Easting:** 418173 **Northing:** 7598499
Habitat: Hillcrest
Soil: Red brown clay loam
Rock type: Ironstone
Vegetation: *Acacia tumida* var. *pilbarensis, A. ancistrocarpa* and *Grevillea wickhamii* tall shrubland over *Triodia wiseana* open hummock grassland.
Veg Condition: Excellent
Fire Age: No fire evident



Species List

Name	Cover (%)	Height (m)
Acacia ancistrocarpa	5	3.1
Acacia bivenosa	0.5	1.2
Acacia inaequilatera	0.5	2.5
Acacia trachycarpa	0.5	1.5
Acacia tumida var. *pilbarensis*	6	3.5
Amphipogon sericeus	0.5	0.2
Bonamia pilbarensis	0.5	0.1
Corymbia hamersleyana	0.5	4.8
Dampiera candicans	0.5	0.6
Grevillea wickhamii	1	4.0
Hybanthus aurantiacus	0.5	0.1
Indigofera monophylla	0.5	0.4
Keraudrenia velutina subsp. *elliptica*	0.5	1.0
Petalostylis labicheoides	0.5	2.0
Tephrosia uniovulata	0.5	0.8
Triodia wiseana	17	0.7

* denotes weed species
? denotes unconfirmed ID

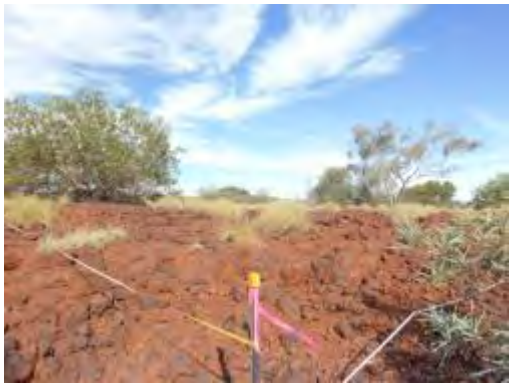
Site: MH41
Location: On Map 3 in gully off Mesa draining into Robe River **Type:** 25x100m Quadrat
Date: 2016-05-07 **Described by:** KMc/LV
MGA Zone: 50 **Easting:** 415208 **Northing:** 7596540
Habitat: Gully
Soil: Reddish brown silty clay loam
Rock type: Ironstone
Vegetation: *Eucalyptus leucophloia* subsp. *leucophloia* low woodland over *Acacia tumida* var. *pilbarensis* tall open shrubland over *Triodia wiseana* and *T.* sp. Robe River (M.E. Trudgen et al. MET 12367) P3 open hummock grassland.
Veg Condition: Excellent
Fire Age: >10 years

Species List

Name	Cover (%)	Height (m)
Abutilon sp. Dioicum (A.A. Mitchell PRP 1618)	0.5	1.1
Acacia tumida var. *pilbarensis*	4	5.0
Capparis spinosa var. *nummularia*	0.5	0.4
Cassytha capillaris	0.5	
Cleome viscosa	0.5	0.3
Clerodendrum floribundum var. *angustifolium*	0.5	1.0
Cymbopogon ambiguus	0.5	0.4
Eriachne mucronata	0.5	0.3
Eucalyptus leucophloia subsp. *leucophloia*	25	6.5
Ficus aculeata var. *indecora*	0.5	2.5
Ficus brachypoda	0.5	3.0
Flueggea virosa subsp. *melanthesoides*	0.5	1.8
Jasminum didymum subsp. *lineare*	0.5	1.1
Paspalidium sp.	0.5	0.02
Petalostylis labicheoides	0.5	2.5
Phyllanthus maderaspatensis	0.5	0.3
Ptilotus obovatus	0.5	0.35
Senna glutinosa subsp. *glutinosa*	0.5	1.5
Sida rohlenae subsp. *rohlenae*	0.5	0.3
Sida sp. Articulation below (A.A. Mitchell PRP 1605)	0.5	0.1
Solanum gabrielae	0.5	0.15
Solanum horridum	0.5	0.15
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	2	0.4
Triodia wiseana	20	0.5

* denotes weed species
? denotes unconfirmed ID

Site: MH42
Location: NA **Type:** 50x50m Quadrat
Date: 2016-04-30 **Described by:** JA/KMc
MGA Zone: 50 **Easting:** 417691 **Northing:** 7594888
Habitat: Hillslope
Soil: Red brown silty clay loam
Rock type: Ironstone
Vegetation: *Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Acacia pruinocarpa* tall open shrubland over *Eremophila fraseri* subsp. *fraseri* low open shrubland over *Triodia wiseana* and *T.* sp. Robe River (M.E. Trudgen et al. MET 12367) P3 very open hummock grassland.
Veg Condition: Very Good
Fire Age: >10 years



Species List

Name	Cover (%)	Height (m)
Acacia inaequilatera	0.5	3.0
Acacia pruinocarpa	7	4.0
Eremophila fraseri subsp. *fraseri*	2	0.7
Eriachne pulchella subsp. *pulchella*	0.5	0.05
Eucalyptus leucophloia subsp. *leucophloia*	1	5.0
Grevillea wickhamii	0.5	0.6
Jasminum didymum subsp. *lineare*	0.5	0.5
Ptilotus astrolasius	0.5	0.1
Ptilotus nobilis subsp. *nobilis*	0.5	0.02
Sarcostemma viminale	0.5	1.2
Senna glutinosa subsp. *x luerssenii*	0.5	1.1
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	1	0.3
Triodia wiseana	6	0.4

* denotes weed species
? denotes unconfirmed ID

Site: MH43
Location: Map 4 **Type:** 20x125m Quadrat
Date: 2016-05-04 **Described by:** JA/LV
MGA Zone: 50 **Easting:** 419042 **Northing:** 7596362
Habitat: Major creek
Soil: Brown sandy loam
Rock type: Ironstone
Vegetation: *Eucalyptus camaldulensis* subsp. *refulgens* and *Eucalyptus victrix* woodland over *Acacia trachycarpa* scattered tall shrubs over **Cenchrus ciliaris* and **C. setiger* very open tussock grassland with *Cyperus vaginatus* scattered sedges.
Veg Condition: Good
Fire Age: >10 years

Species List

Name	Cover (%)	Height (m)
**Cenchrus ciliaris*	1	0.15
**Cenchrus setiger*	1	0.2
**Citrullus colocynthis*	0.5	0.1
Abutilon sp. Dioicum (A.A. Mitchell PRP 1618)	0.5	0.1
Acacia bivenosa	0.5	1.5
Acacia colei var. *ileocarpa*	0.5	2.2
Acacia elachantha	0.5	2.0
Acacia pyrifolia var. *pyrifolia*	0.5	1.2
Acacia trachycarpa	1	2.5
Capparis spinosa var. *nummularia*	0.5	0.15
Cleome viscosa	0.5	0.1
Corchorus lasiocarpus subsp. *parvus*	0.5	0.1
Cucumis variabilis	0.5	0.15
Cyperus vaginatus	1	0.5
Eucalyptus camaldulensis subsp. *refulgens*	14	10.0
Eucalyptus victrix	14	10.0
Euphorbia schultzii	0.5	0.1
Evolvulus alsinoides var. *villosicalyx*	0.5	0.02
Gossypium robinsonii	0.5	0.05
Hybanthus aurantiacus	0.5	0.2
Melaleuca glomerata	0.5	3.5
Notoleptopus decaisnei var. Orbicularis (A.B. Craig 428)	0.5	0.15
Petalostylis labicheoides	0.5	1.7
Phyllanthus maderaspatensis	0.5	0.1

Name	Cover (%)	Height (m)
Pterocaulon sp.	0.5	0.1
Ptilotus astrolasius	0.5	0.3
Ptilotus axillaris	0.5	0.1
Ptilotus nobilis subsp. *nobilis*	0.5	0.15
Solanum diversiflorum	0.5	0.15
Solanum horridum	0.5	0.12
Stylobasium spathulatum	0.5	1.7
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	0.5	0.25
Triodia epactia	0.5	0.5
Triumfetta appendiculata	0.5	0.4
Waltheria indica	0.5	0.01

* denotes weed species
? denotes unconfirmed ID

Site: MH44
Location: NA **Type:** 20x125m Quadrat
Date: 2016-05-04 **Described by:** JA
MGA Zone: 50 **Easting:** 418862 **Northing:** 7596737
Habitat: Major creek
Soil: Orange brown sandy clay loam
Rock type: NA
Vegetation: *Eucalyptus camaldulensis* subsp. *refulgens, E. victrix* low woodland over *Acacia trachycarpa* and *A. bivenosa* scattered tall shrubs to tall open shrubland over **Cenchrus ciliaris* and **C. setiger* very open tussock grassland.
Veg Condition: Good
Fire Age: >10 years

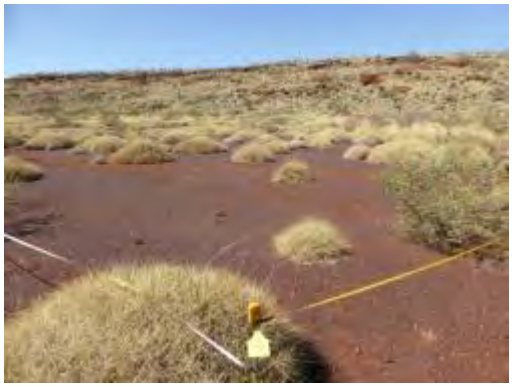
Species List

Name	Cover (%)	Height (m)
**Cenchrus ciliaris*	2	0.15
**Cenchrus setiger*	1	0.15
**Malvastrum americanum*	0.5	0.15
**Vachellia farnesiana*	0.5	1.8
Abutilon lepidum	0.5	0.2
Abutilon sp. Dioicum (A.A. Mitchell PRP 1618)	0.5	0.7
Acacia bivenosa	1	2.2
Acacia pyrifolia var. *pyrifolia*	0.5	2.3
Acacia trachycarpa	2	3.8
Cleome viscosa	0.5	0.1
Corchorus lasiocarpus subsp. *parvus*	0.5	0.5
Cyperus vaginatus	0.5	0.7
Eriachne mucronata	0.5	0.4
Eucalyptus camaldulensis subsp. *refulgens*	20	11.0
Eucalyptus victrix	7	9.0
Flueggea virosa subsp. *melanthesoides*	0.5	1.4
Gossypium robinsonii	0.5	0.3
Hybanthus aurantiacus	0.5	0.1
Melaleuca glomerata	0.5	2.4
Notoleptopus decaisnei var. Orbicularis (A.B. Craig 428)	0.5	0.1
Petalostylis labicheoides	0.5	2.3
Phyllanthus maderaspatensis	0.5	0.25
Pterocaulon sphaeranthoides	0.5	0.1
Ptilotus nobilis subsp. *nobilis*	0.5	0.05

Name	Cover (%)	Height (m)
Rhynchosia minima	0.5	0.1
Solanum cleistogamum	0.5	0.15
Solanum diversiflorum	0.5	0.3
Solanum horridum	0.5	0.15
Stylobasium spathulatum	0.5	1.1
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	0.5	0.15
Themeda triandra	0.5	0.9
Triodia epactia	0.5	0.5
Triumfetta appendiculata	0.5	0.15
Waltheria indica	0.5	0.1

* denotes weed species
? denotes unconfirmed ID

Site: MH100
Location: Map 3 **Type:** 50x50m Quadrat
Date: 2016-05-01 **Described by:** DR/LV
MGA Zone: 50 **Easting:** 415654 **Northing:** 7598689
Habitat: Valley flat
Soil: Red brown sandy loam
Rock type: Ironstone
Vegetation: *Acacia synchronicia* tall open shrubland over *Triodia wiseana* open hummock grassland.
Veg Condition: Very Good
Fire Age: >10 years



Species List

Name	Cover (%)	Height (m)
**Cenchrus ciliaris*	0.5	0.3
Acacia ancistrocarpa	0.5	1.5
Acacia bivenosa	0.5	1.0
Acacia inaequilatera	0.5	0.3
Acacia synchronicia	2	2.1
Aristida holathera var. *holathera*	0.5	0.35
Paraneurachne muelleri	0.5	0.15
Ptilotus astrolasius	0.5	0.15
Ptilotus auriculifolius	0.5	0.1
Triodia wiseana	19	1.0

* denotes weed species
? denotes unconfirmed ID

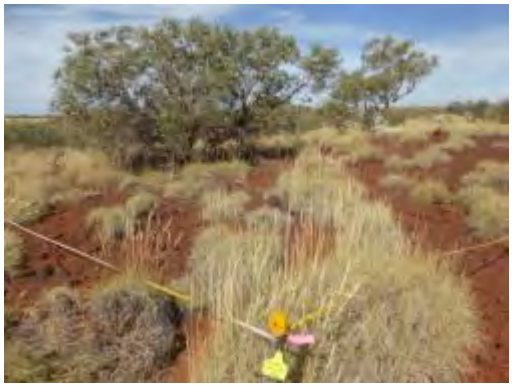
Site: MH101
Location: Map 7 on edge of Mesa and gully **Type:** 50x50m Relevé
Date: 2016-05-07 **Described by:** KMc
MGA Zone: 50 **Easting:** 417063 **Northing:** 7594625
Habitat: Hillslope
Soil: Brown silty clay loam
Rock type: Ironstone
Vegetation: *Acacia pruinocarpa* tall open shrubland over *Eremophila fraseri* scattered low shrubs over *Triodia wiseana* very open hummock grassland.
Veg Condition: Excellent
Fire Age: No fire evident

Species List

Name	Cover (%)	Height (m)
Acacia bivenosa	0.5	1.5
Acacia inaequilatera	0.5	3.5
Acacia pruinocarpa	7	3.5
Corchorus lasiocarpus subsp. *parvus*	0.5	0.6
Eremophila fraseri subsp. *fraseri*	1	0.8
Eriachne mucronata	0.5	0.2
Lysiana casuarinae	0.5	2.5
Senna glutinosa subsp. *x luerssenii*	0.5	0.8
Sida sp. Pilbara (A.A. Mitchell PRP 1543)	0.5	0.6
Solanum horridum	0.5	0.1
Tephrosia virens	0.5	1.4
Tribulus suberosus	0.5	0.6
Trichodesma zeylanicum var. *zeylanicum*	0.5	0.4
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	0.5	0.3
Triodia wiseana	9	0.4
Triumfetta johnstonii	0.5	0.6

* denotes weed species
? denotes unconfirmed ID

Site: MH103
Location: Map 7 **Type:** 50x50m Quadrat
Date: 2016-04-30 **Described by:** DR/LV
MGA Zone: 50 **Easting:** 417837 **Northing:** 7595461
Habitat: Hillcrest
Soil: Red brown sandy clay loam
Rock type: Ironstone
Vegetation: *Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Acacia pruinocarpa* tall open shrubland over *Sarcostemma viminale* scattered low shrubs over *Triodia wiseana* and *T.* sp. Robe River (M.E. Trudgen et al. MET 12367) P3 open hummock grassland.
Veg Condition: Excellent
Fire Age: No fire evident



Species List

Name	Cover (%)	Height (m)
Acacia pruinocarpa	6	4.0
Acacia tumida var. *pilbarensis*	0.5	1.7
Cassytha capillaris	0.5	0.3
Eremophila fraseri subsp. *fraseri*	0.5	0.6
Eucalyptus leucophloia subsp. *leucophloia*	1	5.0
Grevillea pyramidalis subsp. *leucadendron*	0.5	1.7
Jasminum didymum subsp. *lineare*	0.5	0.4
Mollugo molluginea	0.5	0.1
Sarcostemma viminale	1	0.7
Senna glutinosa subsp. *x luerssenii*	0.5	1.6
Trichodesma zeylanicum var. *zeylanicum*	0.5	0.4
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	1	0.4
Triodia wiseana	15	0.8

* denotes weed species
? denotes unconfirmed ID

Site: MH104
Location: Map7 **Type:** 50x50m Quadrat
Date: 2016-04-30 **Described by:** DR/LV
MGA Zone: 50 **Easting:** 417922 **Northing:** 7595431
Habitat: Minor creek
Soil: Red brown sandy clay loam
Rock type: Ironstone
Vegetation: *Corymbia hamersleyana* scattered low trees over *Acacia tumida* var. *pilbarensis* tall open scrub over *Triodia wiseana* and *T.* sp. Robe River (M.E. Trudgen et al. MET 12367) P3 open hummock grassland.
Veg Condition: Excellent
Fire Age: No fire evident

Species List

Name	Cover (%)	Height (m)
Acacia ancistrocarpa	0.5	2.3
Acacia inaequilatera	0.5	0.2
Acacia tumida var. *pilbarensis*	32	3.3
Bonamia pilbarensis	0.5	0.1
Cassytha capillaris	0.5	0.2
Corchorus lasiocarpus subsp. *parvus*	0.5	0.3
Corymbia hamersleyana	1	5.0
Euphorbia australis	0.5	0.01
Gossypium robinsonii	0.5	0.8
Grevillea wickhamii	0.5	3.1
Hibiscus sturtii var. *campylochlamys*	0.5	0.8
Indigofera monophylla	0.5	0.3
Jasminum didymum subsp. *lineare*	0.5	2.2
Mollugo molluginea	0.5	0.1
Paraneurachne muelleri	0.5	0.01
Petalostylis labicheoides	0.5	1.9
Pterocaulon sp.	0.5	0.2
Ptilotus astrolasius	0.5	0.1
Ptilotus calostachyus	0.5	0.3
Ptilotus nobilis subsp. *nobilis*	0.5	0.2
Solanum cleistogamum	0.5	0.1
Solanum diversiflorum	0.5	0.2
Tephrosia uniovulata	0.5	0.8
Trichodesma zeylanicum var. *zeylanicum*	0.5	0.3

Name	Cover (%)	Height (m)
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	12	0.8
Triodia wiseana	12	0.8

* denotes weed species
? denotes unconfirmed ID

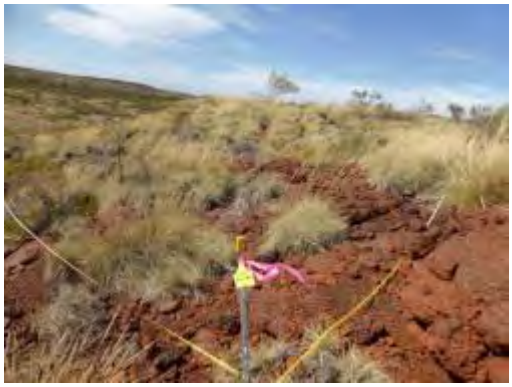
Site: MH105
Location: NA **Type:** 15x120m Quadrat
Date: 2016-05-09 **Described by:** JA
MGA Zone: 50 **Easting:** 416825 **Northing:** 7593654
Habitat: Gully
Soil: Brown clay loam
Rock type: Ironstone
Vegetation: *Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Acacia pruinocarpa* scattered shrubs over *Triumfetta appendiculata* scattered low shrubs over *Triodia wiseana* open hummock grassland.
Veg Condition: Very Good
Fire Age: 2-5 years

Species List

Name	Cover (%)	Height (m)
Abutilon sp. Dioicum (A.A. Mitchell PRP 1618)	0.5	1.1
Acacia bivenosa	0.5	0.6
Acacia inaequilatera	0.5	1.6
Acacia orthocarpa	0.5	0.4
Acacia pruinocarpa	1	1.8
Acacia ptychophylla	0.5	0.7
Bonamia pilbarensis	0.5	0.05
Clerodendrum floribundum var. *angustifolium*	0.5	0.8
Cymbopogon ambiguus	0.5	0.8
Cyperus cunninghamii subsp. *cunninghamii*	0.5	0.1
Eriachne mucronata	0.5	0.3
Eucalyptus leucophloia subsp. *leucophloia*	2	5.5
Euphorbia schultzii	0.5	0.1
Jasminum didymum subsp. *lineare*	0.5	1.1
Petalostylis labicheoides	0.5	1.3
Polycarpaea longiflora	0.5	0.1
Ptilotus astrolasius	0.5	0.4
Ptilotus calostachyus	0.5	0.6
Ptilotus incanus	0.5	0.4
Senna glutinosa subsp. *glutinosa*	0.5	1.2
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	0.5	0.5
Triodia wiseana	12	0.5
Triumfetta appendiculata	1	0.9
Triumfetta maconochieana	0.5	0.5

* denotes weed species
? denotes unconfirmed ID

Site: MH106
Location: Map 7 **Type:** 50x50m Quadrat
Date: 2016-04-30 **Described by:** DR/LV
MGA Zone: 50 **Easting:** 418720 **Northing:** 7595616
Habitat: Hillslope
Soil: Red brown clay loam
Rock type: Ironstone
Vegetation: *Acacia ptychophylla* and *A. bivenosa* open shrubland over *Triodia wiseana* and *T.* sp. Robe River (M.E. Trudgen et al. MET 12367) P3 open hummock grassland.
Veg Condition: Excellent
Fire Age: No fire evident

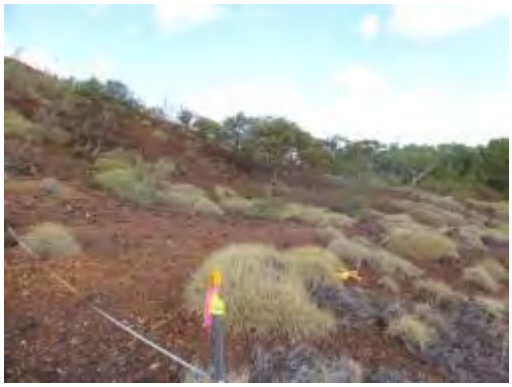


Species List

Name	Cover (%)	Height (m)
Acacia ancistrocarpa	0.5	2.5
Acacia ancistrocarpa x ptychophylla	0.5	2.0
Acacia bivenosa	1	1.6
Acacia ptychophylla	3	2.0
Cassytha capillaris	0.5	0.1
Corymbia hamersleyana	0.5	4.0
Goodenia stobbsiana	0.5	0.2
Grevillea wickhamii	0.5	2.2
Petalostylis labicheoides	0.5	1.4
Ptilotus calostachyus	0.5	0.8
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	4	0.6
Triodia wiseana	25	0.9

* denotes weed species
? denotes unconfirmed ID

Site: MH200
Location: NW corner of survey area **Type:** 50x50m Quadrat
Date: 2016-05-01 **Described by:** JA/KMc
MGA Zone: 50 **Easting:** 415410 **Northing:** 7598434
Habitat: Hillslope
Soil: Brown clay loam
Rock type: Dolerite
Vegetation: *Acacia xiphophylla* tall open shrubland over *A. synchronicia* scattered shrubs over *Triodia wiseana* open hummock grassland.
Veg Condition: Very Good
Fire Age: >10 years



Species List

Name	Cover (%)	Height (m)
**Cenchrus ciliaris*	0.5	0.3
Acacia ancistrocarpa	0.5	2.0
Acacia bivenosa	0.5	1.2
Acacia synchronicia	1	1.8
Acacia trachycarpa	0.5	2.0
Acacia xiphophylla	8	4.0
Bulbostylis barbata	0.5	0.1
Corchorus sp.	0.5	0.5
Cymbopogon ambiguus	0.5	1.2
Eriachne mucronata	0.5	0.4
Ptilotus nobilis subsp. *nobilis*	0.5	0.2
Senna glutinosa subsp. *x luerssenii*	0.5	1.1
Triodia wiseana	20	0.6

* denotes weed species
? denotes unconfirmed ID

Site: MH203
Location: Map 4 **Type:** 50x50m Quadrat
Date: 2016-05-02 **Described by:** DR/LV
MGA Zone: 50 **Easting:** 418754 **Northing:** 7598544
Habitat: Major creek
Soil: Red brown sand
Rock type: Ironstone
Vegetation: *Acacia trachycarpa, Petalostylis labicheoides* and *A. bivenosa* tall open scrub.
Veg Condition: Excellent
Fire Age: >10 years

Species List

Name	Cover (%)	Height (m)
**Cenchrus setiger*	0.5	0.4
Acacia bivenosa	1	2.1
Acacia pyrifolia var. *pyrifolia*	0.5	2.2
Acacia trachycarpa	35	4.5
Adriana tomentosa	0.5	1.3
Cleome viscosa	0.5	0.2
Corchorus lasiocarpus subsp. *parvus*	0.5	0.3
Euphorbia schultzii	0.5	0.15
Hybanthus aurantiacus	0.5	0.2
Petalostylis labicheoides	25	2.5
Ptilotus auriculifolius	0.5	0.3
Rhynchosia bungarensis P4	0.5	0.4

* denotes weed species
? denotes unconfirmed ID

Site: MH204
Location: NA **Type:** 50x50m Quadrat
Date: 2016-05-03 **Described by:** DR/KMc
MGA Zone: 50 **Easting:** 417491 **Northing:** 7598178
Habitat: Major creek
Soil: Red brown sandy loam
Rock type: NA
Vegetation: *Melaleuca argentia* and *Eucalyptus camaldulensis* subsp. *refulgens* open forest over *Acacia trachycarpa* tall open shrubland over *Cyperus vaginatus* scattered sedges.
Veg Condition: Very Good
Fire Age: No fire evident

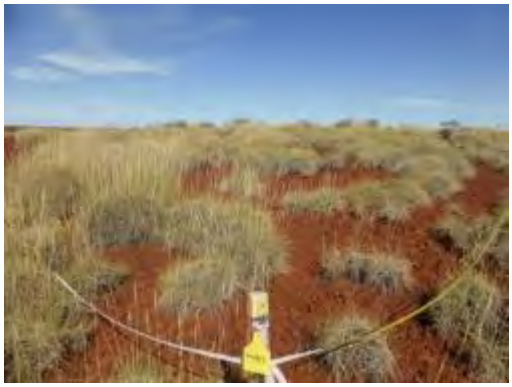
Species List

Name	Cover (%)	Height (m)
**Cenchrus ciliaris*	0.5	0.2
**Euphorbia hirta*	0.5	0.1
**Passiflora foetida* var. *hispida*	0.5	0.9
Acacia bivenosa	0.5	1.5
Acacia synchronicia	0.5	0.3
Acacia trachycarpa	3	2.5
Cleome viscosa	0.5	0.5
Cyperus vaginatus	1	0.9
Eucalyptus camaldulensis subsp. *refulgens*	10	17
Euphorbia australis	0.5	
Euphorbia biconvexa	0.5	0.1
Euphorbia schultzii	0.5	0.2
Ipomoea muelleri	0.5	0.3
Lobelia sp.	0.5	0.2
Melaleuca argentea	40	18
Petalostylis labicheoides	0.5	1.8
Phyllanthus maderaspatensis	0.5	0.2
Pluchea rubelliflora	0.5	0.2
Rhynchosia bungarensis P4	0.5	0.3
Sesbania formosa	0.5	6.7
Stemodia grossa	0.5	0.2
Streptoglossa liatroides	0.5	0.3
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	0.5	1.0
Tephrosia sp. Fortescue (A.A. Mitchell 606)	0.5	
Vigna lanceolata var. *lanceolata*	0.5	0.3

Name	Cover (%)	Height (m)
Waltheria indica	0.5	0.6

* denotes weed species
? denotes unconfirmed ID

Site: MH300
Location: Map 4 south of Robe River **Type:** 50x50m Quadrat
Date: 2016-04-29 **Described by:** DR
MGA Zone: 50 **Easting:** 419716 **Northing:** 7597317
Habitat: Hillcrest
Soil: Red brown silty clay loam
Rock type: Ironstone
Vegetation: *Acacia ptychophylla* open shrubland over *Triodia wiseana* open hummock grassland.
Veg Condition: Excellent
Fire Age: No fire evident



Species List

Name	Cover (%)	Height (m)
Acacia ancistrocarpa	0.5	1.2
Acacia inaequilatera	0.5	1.4
Acacia ptychophylla	3	1.1
Acacia trachycarpa	0.5	1.8
Dysphania rhadinostachya subsp. *rhadinostachya*	0.5	0.1
Eriachne pulchella subsp. *pulchella*	0.5	0.1
Hakea chordophylla	0.5	3.0
Keraudrenia velutina subsp. *elliptica*	0.5	0.7
Polycarpaea holtzei	0.5	0.02
Ptilotus calostachyus	0.5	0.3
Ptilotus nobilis subsp. *nobilis*	0.5	0.15
Senna glutinosa subsp. *glutinosa*	0.5	1.0
Triodia wiseana	20	0.7

* denotes weed species
? denotes unconfirmed ID

Site: MH301
Location: Map 8 east of river **Type:** 50x50m Quadrat
Date: 2016-04-29 **Described by:** DR/LV
MGA Zone: 50 **Easting:** 419923 **Northing:** 7595542
Habitat: Hillcrest
Soil: Red brown clay loam
Rock type: CID
Vegetation: *Acacia inaequilatera* scattered tall shrubs over *A. ptychophylla* scattered shrubs over *Triodia wiseana* and *T.* sp. Robe River (M.E. Trudgen et al. MET 12367) hummock grassland.
Veg Condition: Excellent
Fire Age: No fire evident

Species List

Name	Cover (%)	Height (m)
Acacia ancistrocarpa	0.5	1.9
Acacia bivenosa	0.5	1.9
Acacia inaequilatera	1	4.0
Acacia ptychophylla	1	0.7
Amyema preissii	0.5	3.0
Cassytha capillaris	0.5	0.4
Cymbopogon ambiguus	0.5	0.6
Eriachne mucronata	0.5	0.3
Eucalyptus sp.	0.5	0.3
Goodenia stobbsiana	0.5	0.6
Hakea chordophylla	0.5	2.0
Polycarpaea longiflora	0.5	0.2
Ptilotus calostachyus	0.5	0.5
Sida sp. Pilbara (A.A. Mitchell PRP 1543)	0.5	0.02
Trichodesma zeylanicum var. *zeylanicum*	0.5	0.2
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	3	0.6
Triodia wiseana	29	0.9

* denotes weed species
? denotes unconfirmed ID

Site: MH302
Location: Map 5 north of mine access **Type:** 50x50m Quadrat
Date: 2016-04-28 **Described by:** DR/LV
MGA Zone: 50 **Easting:** 419624 **Northing:** 7594568
Habitat: Floodplain
Soil: Reddish brown silty loam
Rock type: Ironstone
Vegetation: *Corymbia hamersleyana* scattered low trees over *Stylobasium spathulatum*, *Acacia trachycarpa, Acacia pyrifolia* tall open shrubland over *Grevillea pyramidalis* subsp. *leucadendron, Abutilon* sp. Dioicum (A.A. Mitchell PRP 1618) scattered shrubs over *Triodia epactia* open hummock grassland and **Cenchrus setiger* scattered tussock grasses.
Veg Condition: Good
Fire Age: No fire evident

Species List

Name	Cover (%)	Height (m)
**Argemone ochroleuca* subsp. *ochroleuca*	0.5	0.2
**Cenchrus ciliaris*	0.5	0.4
**Cenchrus setiger*	1	0.5
**Flaveria trinervia*	0.5	0.4
**Malvastrum americanum*	0.5	0.4
**Setaria verticillata*	1	0.5
**Tribulus terrestris*	0.5	0.1
Abutilon sp. Dioicum (A.A. Mitchell PRP 1618)	1	1.9
Acacia pyrifolia var. *pyrifolia*	1	2.5
Acacia trachycarpa	2	3.5
Amaranthus mitchellii	0.5	0.25
Boerhavia coccinea	0.5	0.15
Bonamia pilbarensis	0.5	0.05
Bulbostylis barbata	0.5	0.1
Cleome viscosa	0.5	0.4
Corchorus crozophorifolius	0.5	0.6
Corchorus lasiocarpus subsp. *parvus*	0.5	0.6
Corymbia hamersleyana	1	4.0
Cucumis variabilis	0.5	0.3
Dysphania rhadinostachya subsp. *rhadinostachya*	0.5	0.3
Enneapogon caerulescens	0.5	0.3
Eucalyptus sp.	0.5	0.3
Euphorbia australis var. *subtomentosa*	0.5	0.1

Name	Cover (%)	Height (m)
Euphorbia boophthona	0.5	0.25
Gossypium australe	0.5	1.6
Gossypium robinsonii	0.5	1.9
Grevillea pyramidalis subsp. *leucadendron*	1	1.9
Hybanthus aurantiacus	0.5	0.3
Indigofera monophylla	0.5	0.2
Jasminum didymum subsp. *lineare*	0.5	1.6
Melhania oblongifolia	0.5	0.3
Notoleptopus decaisnei var. Orbicularis (A.B. Craig 428)	0.5	0.25
Paspalidium clementii	0.5	0.1
Phyllanthus maderaspatensis	0.5	0.3
Pterocaulon sphaeranthoides	0.5	1.0
Ptilotus aervoides	0.5	0.05
Ptilotus appendiculatus	0.5	0.1
Ptilotus astrolasius	0.5	0.4
Ptilotus axillaris	0.5	0.1
Ptilotus fusiformis	0.5	0.4
Ptilotus nobilis subsp. *nobilis*	0.5	0.1
Ptilotus obovatus	0.5	0.3
Solanum diversiflorum	0.5	0.1
Solanum horridum	0.5	0.15
Stylobasium spathulatum	3	2.5
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	0.5	0.3
Trachymene oleracea subsp. *oleracea*	0.5	0.4
Trichodesma zeylanicum var. *zeylanicum*	0.5	0.4
Triodia epactia	25	0.4
Triumfetta clementii	0.5	0.1
Waltheria indica	0.5	0.35

* denotes weed species
? denotes unconfirmed ID

Site: MH303
Location: NA **Type:** 25x100m Quadrat
Date: 2016-04-29 **Described by:** JA/KMc
MGA Zone: 50 **Easting:** 419534 **Northing:** 7595539
Habitat: Minor creek
Soil: Red brown silty loam
Rock type: Ironstone
Vegetation: *Eucalyptus camaldulensis* subsp. *refulgens* low open forest over *Acacia trachycarpa* and *Petalostylis labicheoides* tall open shrubland over Melaleuca glomerata and *A. bivenosa* open shrubland over *Triumfetta clementii* scattered low shrubs over **Cenchrus setiger* tussock grassland with *Cyperus vaginatus* scattered sedges.
Veg Condition: Good
Fire Age: >10 years

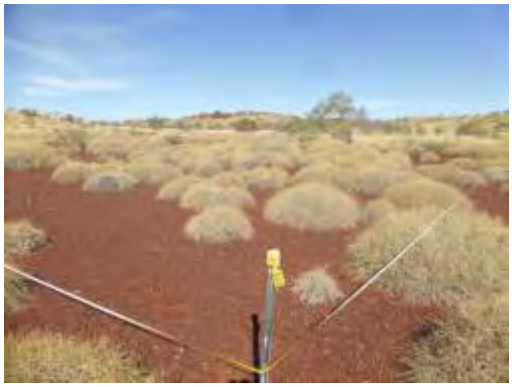
Species List

Name	Cover (%)	Height (m)
**Cenchrus ciliaris*	0.5	0.1
**Cenchrus setiger*	32	0.4
**Echinochloa colona*	0.5	0.1
**Euphorbia hirta*	0.5	0.05
**Malvastrum americanum*	0.5	0.3
**Setaria verticillata*	0.5	0.4
**Sonchus oleraceus*	0.5	0.15
**Vachellia farnesiana*	0.5	0.5
Abutilon lepidum	0.5	0.3
Abutilon sp. Dioicum (A.A. Mitchell PRP 1618)	0.5	2.0
Acacia bivenosa	1	1.2
Acacia colei var. *ileocarpa*	0.5	2.2
Acacia pyrifolia var. *pyrifolia*	0.5	1.5
Acacia trachycarpa	1	2.1
Boerhavia coccinea	0.5	0.1
Cleome viscosa	0.5	0.6
Corchorus lasiocarpus subsp. *parvus*	0.5	0.2
Cucumis variabilis	0.5	
Cymbopogon ambiguus	0.5	0.7
Cyperus vaginatus	1	0.6
Dactyloctenium radulans	0.5	0.2
Eriachne mucronata	0.5	0.4
Eucalyptus camaldulensis subsp. *refulgens*	40	7.0

Name	Cover (%)	Height (m)
Eulalia aurea	0.5	0.6
Euphorbia schultzii	0.5	0.15
Ficus aculeata var. *indecora*	0.5	1.0
Flueggea virosa subsp. *melanthesoides*	0.5	0.4
Gomphrena cunninghamii	0.5	0.05
Gossypium robinsonii	0.5	0.1
Hybanthus aurantiacus	0.5	0.3
Ipomoea muelleri	0.5	0.2
Lepidium pholidogynum	0.5	0.1
Lobelia arnhemiaca	0.5	0.05
Melaleuca glomerata	1	1.2
Notoleptopus decaisnei var. Orbicularis (A.B. Craig 428)	0.5	0.05
Paraneurachne muelleri	0.5	0.5
Paspalidium clementii	0.5	0.2
Petalostylis labicheoides	1	2.3
Phyllanthus maderaspatensis	0.5	0.25
Ptilotus appendiculatus	0.5	0.1
Ptilotus sp.	0.5	0.1
Sida sp. Articulation below (A.A. Mitchell PRP 1605)	0.5	0.3
Solanum diversiflorum	0.5	0.45
Solanum horridum	0.5	0.15
Stylobasium spathulatum	0.5	2.0
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	0.5	0.5
Themeda triandra	0.5	0.9
Trachymene oleracea subsp. *oleracea*	0.5	0.65
Triodia wiseana	0.5	0.6
Triumfetta appendiculata	0.5	0.8
Triumfetta clementii	1	0.1
Triumfetta sp.	0.5	0.2
Waltheria indica	0.5	0.15

* denotes weed species
? denotes unconfirmed ID

Site: MH305
Location: South of robe river, eastern side of Mesa h **Type:** 50x50m Quadrat
Date: 2016-04-29 **Described by:** DR/LV
MGA Zone: 50 **Easting:** 419342 **Northing:** 7597641
Habitat: Plain
Soil: Red brown sandy loam
Rock type: Ironstone
Vegetation: *Acacia synchronicia* scattered tall shrubs over *A. inaequilatera* scattered shrubs over *Triodia wiseana* open hummock grassland.
Veg Condition: Excellent
Fire Age: >10 years



Species List

Name	Cover (%)	Height (m)
Acacia inaequilatera	1	1.5
Acacia synchronicia	1	3.5
Acacia tumida var. *pilbarensis*	0.5	2.0
Bulbostylis barbata	0.5	0.05
Capparis spinosa var. *nummularia*	0.5	0.5
Corymbia hamersleyana	0.5	4.0
Dysphania rhadinostachya subsp. *rhadinostachya*	0.5	0.25
Eriachne pulchella subsp. *pulchella*	0.5	0.1
Euphorbia australis var. *subtomentosa*	0.5	0.1
Mollugo molluginea	0.5	0.1
Paraneurachne muelleri	0.5	0.4
Petalostylis labicheoides	0.5	2.5
Polycarpaea corymbosa	0.5	0.05
Polycarpaea holtzei	0.5	0.05
Ptilotus astrolasius	0.5	0.4
Ptilotus calostachyus	0.5	0.6
Ptilotus nobilis subsp. *nobilis*	0.5	0.55
Senna artemisioides subsp. *oligophylla*	0.5	0.5
Senna glutinosa subsp. *pruinosa*	0.5	1.8
Senna notabilis	0.5	0.15
Sporobolus australasicus	0.5	0.1
Tribulus macrocarpus	0.5	
Triodia wiseana	25	0.6

* denotes weed species
? denotes unconfirmed ID

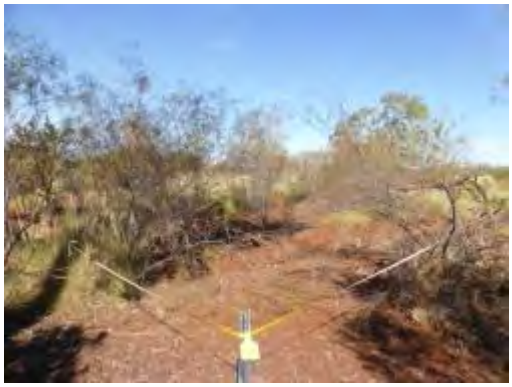
Site: MH306
Location: North east hills of survey area **Type:** 50x50m Quadrat
Date: 2016-05-04 **Described by:** DR/KMc
MGA Zone: 50 **Easting:** 419915 **Northing:** 7599310
Habitat: Hillcrest
Soil: Red brown sandy loam
Rock type: Ironstone
Vegetation: *Acacia inaequilatera* scattered tall shrubs over *Triodia wiseana* hummock grassland.
Veg Condition: Excellent
Fire Age: >10 years

Species List

Name	Cover (%)	Height (m)
Acacia atkinsiana	0.5	2.1
Acacia bivenosa	0.5	2.1
Acacia inaequilatera	2	2.3
Acacia ptychophylla	0.5	1.0
Amphipogon sericeus	0.5	0.35
Dysphania rhadinostachya subsp. *rhadinostachya*	0.5	0.15
Eriachne pulchella subsp. *pulchella*	0.5	0.08
Goodenia microptera	0.5	0.2
Goodenia stobbsiana	0.5	0.4
Polycarpaea holtzei	0.5	0.05
Ptilotus calostachyus	0.5	0.65
Ptilotus clementii	0.5	0.4
Ptilotus incanus	0.5	0.1
Ptilotus nobilis subsp. *nobilis*	0.5	0.2
Senna glutinosa subsp. *glutinosa*	0.5	0.6
Senna glutinosa subsp. *pruinosa*	0.5	1.5
Stackhousia muricata	0.5	0.2
Trachymene oleracea subsp. *oleracea*	0.5	0.8
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	0.5	0.5
Triodia wiseana	33	0.6

* denotes weed species
? denotes unconfirmed ID

Site: MH307
Location: Map 4 south of rail **Type:** 50x50m Quadrat
Date: 2016-04-29 **Described by:** JA/KMc
MGA Zone: 50 **Easting:** 418841 **Northing:** 7599089
Habitat: Floodplain
Soil: Red brown sandy loam
Rock type: Ironstone
Vegetation: *Corymbia candida* scattered low trees over *Acacia ancistrocarpa*, *A. trachycarpa* and *A. bivenosa* tall open shrubland over *Triodia wiseana* and *T. epactia* very open hummock grassland.
Veg Condition: Very Good
Fire Age: No fire evident



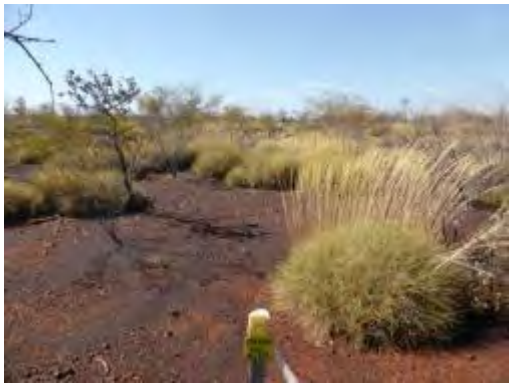
Species List

Name	Cover (%)	Height (m)
**Cenchrus ciliaris*	0.5	0.4
**Cenchrus setiger*	0.5	0.5
Acacia ancistrocarpa	4	2.5
Acacia bivenosa	1	2.5
Acacia inaequilatera	0.5	2.5
Acacia synchronicia	0.5	2.1
Acacia trachycarpa	4	2.5
Acacia trachycarpa x tumida var. *pilbarensis*	0.5	2.4
Acacia tumida var. *pilbarensis*	0.5	2.8
Aristida holathera var. *holathera*	0.5	0.3
Bonamia erecta	0.5	0.25
Bonamia pilbarensis	0.5	0.05
Bulbostylis barbata	0.5	0.1
Corchorus lasiocarpus subsp. *parvus*	0.5	0.4
Corymbia candida	2	7.0
Cucumis variabilis	0.5	0.2
Cymbopogon ambiguus	0.5	0.4
Dysphania rhadinostachya subsp. *rhadinostachya*	0.5	0.3
Eragrostis eriopoda	0.5	0.4
Eriachne mucronata	0.5	0.4
Eriachne pulchella subsp. *dominii*	0.5	0.2
Euphorbia australis var. *subtomentosa*	0.5	0.1
Euphorbia schultzii	0.5	0.3
Gomphrena cunninghamii	0.5	0.2
Goodenia forrestii	0.5	0.3

Name	Cover (%)	Height (m)
Goodenia microptera	0.5	0.1
Gossypium australe	0.5	0.1
Grevillea pyramidalis subsp. *leucadendron*	0.5	0.6
Hakea chordophylla	0.5	3.0
Hibiscus sturtii var. *campylochlamys*	0.5	0.2
Hybanthus aurantiacus	0.5	0.2
Indigofera monophylla	0.5	0.3
Jasminum didymum subsp. *lineare*	0.5	1.2
Mollugo molluginea	0.5	0.1
Paraneurachne muelleri	0.5	0.3
Petalostylis labicheoides	0.5	2.5
Ptilotus appendiculatus	0.5	0.1
Ptilotus astrolasius	0.5	0.4
Ptilotus calostachyus	0.5	0.6
Ptilotus nobilis subsp. *nobilis*	0.5	0.4
Rhynchosia minima	0.5	0.2
Senna artemisioides subsp. *oligophylla*	0.5	1.2
Senna glutinosa subsp. *pruinosa*	0.5	1.8
Sida echinocarpa	0.5	0.5
Solanum diversiflorum	0.5	0.3
Sporobolus australasicus	0.5	0.1
Tribulus macrocarpus	0.5	0.1
Triodia epactia	3	0.4
Triodia wiseana	5	0.8
Triumfetta clementii	0.5	0.3

* denotes weed species
? denotes unconfirmed ID

Site: MH308
Location: North east of Mesa h **Type:** 50x50m Quadrat
Date: 2016-05-03 **Described by:** DR/KMc
MGA Zone: 50 **Easting:** 418157 **Northing:** 7598886
Habitat: Hillcrest
Soil: Red brown sandy loam
Rock type: Ironstone
Vegetation: *Acacia ancistrocarpa* and *A. inaequilatera* tall open shrubland over *Triodia wiseana* open hummock grassland.
Veg Condition: Excellent
Fire Age: >10 years



Species List

Name	Cover (%)	Height (m)
Acacia ancistrocarpa	3	2.4
Acacia atkinsiana	0.5	1.5
Acacia inaequilatera	1	2.8
Bonamia erecta	0.5	0.2
Grevillea wickhamii	0.5	1.1
Petalostylis labicheoides	0.5	1.5
Ptilotus calostachyus	0.5	0.9
Ptilotus nobilis subsp. *nobilis*	0.5	0.5
Triodia wiseana	11	0.6

* denotes weed species
? denotes unconfirmed ID

Site: MH309r
Location: Map4 **Type:** 50x50m Relevé
Date: 2016-05-03 **Described by:** DR/KMc
MGA Zone: 50 **Easting:** 417616 **Northing:** 7599295
Habitat: Hillslope
Soil: Red brown sandy loam
Rock type: Ironstone
Vegetation: *Acacia bivenosa* open shrubland over *Triodia wiseana* hummock grassland.
Veg Condition: Excellent
Fire Age: >10 years

Species List

Name	Cover (%)	Height (m)
Acacia acradenia	0.5	1.0
Acacia bivenosa	3	1.2
Eriachne mucronata	0.5	0.2
Senna glutinosa subsp. *pruinosa*	0.5	0.8
Triodia wiseana	35	0.6

* denotes weed species
? denotes unconfirmed ID

Site: MH310
Location: Map 1 in nw cnr **Type:** 50x50m Quadrat
Date: 2016-05-01 **Described by:** JA/KMc
MGA Zone: 50 **Easting:** 415983 **Northing:** 7599288
Habitat: Floodplain
Soil: Red brown sandy loam
Rock type: Ironstone
Vegetation: *Corymbia hamersleyana* low open woodland over *Triodia epactia* hummock grassland.
Veg Condition: Excellent
Fire Age: >10 years

Species List

Name	Cover (%)	Height (m)
**Cenchrus ciliaris*	0.5	0.5
Acacia ancistrocarpa	0.5	1.8
Bonamia erecta	0.5	0.3
Corymbia hamersleyana	4	4.0
Cullen martinii	0.5	0.15
Eragrostis eriopoda	0.5	0.5
Eriachne aristidea	0.5	0.1
Eriachne mucronata	0.5	0.4
Euphorbia biconvexa	0.5	0.1
Hakea chordophylla	0.5	1.6
Jasminum didymum subsp. *lineare*	0.5	2.0
Ptilotus astrolasius	0.5	0.1
Ptilotus axillaris	0.5	0.1
Tephrosia sp. Bungaroo Creek (M.E. Trudgen 11601)	0.5	0.1
Triodia epactia	32	0.9

* denotes weed species
? denotes unconfirmed ID

Site: MH311r
Location: Map 5, edge of Mesa west of river **Type:** 50x50m Relevé
Date: 2016-05-04 **Described by:** JA
MGA Zone: 50 **Easting:** 418525 **Northing:** 7596487
Habitat: Hillcrest
Soil: Red brown clay loam
Rock type: CID
Vegetation: *Triodia wiseana* open hummock grassland.
Veg Condition: Excellent
Fire Age: No fire evident

Species List

Name	Cover (%)	Height (m)
Acacia ancistrocarpa	0.5	2.5
Acacia bivenosa	0.5	1.6
Acacia inaequilatera	0.5	2.5
Acacia trachycarpa	0.5	1.9
Amyema preissii	0.5	1.6
Corymbia hamersleyana	0.5	5.0
Eriachne pulchella subsp. *pulchella*	0.5	0.1
Hakea chordophylla	0.5	1.8
Ptilotus calostachyus	0.5	1.0
Ptilotus nobilis subsp. *nobilis*	0.5	0.1
Triodia wiseana	28	0.7

* denotes weed species
? denotes unconfirmed ID

Site: MH312
Location: Map 3 Mesa top **Type:** 50x50m Quadrat
Date: 2016-04-28 **Described by:** DR/LV
MGA Zone: 50 **Easting:** 416677 **Northing:** 7594638
Habitat: Hillcrest
Soil: Brown clay loam
Rock type: Dolerite
Vegetation: *Triodia wiseana* open hummock grassland.
Veg Condition: Excellent
Fire Age: 2-5 years

Species List

Name	Cover (%)	Height (m)
Abutilon sp. Pilbara (W.R. Barker 2025)	0.5	0.9
Acacia bivenosa	0.5	0.3
Acacia inaequilatera	0.5	3.0
Acacia tumida var. *pilbarensis*	0.5	0.2
Bonamia pilbarensis	0.5	0.05
Corchorus lasiocarpus subsp. *parvus*	0.5	0.8
Corymbia hamersleyana	0.5	2.5
Dodonaea coriacea	0.5	0.3
Dysphania rhadinostachya subsp. *rhadinostachya*	0.5	0.2
Goodenia stobbsiana	0.5	0.6
Gossypium australe	0.5	0.3
Grevillea wickhamii	0.5	0.1
Heliotropium pachyphyllum	0.5	0.3
Ptilotus astrolasius	0.5	0.4
Ptilotus auriculifolius	0.5	0.4
Ptilotus axillaris	0.5	0.1
Ptilotus calostachyus	0.5	0.8
Ptilotus fusiformis	0.5	0.5
Ptilotus nobilis subsp. *nobilis*	0.5	0.6
Senna glutinosa subsp. *x luerssenii*	0.5	0.2
Sida echinocarpa	0.5	1.2
Sida sp. Pilbara (A.A. Mitchell PRP 1543)	0.5	0.4
Tephrosia sp. Fortescue (A.A. Mitchell 606)	0.5	0.5
Tribulus macrocarpus	0.5	0.2
Tribulus platypterus	0.5	0.8
Trichodesma zeylanicum var. *zeylanicum*	0.5	0.8

Name	Cover (%)	Height (m)
Triodia wiseana	18	0.25
Triumfetta johnstonii	0.5	0.4

* denotes weed species
? denotes unconfirmed ID

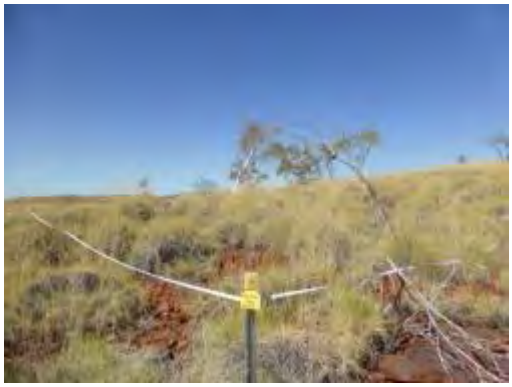
Site: MH313
Location: Map 2 Mesa top east of Robe River **Type:** 62.5x40m Quadrat
Date: 2016-04-28 **Described by:** JA/KMc
MGA Zone: 50 **Easting:** 416152 **Northing:** 7596637
Habitat: Hillslope
Soil: Red brown clay loam
Rock type: CID
Vegetation: *Eucalyptus leucophloia* subsp. *leucophloia* low open woodland over *Triodia wiseana* open hummock grassland.
Veg Condition: Excellent
Fire Age: No fire evident

Species List

Name	Cover (%)	Height (m)
Acacia bivenosa	0.5	1.5
Acacia inaequilatera	0.5	1.7
Acacia tumida var. *pilbarensis*	0.5	2.1
Eriachne pulchella subsp. *pulchella*	0.5	0.1
Eucalyptus leucophloia subsp. *leucophloia*	4	7.0
Ptilotus obovatus	0.5	0.3
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	0.5	0.4
Triodia wiseana	25	0.5

* denotes weed species
? denotes unconfirmed ID

Site: MH314
Location: Southern end **Type:** 50x50m Quadrat
Date: 2016-05-09 **Described by:** KMc
MGA Zone: 50 **Easting:** 417955 **Northing:** 7592828
Habitat: Hillcrest
Soil: Red brown sandy loam
Rock type: Ironstone
Vegetation: *Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Acacia orthocarpa* open shrubland over *Triodia wiseana* and *T.* sp. Robe River (M.E. Trudgen et al. MET 12367) open hummock grassland.
Veg Condition: Excellent
Fire Age: >10 years



Species List

Name	Cover (%)	Height (m)
Acacia inaequilatera	0.5	2.5
Acacia orthocarpa	2	1.3
Cyperus cunninghamii subsp. *cunninghamii*	0.5	0.1
Dampiera candicans	0.5	0.3
Dysphania rhadinostachya subsp. *rhadinostachya*	0.5	0.2
Eriachne pulchella subsp. *pulchella*	0.5	0.08
Eucalyptus leucophloia subsp. *leucophloia*	1	5.0
Hakea chordophylla	0.5	3.5
Ipomoea muelleri	0.5	0.25
Oldenlandia crouchiana	0.5	0.15
Polycarpaea holtzei	0.5	0.05
Polygala glaucifolia	0.5	0.05
Ptilotus astrolasius	0.5	0.2
Ptilotus nobilis subsp. *nobilis*	0.5	0.15
Solanum horridum	0.5	0.1
Stackhousia muricata subsp. annual (W.R. Barker 2172)	0.5	0.2
Trachymene oleracea subsp. *oleracea*	0.5	0.6
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	4	0.45
Triodia wiseana	20	0.5
Triumfetta johnstonii	0.5	0.4
Triumfetta maconochieana	0.5	0.35

* denotes weed species
? denotes unconfirmed ID

Site: MH315
Location: Map 2 in base of large gully **Type:** 50x50m Quadrat
Date: 2016-05-07 **Described by:** LV
MGA Zone: 50 **Easting:** 417426 **Northing:** 7595042
Habitat: Gully
Soil: Red brown sandy loam
Rock type: CID
Vegetation: *Corymbia hamersleyana* scattered low trees over *Acacia bivenosa, Petalostylis labicheoides* and *Gossypium robinsonii* open shrubland over *Triodia wiseana* very open hummock grassland.
Veg Condition: Excellent
Fire Age: No fire evident

Species List

Name	Cover (%)	Height (m)
Acacia bivenosa	3	1.9
Adriana tomentosa	0.5	0.3
Cassytha capillaris	0.5	0.4
Corchorus crozophorifolius	0.5	0.6
Corchorus lasiocarpus subsp. *parvus*	0.5	0.5
Corymbia hamersleyana	2	5.0
Euphorbia tannensis	0.5	0.5
Gossypium robinsonii	1	1.9
Heliotropium pachyphyllum	0.5	0.25
Hybanthus aurantiacus	0.5	0.25
Petalostylis labicheoides	3	1.9
Pimelea ammocharis	0.5	0.4
Ptilotus axillaris	0.5	0.1
Ptilotus nobilis subsp. *nobilis*	0.5	0.4
Senna glutinosa subsp. *glutinosa*	0.5	1.8
Stylobasium spathulatum	0.5	1.2
Tephrosia uniovulata	0.5	0.6
Trichodesma zeylanicum var. *zeylanicum*	0.5	0.8
Triodia wiseana	8	0.5

* denotes weed species
? denotes unconfirmed ID

Site: MH316
Location: Map 6 in gully east of Robe River **Type:** 50x50m Quadrat
Date: 2016-05-11 **Described by:** LV
MGA Zone: 50 **Easting:** 415149 **Northing:** 7595854
Habitat: Gully
Soil: Reddish brown loam
Rock type: Ironstone
Vegetation: *Corymbia hamersleyana* low open woodland over *Acacia bivenosa, Petalostylis labicheoides* tall open scrub over *Codonocarpus cotinifolius* scattered shrubs over *Triodia wiseana* hummock grassland.
Veg Condition: Excellent
Fire Age: No fire evident

Species List

Name	Cover (%)	Height (m)
Acacia bivenosa	55	2.5
Acacia trachycarpa	0.5	2.6
Adriana tomentosa	0.5	1.2
Capparis spinosa var. *nummularia*	0.5	0.2
Cassytha capillaris	0.5	0.5
Codonocarpus cotinifolius	1	1.6
Corymbia hamersleyana	9	6.0
Gossypium robinsonii	0.5	2.1
Hybanthus aurantiacus	0.5	0.25
Jasminum didymum subsp. *lineare*	0.5	0.4
Petalostylis labicheoides	3	2.5
Pimelea ammocharis	0.5	1.2
Stylobasium spathulatum	0.5	1.3
Triodia wiseana	65	0.5

* denotes weed species
? denotes unconfirmed ID

Site: MH317
Location: NA **Type:** 25x100m Quadrat
Date: 2016-04-30 **Described by:** JA/KMc
MGA Zone: 50 **Easting:** 418842 **Northing:** 7595352
Habitat: Drainage depression
Soil: Red brown sandy loam
Rock type: Ironstone
Vegetation: *Corymbia hamersleyana* low open woodland over *Acacia tumida* var. *pilbarensis* and *A. ancistrocarpa* tall open shrubland over *Triodia wiseana* open hummock grassland.
Veg Condition: Excellent
Fire Age: >10 years

Species List

Name	Cover (%)	Height (m)
Acacia ancistrocarpa	1	2.5
Acacia bivenosa	0.5	2.1
Acacia inaequilatera	0.5	2.1
Acacia ptychophylla	0.5	0.7
Acacia pyrifolia var. *pyrifolia*	0.5	1.6
Acacia tumida var. *pilbarensis*	5	2.8
Bonamia pilbarensis	0.5	0.15
Cassytha capillaris	0.5	
Corchorus lasiocarpus subsp. *parvus*	0.5	0.8
Corymbia hamersleyana	4	4.5
Cymbopogon ambiguus	0.5	1.0
Dysphania rhadinostachya subsp. *rhadinostachya*	0.5	0.15
Euphorbia australis var. *subtomentosa*	0.5	0.1
Euphorbia boopthona/tannensis	0.5	0.4
Goodenia stobbsiana	0.5	0.6
Gossypium robinsonii	0.5	2.2
Grevillea wickhamii	0.5	2.5
Hibiscus sturtii var. *campylochlamys*	0.5	0.6
Hybanthus aurantiacus	0.5	0.4
Indigofera monophylla	0.5	0.2
Jasminum didymum subsp. *lineare*	0.5	
Mollugo molluginea	0.5	0.15
Notoleptopus decaisnei var. Orbicularis (A.B. Craig 428)	0.5	0.2
Paraneurachne muelleri	0.5	0.2
Petalostylis labicheoides	0.5	2.0

Name	Cover (%)	Height (m)
Pterocaulon sphacelatum	0.5	0.2
Pterocaulon sphaeranthoides	0.5	0.2
Ptilotus astrolasius	0.5	0.4
Ptilotus calostachyus	0.5	0.4
Ptilotus fusiformis	0.5	0.5
Ptilotus nobilis subsp. *nobilis*	0.5	0.05
Rhynchosia minima	0.5	0.4
Solanum cleistogamum	0.5	0.2
Solanum diversiflorum	0.5	0.2
Solanum horridum	0.5	0.15
Tephrosia uniovulata	0.5	0.5
Trianthema cusackianum	0.5	0.6
Trichodesma zeylanicum var. *zeylanicum*	0.5	0.8
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	0.5	0.5
Triodia wiseana	12	0.5

* denotes weed species
? denotes unconfirmed ID

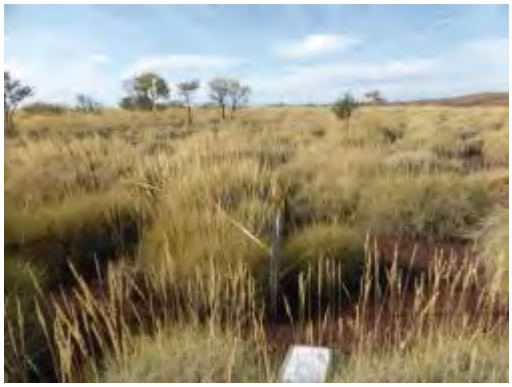
Site: MH318
Location: Minor drainage at top of gully on Mesa **Type:** 50x50m Quadrat
Date: 2016-04-28 **Described by:** JA/KMc
MGA Zone: 50 **Easting:** 415894 **Northing:** 7596615
Habitat: Other
Soil: Red brown sandy loam
Rock type: Ironstone
Vegetation: *Corymbia hamersleyana* scattered low trees over *Acacia tumida* var. *pilbarensis* tall shrubland over *Triodia wiseana* hummock grassland.
Veg Condition: Excellent
Fire Age: >10 years

Species List

Name	Cover (%)	Height (m)
Acacia tumida var. *pilbarensis*	15	2.5
Cassytha capillaris	0.5	
Clerodendrum floribundum var. *angustifolium*	0.5	1.3
Corymbia hamersleyana	1	4.0
Eriachne mucronata	0.5	0.5
Goodenia stobbsiana	0.5	0.8
Grevillea wickhamii	0.5	1.2
Jasminum didymum subsp. *lineare*	0.5	0.5
Petalostylis labicheoides	0.5	1.2
Trachymene oleracea subsp. *oleracea*	0.5	0.7
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	0.5	0.5
Triodia wiseana	35	0.5

* denotes weed species
? denotes unconfirmed ID

Site: MH319
Location: NA **Type:** 50x50m Quadrat
Date: 2016-04-28 **Described by:** JA/KMc
MGA Zone: 50 **Easting:** 416796 **Northing:** 7595701
Habitat: Hillcrest
Soil: Red brown clay loam
Rock type: Ironstone
Vegetation: *Acacia inaequilatera* scattered tall shrubs over *A. bivenosa* scattered shrubs over *Triodia wiseana* hummock grassland.
Veg Condition: Excellent
Fire Age: >10 years



Species List

Name	Cover (%)	Height (m)
Acacia ancistrocarpa	0.5	2.2
Acacia bivenosa	1	1.9
Acacia elachantha	0.5	4.0
Acacia inaequilatera	1	2.8
Acacia maitlandii	0.5	2.8
Clerodendrum floribundum var. *angustifolium*	0.5	1.7
Corymbia hamersleyana	0.5	4.5
Grevillea pyramidalis subsp. *leucadendron*	0.5	2.0
Hakea chordophylla	0.5	2.2
Jasminum didymum subsp. *lineare*	0.5	
Senna glutinosa subsp. *glutinosa*	0.5	1.6
Triodia wiseana	40	0.6

* denotes weed species
? denotes unconfirmed ID

Site: MH320
Location: Map 5 near pipeline **Type:** 50x50m Quadrat
Date: 2016-04-28 **Described by:** JA/KMc
MGA Zone: 50 **Easting:** 419525 **Northing:** 7594373
Habitat: Floodplain
Soil: Reddish brown silty loam
Rock type: Ironstone
Vegetation: *Corymbia hamersleyana* low open woodland over *Acacia bivenosa* and *Stylobasium spathulatum* tall shrubland over *Triodia epactia* open hummock grassland.
Veg Condition: Very Good
Fire Age: No fire evident

Species List

Name	Cover (%)	Height (m)
**Cenchrus ciliaris*	0.5	0.2
**Setaria verticillata*	0.5	0.1
**Sonchus oleraceus*	0.5	0.4
Abutilon leucopetalum	0.5	0.7
Acacia bivenosa	20	3.0
Acacia colei var. *ileocarpa*	0.5	4.5
Acacia elachantha	0.5	0.1
Acacia trachycarpa	0.5	2.8
Aristida holathera var. *holathera*	0.5	0.6
Corchorus lasiocarpus subsp. *parvus*	0.5	0.4
Corchorus tridens	0.5	0.1
Corymbia hamersleyana	4	5.0
Cucumis variabilis	0.5	0.2
Cynanchum pedunculatum	0.5	0.4
Dysphania kalpari	0.5	0.05
Eragrostis eriopoda	0.5	0.4
Eremophila longifolia	0.5	0.4
Euphorbia australis var. *subtomentosa*	0.5	0.05
Euphorbia tannensis	0.5	0.4
Evolvulus alsinoides var. *villosicalyx*	0.5	0.1
Goodenia forrestii	0.5	0.2
Goodenia microptera	0.5	0.2
Gossypium robinsonii	0.5	0.2
Hibiscus sturtii var. *campylochlamys*	0.5	0.3
Hybanthus aurantiacus	0.5	0.1

Name	Cover (%)	Height (m)
Jasminum didymum subsp. *lineare*	0.5	1.0
Melhania oblongifolia	0.5	0.2
Notoleptopus decaisnei var. Orbicularis (A.B. Craig 428)	0.5	0.25
Paraneurachne muelleri	0.5	0.4
Phyllanthus maderaspatensis	0.5	0.3
Pimelea ammocharis	0.5	0.1
Pterocaulon sphaeranthoides	0.5	0.3
Ptilotus axillaris	0.5	0.1
Ptilotus nobilis subsp. *nobilis*	0.5	0.2
Ptilotus obovatus	0.5	0.3
Rhynchosia minima	0.5	0.1
Scaevola spinescens	0.5	0.5
Senna artemisioides subsp. *oligophylla*	0.5	1.3
Senna ferraria	0.5	1.7
Senna glutinosa subsp. *glutinosa*	0.5	0.8
Senna notabilis	0.5	0.2
Senna venusta	0.5	0.2
Sida arsiniata	0.5	0.3
Sida fibulifera	0.5	0.25
Solanum diversiflorum	0.5	0.5
Solanum horridum	0.5	0.1
Sporobolus australasicus	0.5	0.1
Stylobasium spathulatum	1	3.0
Swainsona formosa	0.5	0.2
Tribulus ?*occidentalis*	0.5	0.1
Trichodesma zeylanicum var. *zeylanicum*	0.5	0.8
Triodia epactia	18	0.4

* denotes weed species
? denotes unconfirmed ID

Site: MH321
Location: NA **Type:** 40x60m Quadrat
Date: 2016-05-11 **Described by:** JA/DR
MGA Zone: 50 **Easting:** 414835 **Northing:** 7596664
Habitat: Major creek
Soil: Brown loamy sand
Rock type: NA
Vegetation: *Petalostylis labicheoides* and *Acacia trachycarpa* tall shrubland.
Veg Condition: Very Good
Fire Age: >10 years

Species List

Name	Cover (%)	Height (m)
**Cenchrus ciliaris*	0.5	0.4
**Cenchrus setiger*	0.5	0.5
**Cynodon dactylon*	0.5	0.1
Acacia bivenosa	0.5	1.6
Acacia synchronicia	0.5	3.4
Acacia trachycarpa	6	2.5
Acacia trachycarpa x tumida var. *pilbarensis*	0.5	1.0
Cleome viscosa	0.5	0.2
Corchorus lasiocarpus subsp. *parvus*	0.5	0.5
Euphorbia schultzii	0.5	0.1
Gomphrena cunninghamii	0.5	0.15
Petalostylis labicheoides	8	2.2
Ptilotus astrolasius	0.5	0.5
Ptilotus nobilis subsp. *nobilis*	0.5	0.5
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	0.5	0.7
Triodia epactia	0.5	0.3
Triodia wiseana	0.5	0.4
Triumfetta ?chaetocarpa	0.5	0.5

* denotes weed species
? denotes unconfirmed ID

Site: MH322
Location: South east of survey area **Type:** 50x50m Quadrat
Date: 2016-05-11 **Described by:** KMc/LV
MGA Zone: 50 **Easting:** 414594 **Northing:** 7595594
Habitat: Floodplain
Soil: Red brown silty loam
Rock type: NA
Vegetation: *Acacia synchronicia* and *A. bivenosa* tall scattered shrubs over *Triodia wiseana* very scattered hummock grasses and **Cenchrus ciliaris* and **C. setiger* very scattered tussocks.
Veg Condition: Very Poor
Fire Age: >10 years

Species List

Name	Cover (%)	Height (m)
**Cenchrus ciliaris*	0.5	0.4
**Cenchrus setiger*	0.5	0.5
Acacia bivenosa	1	2.1
Acacia synchronicia	0.5	2.2
Acacia trachycarpa	0.5	1.2
Eucalyptus leucophloia subsp. *leucophloia*	0.5	1.2
Eucalyptus sp.	0.5	1.0
Petalostylis labicheoides	0.5	2.1
Triodia wiseana	0.5	0.3

* denotes weed species
? denotes unconfirmed ID

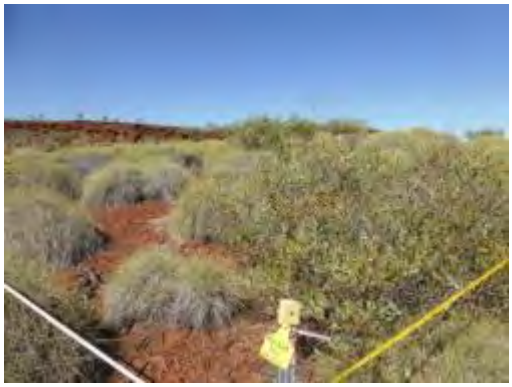
Site: MH324
Location: Northern slope of Mesa adjacent robe river **Type:** 50x50m Quadrat
Date: 2016-04-28 **Described by:** JA/KMc
MGA Zone: 50 **Easting:** 417502 **Northing:** 7597722
Habitat: Hillslope
Soil: Red brown sandy loam
Rock type: Ironstone
Vegetation: *Acacia bivenosa* open shrubland over *Triodia wiseana* hummock grassland.
Veg Condition: Excellent
Fire Age: >10 years

Species List

Name	Cover (%)	Height (m)
Acacia bivenosa	4	1.5
Acacia inaequilatera	0.5	2.4
Acacia synchronicia	0.5	0.5
Acacia trachycarpa	0.5	2.1
Eriachne mucronata	0.5	0.2
Grevillea pyramidalis subsp. *leucadendron*	0.5	0.6
Polycarpaea longiflora	0.5	0.15
Ptilotus astrolasius	0.5	0.65
Ptilotus incanus	0.5	0.3
Senna glutinosa subsp. *glutinosa*	0.5	1.5
Tephrosia sp. B Kimberley Flora (C.A. Gardner 7300)	0.5	0.8
Trachymene oleracea subsp. *oleracea*	0.5	0.6
Trichodesma zeylanicum var. *zeylanicum*	0.5	1.1
Triodia wiseana	45	0.55
Triumfetta maconochieana	0.5	0.25

* denotes weed species
? denotes unconfirmed ID

Site: MH325
Location: West of survey area right near robe river **Type:** 50x50m Quadrat
Date: 2016-05-11 **Described by:** DR
MGA Zone: 50 **Easting:** 414561 **Northing:** 7597523
Habitat: Hillcrest
Soil: Red brown sandy loam
Rock type: Ironstone
Vegetation: *Acacia bivenosa* open shrubland over *Triodia wiseana* hummock grassland.
Veg Condition: Excellent
Fire Age: >10 years

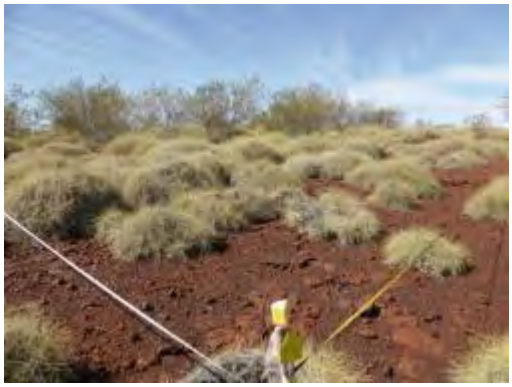


Species List

Name	Cover (%)	Height (m)
Acacia acradenia	0.5	1.1
Acacia bivenosa	4	1.3
Corymbia hamersleyana	0.5	1.0
Fimbristylis dichotoma	0.5	0.08
Hibiscus coatesii	0.5	0.25
Ixiochlamys cuneifolia	0.5	0.15
Oldenlandia crouchiana	0.5	0.15
Pluchea rubelliflora	0.5	0.1
Polycarpaea holtzei	0.5	0.05
Ptilotus astrolasius	0.5	0.4
Ptilotus nobilis subsp. *nobilis*	0.5	0.1
Senna glutinosa subsp. *glutinosa*	0.5	1.5
Senna glutinosa subsp. *pruinosa*	0.5	1.8
Sida rohlenae subsp. *rohlenae*	0.5	0.5
Solanum gabrielae	0.5	0.35
Solanum horridum	0.5	0.1
Solanum lasiophyllum	0.5	0.35
Triodia wiseana	28	0.6

* denotes weed species
? denotes unconfirmed ID

Site: MH326
Location: Map 2 Mesa top east of Robe River **Type:** 50x50m Quadrat
Date: 2016-04-28 **Described by:** DR/LV
MGA Zone: 50 **Easting:** 415179 **Northing:** 7597153
Habitat: Hillcrest
Soil: Red brown clay loam
Rock type: CID
Vegetation: *Acacia acradenia* tall open shrubland over *Triodia wiseana* and *T.* sp. Robe River (M.E. Trudgen et al. MET 12367) open hummock grassland.
Veg Condition: Excellent
Fire Age: No fire evident



Species List

Name	Cover (%)	Height (m)
Acacia acradenia	9	2.8
Acacia inaequilatera	0.5	4.0
Grevillea wickhamii	0.5	4.0
Ptilotus calostachyus	0.5	0.8
Tephrosia uniovulata	0.5	0.6
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	1	0.45
Triodia wiseana	16	0.7

* denotes weed species
? denotes unconfirmed ID

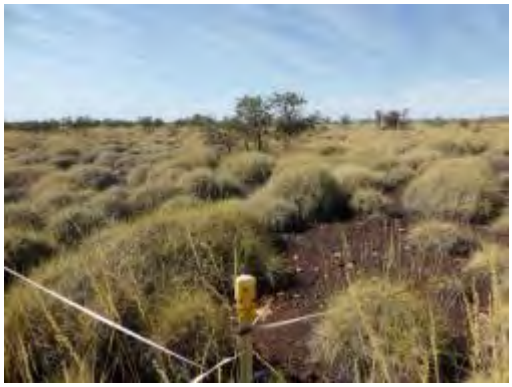
Site: MH327
Location: Map 2, Mesa top south of Robe River **Type:** 50x50m Quadrat
Date: 2016-04-28 **Described by:** DR/LV
MGA Zone: 50 **Easting:** 416340 **Northing:** 7597314
Habitat: Hillcrest
Soil: Red brown clay loam
Rock type: CID
Vegetation: *Acacia acradenia* tall open shrubland over *Triodia wiseana* open hummock grassland.
Veg Condition: Excellent
Fire Age: No fire evident

Species List

Name	Cover (%)	Height (m)
Acacia acradenia	5	2.5
Acacia bivenosa	0.5	1.9
Acacia inaequilatera	0.5	1.2
Corymbia hamersleyana	0.5	4.0
Cymbopogon ambiguus	0.5	1.2
Dysphania rhadinostachya subsp. *rhadinostachya*	0.5	0.3
Eucalyptus leucophloia subsp. *leucophloia*	0.5	4.5
Grevillea wickhamii	0.5	3.0
Jasminum didymum subsp. *lineare*	0.5	2.5
Ptilotus nobilis subsp. *nobilis*	0.5	0.4
Sida sp. Pilbara (A.A. Mitchell PRP 1543)	0.5	0.1
Solanum horridum	0.5	0.2
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	0.5	0.4
Triodia wiseana	20	0.9

* denotes weed species
? denotes unconfirmed ID

Site: MH328
Location: Map 2 Mesa top east of Robe River **Type:** 50x50m Quadrat
Date: 2016-04-28 **Described by:** DR/LV
MGA Zone: 50 **Easting:** 415639 **Northing:** 7596919
Habitat: Hillcrest
Soil: Red brown clay loam
Rock type: CID
Vegetation: *Acacia inaequilatera* tall open shrubland over *A. bivenosa* scattered shrubs over *Triodia wiseana* open hummock grassland.
Veg Condition: Excellent
Fire Age: No fire evident



Species List

Name	Cover (%)	Height (m)
Acacia acradenia	0.5	2.1
Acacia bivenosa	1	1.6
Acacia inaequilatera	3	3.0
Bonamia pilbarensis	0.5	0.4
Dysphania rhadinostachya subsp. *rhadinostachya*	0.5	0.25
Grevillea pyramidalis subsp. *leucadendron*	0.5	1.9
Lysiana casuarinae	0.5	2.0
Petalostylis labicheoides	0.5	1.7
Trichodesma zeylanicum var. *zeylanicum*	0.5	1.1
Triodia wiseana	25	0.7

* denotes weed species
? denotes unconfirmed ID

Site: MH329
Location: Map 2 Mesa top south of the robe river **Type:** 50x50m Quadrat
Date: 2016-04-28 **Described by:** DR/LV
MGA Zone: 50 **Easting:** 417306 **Northing:** 7597580
Habitat: Hillcrest
Soil: Red brown clay loam
Rock type: CID
Vegetation: *Acacia inaequilatera* and *A. ancistrocarpa* tall open shrubland over *Triodia wiseana* hummock grassland.
Veg Condition: Excellent
Fire Age: No fire evident

Species List

Name	Cover (%)	Height (m)
Acacia ancistrocarpa	2	3.0
Acacia bivenosa	0.5	1.2
Acacia inaequilatera	2	3.0
Corchorus lasiocarpus subsp. *parvus*	0.5	0.25
Dysphania rhadinostachya subsp. *rhadinostachya*	0.5	0.1
Grevillea wickhamii	0.5	2.1
Lysiana casuarinae	0.5	1.8
Ptilotus auriculifolius	0.5	0.25
Ptilotus calostachyus	0.5	0.3
Ptilotus nobilis subsp. *nobilis*	0.5	0.3
Senna glutinosa subsp. *pruinosa*	0.5	1.3
Solanum elatius	0.5	1.1
Solanum horridum	0.5	0.05
Triodia wiseana	35	0.8

* denotes weed species
? denotes unconfirmed ID

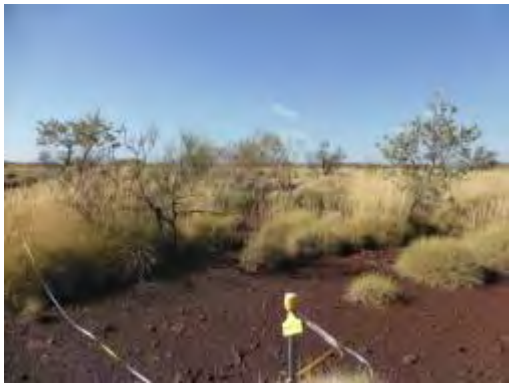
Site: MH330
Location: Eastern Mesa top **Type:** 50x50m Quadrat
Date: 2016-04-28 **Described by:** JA/KMc
MGA Zone: 50 **Easting:** 417011 **Northing:** 7596903
Habitat: Hillcrest
Soil: Red brown sandy loam
Rock type: Ironstone
Vegetation: *Acacia pruinocarpa* and *A. inaequilatera* tall open shrubland over *Triodia wiseana* open hummock grassland.
Veg Condition: Excellent
Fire Age: >10 years

Species List

Name	Cover (%)	Height (m)
Acacia ancistrocarpa	0.5	1.6
Acacia inaequilatera	1	2.5
Acacia pruinocarpa	4	4.5
Amyema preissii	0.5	
Corchorus lasiocarpus subsp. *parvus*	0.5	1.0
Dysphania rhadinostachya subsp. *rhadinostachya*	0.5	0.15
Ptilotus nobilis subsp. *nobilis*	0.5	0.15
Senna stricta	0.5	1.0
Solanum elatius	0.5	0.7
Trachymene oleracea subsp. *oleracea*	0.5	0.8
Trichodesma zeylanicum var. *zeylanicum*	0.5	0.9
Triodia wiseana	20	0.55

* denotes weed species
? denotes unconfirmed ID

Site: MH331
Location: Map 1, Mesa top south of rail **Type:** 50x50m Quadrat
Date: 2016-05-03 **Described by:** JA/LV
MGA Zone: 50 **Easting:** 417048 **Northing:** 7599186
Habitat: Hillcrest
Soil: Red brown clay loam
Rock type: CID
Vegetation: *Acacia inaequilatera* and *A. ancistrocarpa* tall open shrubland over *Triodia wiseana* open hummock grassland.
Veg Condition: Excellent
Fire Age: No fire evident



Species List

Name	Cover (%)	Height (m)
Acacia ancistrocarpa	1	2.5
Acacia atkinsiana	0.5	0.6
Acacia bivenosa	0.5	1.3
Acacia inaequilatera	1	3.0
Grevillea wickhamii	0.5	3.5
Hakea chordophylla	0.5	1.8
Petalostylis labicheoides	0.5	1.8
Ptilotus calostachyus	0.5	0.7
Ptilotus nobilis subsp. *nobilis*	0.5	0.3
Senna artemisioides subsp. *oligophylla*	0.5	0.4
Triodia wiseana	18	0.8

* denotes weed species
? denotes unconfirmed ID

Site: MH332
Location: NA **Type:** 50x50m Quadrat
Date: 2016-05-11 **Described by:** JA/DR
MGA Zone: 50 **Easting:** 414398 **Northing:** 7597069
Habitat: Major creek
Soil: Red brown silty clay loam
Rock type: NA
Vegetation: *Melaleuca argentea* open forest over *Acacia trachycarpa* and *Petalostylis labicheoides* tall open shrubland over *Cyperus vaginatus* scattered sedges.
Veg Condition: Excellent
Fire Age: >10 years

Species List

Name	Cover (%)	Height (m)
**Cenchrus ciliaris*	0.5	0.45
**Cynodon dactylon*	0.5	0.1
**Lactuca serriola*	0.5	0.2
**Passiflora foetida* var. *hispida*	0.5	
**Vachellia farnesiana*	0.5	0.7
Abutilon sp. Dioicum (A.A. Mitchell PRP 1618)	0.5	2.5
Acacia bivenosa	0.5	2.8
Acacia pyrifolia var. *pyrifolia*	0.5	1.5
Acacia trachycarpa	2	2.8
Capparis spinosa var. *nummularia*	0.5	0.5
Cleome viscosa	0.5	0.2
Corchorus crozophorifolius	0.5	1.1
Cyperus vaginatus	1	1.0
Eleocharis geniculata	0.5	0.08
Eucalyptus sp.	0.5	5.5
Eucalyptus victrix	0.5	5.5
Euphorbia schultzii	0.5	0.3
Gossypium robinsonii	0.5	2.5
Helichrysum luteoalbum	0.5	0.15
Ipomoea muelleri	0.5	
Jasminum didymum subsp. *lineare*	0.5	1.2
Lobelia arnhemiaca	0.5	
Melaleuca argentea	32	15.0
Petalostylis labicheoides	1	2.5
Phyllanthus maderaspatensis	0.5	0.2

Name	Cover (%)	Height (m)
Pluchea rubelliflora	0.5	0.2
Rhynchosia bungarensis P4	0.5	
Schoenoplectus subulatus	0.5	1.4
Sesbania formosa	0.5	4.5
Stemodia grossa	0.5	0.1
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	0.5	1.1
Trachymene oleracea subsp. *oleracea*	0.5	1.0
Triumfetta appendiculata	0.5	1.3
Triumfetta johnstonii	0.5	1.3
Typha domingensis	0.5	1.5
Vigna lanceolata var. *lanceolata*	0.5	

* denotes weed species
? denotes unconfirmed ID

Site: MH333r
Location: Map 4 just north of rail **Type:** 50x50m Relevé
Date: 2016-05-05 **Described by:** DR/KMc
MGA Zone: NA **Easting:** 418596 **Northing:** 7599434
Habitat: Floodplain
Soil: Red brown sandy loam
Rock type: Ironstone
Vegetation: *Acacia trachycarpa* and *A. synchronicia* tall open shrubland over *Triodia epactia* and *T. wiseana*, open hummock grassland with **Cenchrus setiger* scattered tussock grasses.
Veg Condition: Good
Fire Age: No fire evident

Species List

Name	Cover (%)	Height (m)
**Cenchrus ciliaris*	0.5	0.3
**Cenchrus setiger*	1	0.5
Acacia ancistrocarpa	0.5	1.5
Acacia atkinsiana	0.5	2.3
Acacia bivenosa	0.5	1.8
Acacia sclerosperma subsp. *sclerosperma*	0.5	1.8
Acacia synchronicia	1	2.5
Acacia trachycarpa	3	2.5
Boerhavia sp.	0.5	0.2
Bulbostylis barbata	0.5	0.1
Corymbia candida	0.5	4.5
Dysphania rhadinostachya subsp. *rhadinostachya*	0.5	0.1
Eriachne aristidea	0.5	0.1
Goodenia forrestii	0.5	0.2
Gossypium australe	0.5	0.1
Mollugo molluginea	0.5	0.2
Petalostylis labicheoides	0.5	2.4
Polycarpaea corymbosa	0.5	0.15
Ptilotus astrolasius	0.5	0.5
Ptilotus axillaris	0.5	0.1
Ptilotus nobilis subsp. *nobilis*	0.5	0.6
Rhynchosia minima	0.5	0.3
Senna artemisioides subsp. *oligophylla*	0.5	0.9
Senna notabilis	0.5	0.1
Triodia epactia	12	0.9

Name	Cover (%)	Height (m)
Triodia wiseana	8	0.5

* denotes weed species
? denotes unconfirmed ID

Site: MH334r
Location: Map 9 **Type:** 50x50m Relevé
Date: 2016-05-08 **Described by:** LV
MGA Zone: 50 **Easting:** 418541 **Northing:** 7592578
Habitat: Hillslope
Soil: Red brown sandy loam
Rock type: Ironstone
Vegetation: *Acacia inaequilatera* tall scattered shrubs over *Triodia wiseana* open hummock grassland.
Veg Condition: Excellent
Fire Age: 2-5 years

Species List

Name	Cover (%)	Height (m)
Acacia bivenosa	0.5	2.2
Acacia inaequilatera	2	2.1
Corchorus lasiocarpus subsp. *parvus*	0.5	0.4
Corymbia hamersleyana	0.5	1.8
Dysphania rhadinostachya subsp. *rhadinostachya*	0.5	0.15
Hakea chordophylla	0.5	1.4
Oldenlandia crouchiana	0.5	0.1
Polycarpaea holtzei	0.5	0.05
Polycarpaea longiflora	0.5	0.3
Ptilotus astrolasius	0.5	0.4
Ptilotus auriculifolius	0.5	0.6
Ptilotus axillaris	0.5	
Ptilotus calostachyus	0.5	0.55
Ptilotus fusiformis	0.5	0.5
Ptilotus nobilis subsp. *nobilis*	0.5	0.5
Scaevola ?*parviflolia*	0.5	0.25
Senna glutinosa subsp. *glutinosa*	0.5	0.6
Trichodesma zeylanicum var. *zeylanicum*	0.5	0.8
Triodia wiseana	20	0.3

* denotes weed species
? denotes unconfirmed ID

Site: MH335
Location: Map 4 **Type:** 50x50m Quadrat
Date: 2016-05-04 **Described by:** LV
MGA Zone: 50 **Easting:** 418651 **Northing:** 7596944
Habitat: Footslope
Soil: Red brown silty clay
Rock type: CID
Vegetation: *Acacia xiphophylla* scattered tall shrubs over *Triodia wiseana* open hummock grassland.
Veg Condition: Excellent
Fire Age: No fire evident

Species List

Name	Cover (%)	Height (m)
Acacia bivenosa	0.5	1.2
Acacia synchronicia	0.5	3.0
Acacia xiphophylla	1	4.0
Cynodon prostrata	0.5	0.01
Cassytha capillaris	0.5	0.4
Cymbopogon ambiguus	0.5	1.0
Goodenia forrestii	0.5	0.25
Hakea chordophylla	0.5	2.3
Lepidium pholidogynum	0.5	0.1
Pterocaulon sp.	0.5	0.2
Ptilotus nobilis subsp. *nobilis*	0.5	0.25
Salsola australis	0.5	0.25
Senna artemisioides subsp. *oligophylla*	0.5	1.1
Solanum horridum	0.5	0.3
Triodia epactia	0.5	0.4
Triodia wiseana	13	0.6

* denotes weed species
? denotes unconfirmed ID

Site: MH336
Location: Map 3 **Type:** 50x50m Quadrat
Date: 2016-05-01 **Described by:** DR/LV
MGA Zone: 50 **Easting:** 415650 **Northing:** 7599250
Habitat: Floodplain
Soil: Red brown sandy loam
Rock type: Ironstone
Vegetation: *Corymbia hamersleyana* scattered low trees over *Triodia epactia* open hummock grassland.
Veg Condition: Very Good
Fire Age: >10 years

Species List

Name	Cover (%)	Height (m)
**Cenchrus ciliaris*	0.5	0.5
Acacia ancistrocarpa	0.5	1.8
Acacia bivenosa	0.5	1.4
Acacia inaequilatera	0.5	0.4
Acacia synchronicia	0.5	1.8
Aristida contorta	0.5	0.1
Boerhavia sp.	0.5	0.1
Bonamia erecta	0.5	0.3
Corymbia hamersleyana	1	4.0
Dodonaea coriacea	0.5	0.45
Dysphania rhadinostachya subsp. *rhadinostachya*	0.5	0.2
Eragrostis eriopoda	0.5	0.5
Eriachne aristidea	0.5	0.2
Goodenia forrestii	0.5	0.3
Goodenia microptera	0.5	0.3
Hakea chordophylla	0.5	2.5
Hibiscus sp.	0.5	0.05
Ptilotus axillaris	0.5	0.1
Ptilotus nobilis subsp. *nobilis*	0.5	0.4
Senna venusta	0.5	0.1
Sporobolus australasicus	0.5	0.1
Trianthema triquetrum	0.5	0.1
Tribulus sp.	0.5	0.1
Triodia epactia	20	0.9
Triodia wiseana	0.5	0.6

* denotes weed species
? denotes unconfirmed ID

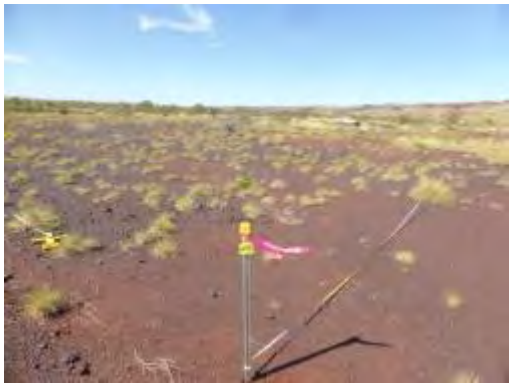
Site: MH337r
Location: NA **Type:** 50x50m Relevé
Date: 2016-05-05 **Described by:** DR/KMc
MGA Zone: 50 **Easting:** 419227 **Northing:** 7597959
Habitat: Major creek
Soil: Red brown silty clay loam
Rock type: NA
Vegetation: *Melaleuca argentea* open forest over *Cyperus vaginatus* scattered sedges.
Veg Condition: Very Good
Fire Age: >10 years

Species List

Name	Cover (%)	Height (m)
**Argemone ochroleuca* subsp. *ochroleuca*	0.5	0.8
**Cenchrus setiger*	0.5	0.6
**Passiflora foetida* var. *hispida*	0.5	
Acacia trachycarpa	0.5	1.5
Cucumis variabilis	0.5	0.1
Cymbopogon ambiguus	0.5	0.5
Cyperus vaginatus	1	1.0
Ipomoea muelleri	0.5	
Lobelia arnhemiaca	0.5	
Melaleuca argentea	50	25
Petalostylis labicheoides	0.5	1.5
Phyllanthus maderaspatensis	0.5	0.5
Rhynchosia bungarensis P4	0.5	0.3
Stemodia grossa	0.5	0.5
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	0.5	1.2
Trachymene oleracea subsp. *oleracea*	0.5	1.1
Vigna lanceolata var. *lanceolata*	0.5	

* denotes weed species
? denotes unconfirmed ID

Site: MH338
Location: Map 10 **Type:** 50x50m Quadrat
Date: 2016-05-12 **Described by:** KMc/LV
MGA Zone: 50 **Easting:** 421161 **Northing:** 7591733
Habitat: Other
Soil: Red brown clay loam
Rock type: Ironstone
Vegetation: *Acacia bivenosa* scattered shrubs over *Triodia wiseana* and *Triodia* sp. Robe River (M.E. Trudgen et al. MET 12367) P3 open hummock grassland.
Veg Condition: Excellent
Fire Age: 2-5 years

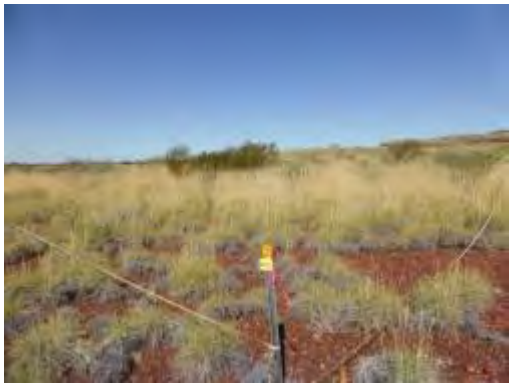


Species List

Name	Cover (%)	Height (m)
Acacia ancistrocarpa	0.5	0.4
Acacia bivenosa	1	1.6
Bonamia pilbarensis	0.5	0.15
Corchorus lasiocarpus subsp. *parvus*	0.5	0.4
Dampiera candicans	0.5	0.5
Dodonaea coriacea	0.5	0.25
Goodenia stobbsiana	0.5	0.2
Grevillea wickhamii	0.5	0.6
Keraudrenia velutina subsp. *elliptica*	0.5	0.35
Paraneurachne muelleri	0.5	0.3
Petalostylis labicheoides	0.5	2.0
Ptilotus astrolasius	0.5	0.25
Ptilotus calostachyus	0.5	0.4
Senna glutinosa subsp. *x luerssenii*	0.5	0.25
Sida sp. Pilbara (A.A. Mitchell PRP 1543)	0.5	0.3
Solanum cleistogamum	0.5	0.1
Solanum diversiflorum	0.5	0.2
Tephrosia sp. Bungaroo Creek (M.E. Trudgen 11601)	0.5	0.3
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	2	0.45
Triodia wiseana	13	0.3

* denotes weed species
? denotes unconfirmed ID

Site: MH339
Location: Bottom of Map 10 **Type:** 50x50m Quadrat
Date: 2016-05-10 **Described by:** KMc/LV
MGA Zone: 50 **Easting:** 422704 **Northing:** 7589575
Habitat: Footslope
Soil: Red brown silty clay loam
Rock type: Ironstone
Vegetation: *Acacia inaequilatera* and *A. ancistrocarpa* scattered tall shrubs over *A. bivenosa* open shrubland over *Triodia wiseana* hummock grassland.
Veg Condition: Excellent
Fire Age: >10 years



Species List

Name	Cover (%)	Height (m)
Acacia ancistrocarpa	1	2.2
Acacia bivenosa	4	1.3
Acacia inaequilatera	1	2.1
Acacia pyrifolia var. *pyrifolia*	0.5	2.1
Indigofera monophylla	0.5	0.4
Ptilotus astrolasius	0.5	0.1
Senna artemisioides subsp. *oligophylla*	0.5	0.7
Stylobasium spathulatum	0.5	0.4
Triodia wiseana	65	0.7

* denotes weed species
? denotes unconfirmed ID

Site: MH342
Location: Map 4 **Type:** 50x50m Quadrat
Date: 2016-05-12 **Described by:** DR
MGA Zone: 50 **Easting:** 418236 **Northing:** 7598271
Habitat: Hillslope
Soil: Red brown clay loam
Rock type: Ironstone
Vegetation: *Eucalyptus leucophloia* subsp*. leucophloia* scattered low trees over *Acacia bivenosa* open shrubland over *Triodia wiseana* hummock grassland.
Veg Condition: Excellent
Fire Age: No fire evident

Species List

Name	Cover (%)	Height (m)
Acacia ancistrocarpa	0.5	1.7
Acacia bivenosa	5	1.9
Cymbopogon ambiguus	0.5	0.2
Eriachne mucronata	0.5	0.2
Eucalyptus leucophloia subsp. *leucophloia*	1	5.5
Ptilotus calostachyus	0.5	0.2
Ptilotus obovatus	0.5	0.1
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	0.5	0.3
Triodia wiseana	35	0.6

* denotes weed species
? denotes unconfirmed ID

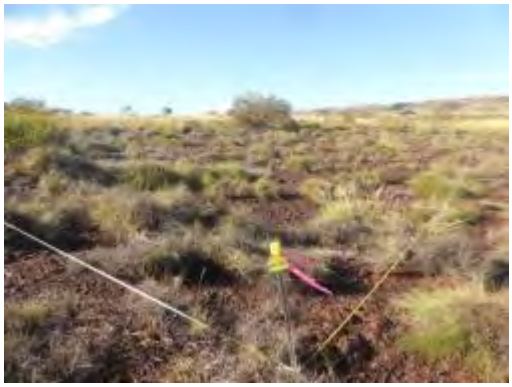
Site: MH343
Location: Northwest Mesa **Type:** 50x50m Quadrat
Date: 2016-05-03 **Described by:** JA/LV
MGA Zone: 50 **Easting:** 417270 **Northing:** 7599073
Habitat: Hillcrest
Soil: Reddish brown silty clay loam
Rock type: Ironstone
Vegetation: *Grevillea wickhamii* and *Acacia ancistrocarpa* scattered tall shrubs to tall open shrubland over *A. bivenosa* scattered shrubs over *Triodia wiseana* open hummock grassland.
Veg Condition: Very Good
Fire Age: >10 years

Species List

Name	Cover (%)	Height (m)
Acacia acradenia	0.5	1.3
Acacia ancistrocarpa	1	2.4
Acacia bivenosa	1	1.8
Acacia inaequilatera	0.5	3.0
Aristida holathera var. *holathera*	0.5	0.2
Bonamia pilbarensis	0.5	0.05
Grevillea wickhamii	1	3.2
Mollugo molluginea	0.5	0.15
Ptilotus astrolasius	0.5	0.3
Ptilotus calostachyus	0.5	0.4
Triodia wiseana	20	0.6

* denotes weed species
? denotes unconfirmed ID

Site: MH344
Location: Map 10 **Type:** 50x50m Quadrat
Date: 2016-05-12 **Described by:** KMc/LV
MGA Zone: 50 **Easting:** 421916 **Northing:** 7591804
Habitat: Other
Soil: Reddish brown silty clay loam
Rock type: Ironstone
Vegetation: *Acacia bivenosa* tall open shrubland over *Triodia wiseana* and *T.* sp. Robe River (M.E. Trudgen et al. MET 12367) P3 hummock grassland.
Veg Condition: Excellent
Fire Age: >10 years

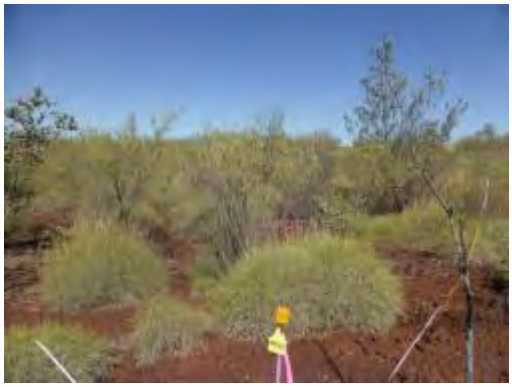


Species List

Name	Cover (%)	Height (m)
Acacia ancistrocarpa	0.5	3.0
Acacia bivenosa	2	2.2
Bonamia pilbarensis	0.5	0.02
Cassytha capillaris	0.5	0.3
Corchorus lasiocarpus subsp. *parvus*	0.5	0.5
Dodonaea coriacea	0.5	0.25
Goodenia microptera	0.5	0.4
Oldenlandia crouchiana	0.5	0.1
Ptilotus astrolasius	0.5	0.3
Ptilotus calostachyus	0.5	0.3
Ptilotus incanus	0.5	0.35
Ptilotus nobilis subsp. *nobilis*	0.5	0.02
Senna artemisioides subsp. *oligophylla*	0.5	1.1
Senna glutinosa subsp. *pruinosa*	0.5	1.0
Senna glutinosa subsp. *x luerssenii*	0.5	2.3
Sida sp. Pilbara (A.A. Mitchell PRP 1543)	0.5	0.25
Solanum cleistogamum	0.5	0.5
Swainsona sp.	0.5	0.05
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	4	0.35
Triodia wiseana	28	0.4

* denotes weed species
? denotes unconfirmed ID

Site: MH345
Location: NW of Mesa **Type:** 50x50m Quadrat
Date: 2016-05-09 **Described by:** JA
MGA Zone: 50 **Easting:** 415308 **Northing:** 7597645
Habitat: Hillcrest
Soil: Reddish brown silty clay loam
Rock type: Ironstone
Vegetation: *Acacia acradenia* and *A. inaequilatera* tall shrubland over *Triodia wiseana* open hummock grassland.
Veg Condition: Excellent
Fire Age: >10 years

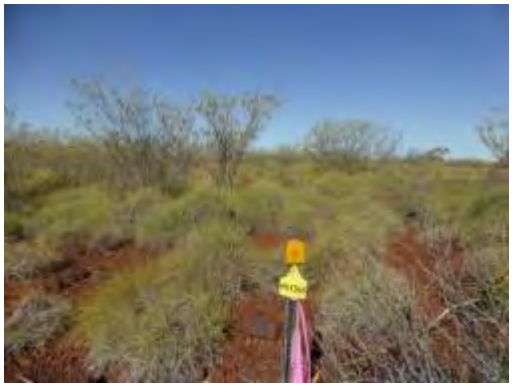


Species List

Name	Cover (%)	Height (m)
Acacia acradenia	12	2.2
Acacia inaequilatera	1	3.0
Acacia tumida var. *pilbarensis*	0.5	3.6
Amyema preissii	0.5	
Bonamia pilbarensis	0.5	0.05
Grevillea pyramidalis subsp. *leucadendron*	0.5	2.2
Grevillea wickhamii	0.5	4.5
Petalostylis labicheoides	0.5	3.6
Ptilotus astrolasius	0.5	0.2
Ptilotus calostachyus	0.5	1.1
Triodia wiseana	15	0.55

* denotes weed species
? denotes unconfirmed ID

Site: MH346
Location: North of Mesa **Type:** 50x50m Relevé
Date: 2016-05-09 **Described by:** JA
MGA Zone: 50 **Easting:** 415751 **Northing:** 7597232
Habitat: Hillcrest
Soil: Red brown silty clay loam
Rock type: Ironstone
Vegetation: *Acacia acradenia* tall open shrubland over *Triodia wiseana* and *T.* sp. Robe River (M.E. Trudgen et al. MET 12367) P3 open hummock grassland.
Veg Condition: Excellent
Fire Age: >10 years



Species List

Name	Cover (%)	Height (m)
Acacia acradenia	8	2.3
Acacia inaequilatera	0.5	2.7
Acacia tumida var. *pilbarensis*	0.5	3.1
Amyema preissii	0.5	
Bonamia pilbarensis	0.5	0.05
Cassytha capillaris	0.5	
Grevillea pyramidalis subsp. *leucadendron*	0.5	3.0
Grevillea wickhamii	0.5	
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	2	0.4
Triodia wiseana	20	0.5

* denotes weed species
? denotes unconfirmed ID

Site: MH348
Location: Map 10 **Type:** 50x50m Quadrat
Date: 2016-05-02 **Described by:** DR/LV
MGA Zone: 50 **Easting:** 422804 **Northing:** 7590980
Habitat: Plain
Soil: Red brown sandy loam
Rock type: Ironstone
Vegetation: *Acacia ancistrocarpa* tall shrubland over *Triodia epactia* and *T. wiseana* hummock grassland.
Veg Condition: Excellent
Fire Age: 5-10 years

Species List

Name	Cover (%)	Height (m)
Acacia ancistrocarpa	17	2.1
Acacia bivenosa	0.5	1.8
Acacia synchronicia	0.5	0.4
Goodenia microptera	0.5	0.1
Hakea chordophylla	0.5	0.5
Ptilotus astrolasius	0.5	0.3
Senna artemisioides subsp. *oligophylla*	0.5	0.4
Triodia epactia	54	0.4
Triodia wiseana	1	0.4

* denotes weed species
? denotes unconfirmed ID

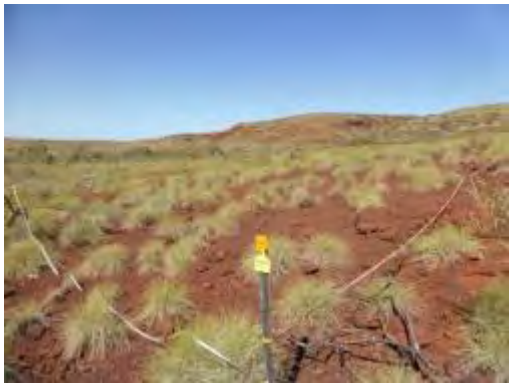
Site: MH350
Location: Map 10 **Type:** 50x50m Quadrat
Date: 2016-05-02 **Described by:** JA/KMc
MGA Zone: 50 **Easting:** 422193 **Northing:** 7591211
Habitat: Pediment
Soil: Reddish brown silty clay loam
Rock type: Ironstone
Vegetation: *Acacia inaequilatera* and *A. ancistrocarpa* tall open shrubland over *A. bivenosa* open shrubland over *Triodia wiseana* hummock grassland.
Veg Condition: Excellent
Fire Age: >10 years

Species List

Name	Cover (%)	Height (m)
Acacia ancistrocarpa	5	2.1
Acacia bivenosa	4	1.8
Acacia inaequilatera	1	2.6
Acacia ptychophylla	0.5	1.1
Acacia tumida var. *pilbarensis*	0.5	2.5
Amyema preissii	0.5	
Cassytha capillaris	0.5	
Corchorus lasiocarpus subsp. *parvus*	0.5	0.4
Eriachne mucronata	0.5	0.5
Goodenia microptera	0.5	0.02
Gossypium australe	0.5	0.5
Hakea lorea subsp. *lorea*	0.5	2.1
Indigofera monophylla	0.5	0.3
Petalostylis labicheoides	0.5	2.1
Ptilotus astrolasius	0.5	0.2
Ptilotus axillaris	0.5	0.05
Solanum diversiflorum	0.5	0.3
Solanum horridum	0.5	0.3
Trichodesma zeylanicum var. *zeylanicum*	0.5	0.8
Triodia epactia	0.5	0.7
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	0.5	0.4
Triodia wiseana	55	0.7

* denotes weed species
? denotes unconfirmed ID

Site: MH352
Location: Map 9 near new boundary **Type:** 50x50m Quadrat
Date: 2016-05-09 **Described by:** KMc/LV
MGA Zone: 50 **Easting:** 418233 **Northing:** 7592067
Habitat: Hillslope
Soil: Red brown silty clay loam
Rock type: Ironstone
Vegetation: *Triodia wiseana* and *T.* sp. Robe River (M.E. Trudgen et al. MET 12367) P3 open hummock grassland.
Veg Condition: Excellent
Fire Age: 5-10 years



Species List

Name	Cover (%)	Height (m)
Acacia inaequilatera	0.5	2.5
Acacia pruinocarpa	0.5	0.9
Acacia tumida var. *pilbarensis*	0.5	0.8
Bonamia pilbarensis	0.5	0.1
Corchorus lasiocarpus subsp. *parvus*	0.5	0.4
Eriachne mucronata	0.5	0.2
Grevillea wickhamii	0.5	0.4
Hibiscus sturtii var. *campylochlamys*	0.5	0.3
Petalostylis labicheoides	0.5	0.9
Ptilotus astrolasius	0.5	0.4
Ptilotus calostachyus	0.5	0.8
Ptilotus fusiformis	0.5	0.3
Senna glutinosa subsp. *glutinosa*	0.5	0.5
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	12	0.3
Triodia wiseana	13	0.3

* denotes weed species
? denotes unconfirmed ID

Site: MH353
Location: Map 4 on footslope west of Mesa h **Type:** 50x50m Quadrat
Date: 2016-05-05 **Described by:** KMc
MGA Zone: 50 **Easting:** 418095 **Northing:** 7596916
Habitat: Footslope
Soil: Reddish brown clay loam
Rock type: Ironstone
Vegetation: *Acacia synchronicia* tall open shrubland over A. *inaequilatera* and *Senna artemisioides* subsp. *oligophylla* open shrubland over *Triodia wiseana* hummock grassland.
Veg Condition: Excellent
Fire Age: >10 years

Species List

Name	Cover (%)	Height (m)
Acacia inaequilatera	1	1.9
Acacia synchronicia	6	2.2
Cassytha capillaris	0.5	0.4
Cleome viscosa	0.5	0.2
Dysphania sp.	0.5	0.2
Hakea chordophylla	0.5	2.1
Lysiana casuarinae	0.5	2.0
Pterocaulon sphaeranthoides	0.5	0.4
Ptilotus astrolasius	0.5	0.25
Ptilotus sp.	0.5	0.05
Rhynchosia minima	0.5	0.4
Senna artemisioides subsp. *oligophylla*	1	1.8
Senna glutinosa subsp. *x luerssenii*	0.5	1.9
Sida echinocarpa	0.5	0.2
Solanum horridum	0.5	0.2
Trichodesma zeylanicum var. *zeylanicum*	0.5	0.4
Triodia wiseana	60	0.7

* denotes weed species
? denotes unconfirmed ID

Site: MH354
Location: Map 4 in river north of Mesa h **Type:** 50x50m Quadrat
Date: 2016-05-05 **Described by:** DR/KMc
MGA Zone: 50 **Easting:** 418262 **Northing:** 7597672
Habitat: Major creek
Soil: Red brown sandy loam
Rock type: Ironstone
Vegetation: *Acacia trachycarpa* and *Petalostylis labicheoides* tall open scrub.
Veg Condition: Very Good
Fire Age: No fire evident

Species List

Name	Cover (%)	Height (m)
**Cenchrus ciliaris*	0.5	0.3
**Cenchrus setiger*	0.5	0.2
Acacia bivenosa	0.5	1.3
Acacia trachycarpa	32	3.0
Cleome viscosa	0.5	0.2
Corchorus lasiocarpus subsp. *parvus*	0.5	1.1
Cymbopogon ambiguus	0.5	0.8
Enneapogon caerulescens	0.5	0.3
Eucalyptus camaldulensis subsp. *refulgens*	0.5	5.0
Euphorbia schultzii	0.5	0.3
Indigofera monophylla	0.5	0.4
Petalostylis labicheoides	1	2.8
Phyllanthus maderaspatensis	0.5	0.3
Ptilotus nobilis subsp. *nobilis*	0.5	0.1
Rhynchosia bungarensis P4	0.5	0.5
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	0.5	0.6
Triodia epactia	0.5	0.4

* denotes weed species
? denotes unconfirmed ID

Site: MH356
Location: Map 8 near pipeline track **Type:** 50x50m Quadrat
Date: 2016-05-09 **Described by:** KMc/LV
MGA Zone: 50 **Easting:** 419372 **Northing:** 7594494
Habitat: Floodplain
Soil: Light reddish brown silty clay
Rock type: Ironstone
Vegetation: *Corymbia hamersleyana* low open woodland over *Acacia bivenosa* and *Codonocarpus cotinifolius* tall shrubland over *Triodia wiseana* and *T. epactia* hummock grassland.
Veg Condition: Very Good
Fire Age: >10 years

Species List

Name	Cover (%)	Height (m)
Acacia ancistrocarpa	0.5	0.2
Acacia bivenosa	26	2.4
Acacia colei var. *ileocarpa*	0.5	4.0
Cassytha capillaris	0.5	0.15
Codonocarpus cotinifolius	3	2.5
Corchorus lasiocarpus subsp. *parvus*	0.5	0.4
Corymbia hamersleyana	3	6.0
Cyperus vaginatus	0.5	0.5
Eragrostis eriopoda	0.5	0.2
Eucalyptus camaldulensis subsp. *refulgens*	0.5	5.0
Euphorbia boopthona/tannensis	0.5	0.9
Evolvulus alsinoides var. *villosicalyx*	0.5	0.1
Heliotropium pachyphyllum	0.5	0.25
Jasminum didymum subsp. *lineare*	0.5	1.0
Melhania oblongifolia	0.5	0.9
Notoleptopus decaisnei var. Orbicularis (A.B. Craig 428)	0.5	0.1
Pimelea ammocharis	0.5	0.05
Pterocaulon sp.	0.5	0.15
Ptilotus nobilis subsp. *nobilis*	0.5	0.02
Rhynchosia bungarensis P4	0.5	0.3
Scaevola spinescens	0.5	0.3
Senna artemisioides subsp. *oligophylla*	0.5	1.2
Sida arsiniata	0.5	0.4
Sida fibulifera	0.5	0.2
Solanum cleistogamum	0.5	0.02

Name	Cover (%)	Height (m)
Stemodia grossa	0.5	0.4
Stylobasium spathulatum	0.5	1.8
Tribulus platypterus	0.5	0.05
Triodia epactia	1	0.5
Triodia wiseana	59	1.0

* denotes weed species
? denotes unconfirmed ID

Site: MH357
Location: Large gully on Map 7 **Type:** 50x50m Quadrat
Date: 2016-05-13 **Described by:** KMc/LV
MGA Zone: 50 **Easting:** 417717 **Northing:** 7595648
Habitat: Gully
Soil: Red brown sandy clay loam
Rock type: NA
Vegetation: *Corymbia hamersleyana* low open woodland over *Petalostylis labicheoides* and *Gossypium robinsonii* tall open shrubland over *Triodia wiseana* and *T. angusta* open hummock grassland.
Veg Condition: Excellent
Fire Age: 2-5 years

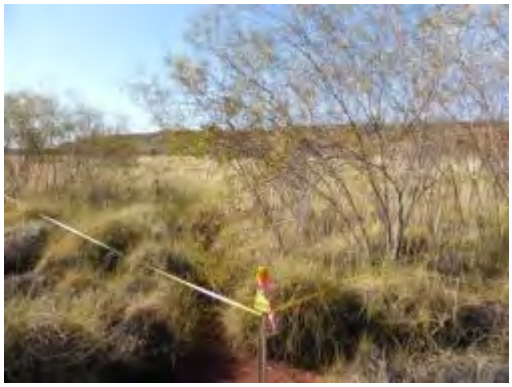
Species List

Name	Cover (%)	Height (m)
Abutilon lepidum	0.5	0.02
Acacia bivenosa	0.5	0.5
Acacia pyrifolia var. *pyrifolia*	0.5	0.35
Acacia tumida var. *pilbarensis*	0.5	0.8
Cenchrus sp.	0.5	0.2
Corchorus lasiocarpus subsp. *parvus*	0.5	0.7
Corymbia hamersleyana	4	5.0
Euphorbia biconvexa	0.5	0.25
Goodenia stobbsiana	0.5	0.25
Gossypium robinsonii	2	2.5
Grevillea pyramidalis subsp. *leucadendron*	0.5	1.5
Hibiscus brachychlaenus	0.5	1.0
Hibiscus sturtii var. *campylochlamys*	0.5	0.4
Hybanthus aurantiacus	0.5	0.3
Indigofera monophylla	0.5	0.3
Jasminum didymum subsp. *lineare*	0.5	1.1
Petalostylis labicheoides	6	2.5
Ptilotus astrolasius	0.5	0.3
Ptilotus calostachyus	0.5	0.9
Ptilotus nobilis subsp. *nobilis*	0.5	0.3
Senna artemisioides subsp. *oligophylla*	0.5	0.8
Sida sp. Articulation below (A.A. Mitchell PRP 1605)	0.5	1.2
Sida sp. Pilbara (A.A. Mitchell PRP 1543)	0.5	0.3
Stylobasium spathulatum	0.5	1.0
Tephrosia uniovulata	1	0.6

Name	Cover (%)	Height (m)
Triodia angusta	2	0.5
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	0.5	0.5
Triodia wiseana	26	0.5
Triumfetta johnstonii	0.5	0.4

* denotes weed species
? denotes unconfirmed ID

Site: MH358
Location: NW corner of survey area **Type:** 50x50m Quadrat
Date: 2016-05-01 **Described by:** JA/KMc
MGA Zone: 50 **Easting:** 416317 **Northing:** 7599519
Habitat: Plain
Soil: Red brown silty clay loam
Rock type: Ironstone
Vegetation: *Corymbia hamersleyana* scattered low trees over *Acacia ancistrocarpa* tall open shrubland over *Triodia epactia* and *T. wiseana* hummock grassland.
Veg Condition: Very Good
Fire Age: >10 years



Species List

Name	Cover (%)	Height (m)
Acacia ancistrocarpa	3	2.5
Acacia pyrifolia var. *pyrifolia*	0.5	1.0
Acacia synchronicia	0.5	2.5
Acacia trachycarpa	0.5	2.5
Corymbia hamersleyana	1	3.5
Hakea chordophylla	0.5	2.2
Triodia epactia	30	0.6
Triodia wiseana	2	0.6

* denotes weed species
? denotes unconfirmed ID

Site: MH359
Location: Northwest Mesa **Type:** 50x50m Quadrat
Date: 2016-05-03 **Described by:** JA/LV
MGA Zone: 50 **Easting:** 417194 **Northing:** 7598752
Habitat: Hillslope
Soil: Red brown clay loam
Rock type: Ironstone
Vegetation: *Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Acacia inaequilatera* scattered tall shrubs over *A. bivenosa* and *A. acradenia* open shrubland over *Triodia wiseana* hummock grassland.
Veg Condition: Excellent
Fire Age: >10 years

Species List

Name	Cover (%)	Height (m)
Acacia acradenia	1	1.2
Acacia bivenosa	4	1.8
Acacia inaequilatera	1	2.3
Acacia trachycarpa	0.5	3.5
Acacia tumida var. *pilbarensis*	0.5	1.5
Capparis spinosa var. *nummularia*	0.5	0.15
Cassytha capillaris	0.5	
Corymbia hamersleyana	0.5	4.2
Cymbopogon ambiguus	0.5	0.5
Dampiera candicans	0.5	0.2
Eriachne mucronata	0.5	0.3
Eucalyptus leucophloia subsp. *leucophloia*	1	4.5
Grevillea wickhamii	0.5	4.5
Indigofera monophylla	0.5	0.4
Ptilotus astrolasius	0.5	0.4
Senna glutinosa subsp. *glutinosa*	0.5	1.3
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	0.5	0.4
Triodia wiseana	35	0.5

* denotes weed species
? denotes unconfirmed ID

Site: MH360r
Location: Edge of large gully top of Map 7 **Type:** 10x200m Relevé
Date: 2016-05-13 **Described by:** KMc/LV
MGA Zone: 50 **Easting:** 416777 **Northing:** 7596252
Habitat: Breakaway
Soil: Red brown silty clay loam
Rock type: Ironstone
Vegetation: *Corymbia hamersleyana* and *Eucalyptus leucophloia* subsp. *leucophloia* low open woodland over *Triodia wiseana* and *T.* sp. Robe River (M.E. Trudgen et al. MET 12367) P3 very open hummock grassland.
Veg Condition: Excellent
Fire Age: 2-5 years

Species List

Name	Cover (%)	Height (m)
Acacia inaequilatera	0.5	2.5
Acacia tumida var. *pilbarensis*	0.5	1.3
Bonamia pilbarensis	0.5	0.1
Corchorus lasiocarpus subsp. *parvus*	0.5	0.5
Corymbia hamersleyana	1	4.0
Cyperus cunninghamii subsp. *cunninghamii*	0.5	0.2
Eriachne mucronata	0.5	0.25
Eucalyptus leucophloia subsp. *leucophloia*	1	6.0
Senna artemisioides subsp. *oligophylla*	0.5	1.2
Senna glutinosa subsp. *glutinosa*	0.5	1.1
Senna glutinosa subsp. *x luerssenii*	0.5	0.7
Senna venusta	0.5	1.2
Tephrosia uniovulata	0.5	0.6
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	2	0.4
Triodia wiseana	3	0.4

* denotes weed species
? denotes unconfirmed ID

Site: MH361
Location: Northwest Mesa **Type:** 50x50m Quadrat
Date: 2016-05-03 **Described by:** JA/LV
MGA Zone: 50 **Easting:** 416171 **Northing:** 7598748
Habitat: Hillcrest
Soil: Light reddish brown silty clay loam
Rock type: Ironstone
Vegetation: *Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Acacia acradenia, Grevillea wickhamii* and *A. ancistrocarpa* tall open shrubland over *Triodia wiseana* open hummock grassland.
Veg Condition: Excellent
Fire Age: >10 years

Species List

Name	Cover (%)	Height (m)
Acacia acradenia	3	2.1
Acacia ancistrocarpa	1	2.6
Acacia pyrifolia var. *pyrifolia*	0.5	3.5
Acacia trachycarpa	0.5	2.1
Acacia tumida var. *pilbarensis*	0.5	3.8
Eucalyptus leucophloia subsp. *leucophloia*	1	5.0
Grevillea wickhamii	1	3.4
Petalostylis labicheoides	0.5	2.5
Ptilotus calostachyus	0.5	0.5
Senna glutinosa subsp. *pruinosa*	0.5	1.1
Tephrosia uniovulata	0.5	0.5
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	0.5	0.45
Triodia wiseana	15	0.6

* denotes weed species
? denotes unconfirmed ID

Site: MH363
Location: Map 3 **Type:** 50x50m Quadrat
Date: 2016-05-03 **Described by:** DR/KMc
MGA Zone: 50 **Easting:** 415908 **Northing:** 7598273
Habitat: Major creek
Soil: Red brown sandy loam
Rock type: NA
Vegetation: *Melaleuca argentia* and *Eucalyptus camaldulensis* subsp. *refulgens* open forest over *Acacia trachycarpa* scattered tall shrubs shrubland over *Cyperus vaginatus* scattered sedges.
Veg Condition: Very Good
Fire Age: No fire evident

Species List

Name	Cover (%)	Height (m)
**Argemone ochroleuca* subsp. *ochroleuca*	0.5	0.1
**Cynodon dactylon*	0.5	0.1
**Euphorbia hirta*	0.5	0.1
**Passiflora foetida* var. *hispida*	0.5	1.0
Acacia trachycarpa	1	2.3
Cleome viscosa	0.5	0.2
Corchorus lasiocarpus subsp. *parvus*	0.5	1.9
Cyperus vaginatus	1	0.9
Eucalyptus camaldulensis subsp. *refulgens*	2	11.0
Gossypium robinsonii	0.5	2.3
Heliotropium pachyphyllum	0.5	0.2
Melaleuca argentea	62	14.0
Petalostylis labicheoides	0.5	2.5
Phyllanthus maderaspatensis	0.5	0.2
Pluchea rubelliflora	0.5	0.2
Ptilotus sp.	0.5	0.1
Sesbania formosa	0.5	4.5
Sporobolus australasicus	0.5	0.1
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	0.5	1.5
Trachymene oleracea subsp. *oleracea*	0.5	0.3
Vigna lanceolata var. *lanceolata*	0.5	0.5
Wahlenbergia tumidifructa	0.5	0.2

* denotes weed species
? denotes unconfirmed ID

Site: MH364
Location: Map 9 **Type:** 28x90m Quadrat
Date: 2016-05-08 **Described by:** LV
MGA Zone: 50 **Easting:** 418577 **Northing:** 7592127
Habitat: Major creek
Soil: Brown sand
Rock type: Ironstone
Vegetation: *Gossypium robinsonii* scattered shrubs over *Tephrosia rosea* var. Fortescue creeks (M.I.H. Brooker 2186) scattered low shrubs over *Triodia epactia* scattered hummock grasses.
Veg Condition: Excellent
Fire Age: 5-10 years

Species List

Name	Cover (%)	Height (m)
**Argemone ochroleuca* subsp. *ochroleuca*	0.5	0.2
**Cenchrus ciliaris*	0.5	0.3
**Flaveria trinervia*	0.5	0.35
Abutilon sp.	0.5	0.07
Abutilon sp. Dioicum (A.A. Mitchell PRP 1618)	0.5	0.8
Acacia orthocarpa	0.5	1.2
Acacia pyrifolia var. *pyrifolia*	0.5	1.4
Acacia tumida var. *pilbarensis*	0.5	1.5
Amaranthus undulatus	0.5	0.65
Boerhavia coccinea	0.5	0.05
Capparis spinosa var. *nummularia*	0.5	1.0
Cleome viscosa	0.5	0.5
Corchorus lasiocarpus subsp. *parvus*	0.5	0.35
Crotalaria ?*novae-hollindae*	0.5	0.03
Crotalaria medicaginea var. *neglecta*	0.5	0.3
Cucumis melo	0.5	0.35
Cucumis variabilis	0.5	0.2
Cymbopogon ambiguus	0.5	1.4
Cynanchum floribundum	0.5	0.03
Cyperus cunninghamii subsp. *cunninghamii*	0.5	0.25
Eremophila longifolia	0.5	2.2
Eriachne mucronata	0.5	0.4
Eulalia aurea	0.5	0.5
Euphorbia boopthona/tannensis	0.5	0.15
Gomphrena cunninghamii	0.5	0.1

Name	Cover (%)	Height (m)
Gossypium robinsonii	1	1.2
Grevillea pyramidalis subsp. *leucadendron*	0.5	1.9
Hibiscus goldsworthii	0.5	0.15
Hybanthus aurantiacus	0.5	0.5
Indigofera monophylla	0.5	0.35
Ipomoea muelleri	0.5	0.2
Notoleptopus decaisnei var. Orbicularis (A.B. Craig 428)	0.5	0.1
Paspalidium clementii	0.5	0.03
Pentalepis trichodesmoides	0.5	0.4
Phyllanthus maderaspatensis	0.5	0.5
Polycarpaea longiflora	0.5	0.35
Ptilotus fusiformis	0.5	0.5
Ptilotus incanus	0.5	0.35
Ptilotus nobilis subsp. *nobilis*	0.5	0.1
Scaevola spinescens	0.5	0.5
Senna artemisioides subsp. *oligophylla*	0.5	0.4
Senna notabilis	0.5	0.3
Solanum diversiflorum	0.5	0.25
Solanum horridum	0.5	0.3
Stemodia grossa	0.5	0.5
Stylobasium spathulatum	0.5	1.4
Swainsona formosa	0.5	0.1
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	1	0.5
Tribulus platypterus	0.5	0.5
Trichodesma zeylanicum var. *zeylanicum*	0.5	0.4
Triodia epactia	1	0.35
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	0.5	0.35
Triumfetta appendiculata	0.5	1.1
Waltheria indica	0.5	0.2

* denotes weed species
? denotes unconfirmed ID

Site: MH365
Location: Map 7 **Type:** 50x50m Quadrat
Date: 2016-05-07 **Described by:** DR
MGA Zone: 50 **Easting:** 416369 **Northing:** 7594935
Habitat: Plain
Soil: Brown clay loam
Rock type: NA
Vegetation: *Triodia wiseana* open hummock grassland.
Veg Condition: Excellent
Fire Age: 2-5 years

Species List

Name	Cover (%)	Height (m)
Acacia bivenosa	0.5	0.3
Bonamia pilbarensis	0.5	0.01
Corchorus lasiocarpus subsp. *parvus*	0.5	0.6
Cullen leucochaites	0.5	1.0
Heliotropium pachyphyllum	0.5	0.2
Ptilotus astrolasius	0.5	0.3
Sida sp. Pilbara (A.A. Mitchell PRP 1543)	0.5	0.3
Triodia wiseana	11	0.5

* denotes weed species
? denotes unconfirmed ID

Site: MH368
Location: Map 5, hills north of rail **Type:** 50x50m Quadrat
Date: 2016-05-04 **Described by:** DR/KMc
MGA Zone: 50 **Easting:** 420383 **Northing:** 7599337
Habitat: Hillcrest
Soil: Reddish brown silty clay loam
Rock type: BIF
Vegetation: *Acacia inaequilatera* scattered tall shrubs over *A. ptychophylla* low open shrubland over *Triodia wiseana* open hummock grassland.
Veg Condition: Excellent
Fire Age: >10 years

Species List

Name	Cover (%)	Height (m)
Acacia bivenosa	0.5	1.1
Acacia inaequilatera	1	2.5
Acacia ptychophylla	8	0.8
Acacia trachycarpa	0.5	0.4
Amphipogon sericeus	0.5	0.3
Bonamia pilbarensis	0.5	0.1
Dodonaea coriacea	0.5	0.6
Eriachne mucronata	0.5	0.2
Eriachne pulchella subsp. *pulchella*	0.5	0.1
Hakea chordophylla	0.5	2.8
Indigofera monophylla	0.5	0.3
Polycarpaea longiflora	0.5	0.2
Ptilotus astrolasius	0.5	0.2
Ptilotus calostachyus	0.5	0.4
Senna glutinosa subsp. *pruinosa*	0.5	0.9
Trachymene oleracea subsp. *oleracea*	0.5	0.4
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	0.5	0.4
Triodia wiseana	20	0.6

* denotes weed species
? denotes unconfirmed ID

Site: MH370
Location: NA **Type:** 50x50m Quadrat
Date: 2016-05-05 **Described by:** JA/LV
MGA Zone: 50 **Easting:** 420586 **Northing:** 7596886
Habitat: Floodplain
Soil: Red brown silty clay loam
Rock type: Ironstone
Vegetation: *Acacia synchronicia, A. bivenosa* tall open shrubland over *Triodia wiseana* very open hummock grassland.
Veg Condition: Good
Fire Age: >10 years

Species List

Name	Cover (%)	Height (m)
**Cenchrus ciliaris*	0.5	0.15
**Cenchrus setiger*	0.5	0.15
Abutilon sp. Dioicum (A.A. Mitchell PRP 1618)	0.5	0.3
Acacia bivenosa	2	2.3
Acacia synchronicia	3	3.5
Acacia trachycarpa	0.5	3.0
Amyema preissii	0.5	
Bonamia pilbarensis	0.5	0.1
Corchorus lasiocarpus subsp. *parvus*	0.5	0.7
Eucalyptus sp.	0.5	0.4
Euphorbia australis var. *subtomentosa*	0.5	0.85
Euphorbia boopthona/tannensis	0.5	0.8
Euphorbia schultzii	0.5	0.1
Gossypium robinsonii	0.5	3.7
Petalostylis labicheoides	0.5	2.5
Phyllanthus maderaspatensis	0.5	0.25
Ptilotus astrolasius	0.5	0.3
Ptilotus nobilis subsp. *nobilis*	0.5	0.1
Stylobasium spathulatum	0.5	0.6
Triodia wiseana	7	0.7

* denotes weed species
? denotes unconfirmed ID

Site: MH371
Location: Map 11 **Type:** 50x50m Quadrat
Date: 2016-05-10 **Described by:** JA/DR
MGA Zone: 50 **Easting:** 425572 **Northing:** 7592497
Habitat: Hillslope
Soil: Red brown clay loam
Rock type: Ironstone
Vegetation: *Triodia wiseana* and *T.* sp. Robe River (M.E. Trudgen et al. MET 12367) hummock grassland.
Veg Condition: Excellent
Fire Age: No fire evident

Species List

Name	Cover (%)	Height (m)
Acacia ancistrocarpa	0.5	2.0
Acacia bivenosa	0.5	1.2
Acacia inaequilatera	0.5	1.8
Acacia ptychophylla	0.5	0.8
Cassytha capillaris	0.5	0.3
Corchorus lasiocarpus subsp. *parvus*	0.5	0.3
Dampiera candicans	0.5	0.4
Eucalyptus leucophloia subsp. *leucophloia*	0.5	0.7
Grevillea wickhamii	0.5	2.1
Hakea chordophylla	0.5	1.8
Ptilotus calostachyus	0.5	0.5
Senna glutinosa subsp. *glutinosa*	0.5	2.0
Senna glutinosa subsp. *x luerssenii*	0.5	1.7
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	2	0.3
Triodia wiseana	32	0.5

* denotes weed species
? denotes unconfirmed ID

Site: MH373
Location: Map 11 in Bungaroo creek **Type:** 50x50m Quadrat
Date: 2016-05-10 **Described by:** KMc/LV
MGA Zone: 50 **Easting:** 424165 **Northing:** 7592224
Habitat: Major creek
Soil: Brown silty clay
Rock type: NA
Vegetation: *Eucalyptus victrix* and *E. camaldulensis* subsp. *refulgens* woodland over **Cenchrus* sp. open tussock grassland.
Veg Condition: Poor
Fire Age: No fire evident

Species List

Name	Cover (%)	Height (m)
**Echinochloa colona*	0.5	0.05
**Euphorbia hirta*	0.5	0.2
**Malvastrum americanum*	0.5	0.1
**Vachellia farnesiana*	0.5	0.1
Abutilon sp.	0.5	0.1
Acacia colei var. *ileocarpa*	0.5	0.5
Acacia pyrifolia var. *pyrifolia*	0.5	0.8
Acacia trachycarpa	0.5	2.5
Cenchrus sp.	25	0.1
Cyperus vaginatus	0.5	0.5
Eucalyptus camaldulensis subsp. *refulgens*	6	13.0
Eucalyptus victrix	6	13.0
Gossypium robinsonii	0.5	0.7
Hakea chordophylla	0.5	9.0
Hybanthus aurantiacus	0.5	0.4
Indigofera boviperda	0.5	0.5
Ipomoea polymorpha	0.5	0.05
Marsilea sp.	0.5	0.02
Mollugo molluginea	0.5	0.05
Phyllanthus maderaspatensis	0.5	0.1
Phyllanthus sp.	0.5	0.01
Pterocaulon sp.	0.5	0.1
Sida fibulifera	0.5	0.05
Solanum cleistogamum	0.5	0.2
Vigna lanceolata var. *lanceolata*	0.5	0.05

* denotes weed species
? denotes unconfirmed ID

Site: MH374
Location: Map 9 **Type:** 50x50m Quadrat
Date: 2016-05-08 **Described by:** DR/KMc
MGA Zone: 50 **Easting:** 419154 **Northing:** 7591787
Habitat: Pediment
Soil: Red brown silty clay loam
Rock type: Ironstone
Vegetation: *Corymbia hamersleyana* scattered low trees over *Stylobasium spathulatum* and *Acacia inaequilatera* open shrubland over *A. pyrifolia* var *pyrifolia, Corchorus lasiocarpus* subsp. *parvus* and *Indigofera monophylla* low open shrubland over *Triodia wiseana* very open hummock grassland.
Veg Condition: Excellent
Fire Age: 2-5 years

Species List

Name	Cover (%)	Height (m)
Acacia ?elacantha	0.5	0.6
Acacia ancistrocarpa	0.5	0.5
Acacia bivenosa	0.5	0.3
Acacia inaequilatera	1	1.9
Acacia pyrifolia var. *pyrifolia*	1	0.6
Acacia tumida var. *pilbarensis*	0.5	1.3
Aristida holathera var. *holathera*	0.5	0.3
Bonamia pilbarensis	0.5	0.1
Capparis spinosa var. *nummularia*	0.5	0.4
Clerodendrum floribundum var. *angustifolium*	0.5	0.5
Corchorus lasiocarpus subsp. *parvus*	1	0.5
Corymbia hamersleyana	1	4.2
Gossypium australe	0.5	0.5
Gossypium robinsonii	0.5	1.0
Grevillea pyramidalis subsp. *leucadendron*	0.5	0.4
Hibiscus coatesii	0.5	0.9
Hibiscus sturtii var. *campylochlamys*	0.5	0.7
Hybanthus aurantiacus	0.5	0.3
Indigofera monophylla	1	0.4
Jasminum didymum subsp. *lineare*	0.5	1.0
Mollugo molluginea	0.5	0.1
Ptilotus astrolasius	0.5	0.5
Ptilotus nobilis subsp. *nobilis*	0.5	0.2
Rhynchosia minima	0.5	0.2

Name	Cover (%)	Height (m)
Senna artemisioides subsp. *oligophylla*	0.5	0.5
Senna glutinosa subsp. *glutinosa*	0.5	0.5
Senna glutinosa subsp. *pruinosa*	0.5	1.1
Sida arsiniata	0.5	0.5
Solanum horridum	0.5	0.1
Stylobasium spathulatum	1	1.5
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	0.5	1.0
Trachymene oleracea subsp. *oleracea*	0.5	0.4
Triodia wiseana	6	0.4
Triumfetta appendiculata	0.5	0.4

* denotes weed species
? denotes unconfirmed ID

Site: MH375r
Location: Map 9 **Type:** 50x50m Relevé
Date: 2016-05-08 **Described by:** DR/KMc
MGA Zone: 50 **Easting:** 419807 **Northing:** 7591301
Habitat: Hillcrest
Soil: Reddish brown clay loam
Rock type: Ironstone
Vegetation: *Triodia wiseana* and *T.* sp. Robe River (M.E. Trudgen et al. MET 12367) open hummock grassland.
Veg Condition: Excellent
Fire Age: 5-10 years

Species List

Name	Cover (%)	Height (m)
Fimbristylis dichotoma	0.5	0.01
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	1	0.4
Triodia wiseana	12	0.3

* denotes weed species
? denotes unconfirmed ID

Site: MH376
Location: On Map 9 in new area, floodplain between hills **Type:** 50x50m Quadrat
Date: 2016-05-08 **Described by:** DR/KMc
MGA Zone: 50 **Easting:** 419227 **Northing:** 7591466
Habitat: Floodplain
Soil: Reddish brown silty loam
Rock type: Ironstone
Vegetation: *Corymbia hamersleyana* low open woodland over *Corchorus lasiocarpus* subsp. *parvus* low open shrubland over *Triodia wiseana* and *T. epactia* open hummock grassland.
Veg Condition: Excellent
Fire Age: 2-5 years

Species List

Name	Cover (%)	Height (m)
Acacia ancistrocarpa	0.5	1.1
Acacia bivenosa	0.5	0.2
Acacia colei var. *ileocarpa*	0.5	1.4
Acacia inaequilatera	0.5	0.6
Acacia monticola	0.5	0.4
Acacia orthocarpa	0.5	0.4
Acacia pyrifolia var. *pyrifolia*	0.5	0.7
Acacia tumida var. *pilbarensis*	0.5	0.2
Bonamia pilbarensis	0.5	0.05
Clerodendrum floribundum var. *angustifolium*	0.5	0.3
Corchorus lasiocarpus subsp. *parvus*	2	0.5
Corymbia hamersleyana	2	5.0
Eriachne mucronata	0.5	0.3
Gossypium robinsonii	0.5	1.2
Grevillea pyramidalis subsp. *leucadendron*	0.5	0.6
Hibiscus sturtii var. *campylochlamys*	0.5	0.5
Indigofera monophylla	0.5	0.3
Jasminum didymum subsp. *lineare*	0.5	0.5
Mollugo molluginea	0.5	0.1
Pentalepis trichodesmoides	0.5	0.7
Ptilotus astrolasius	0.5	0.4
Sesbania formosa	0.5	0.2
Sida arsiniata	0.5	0.3
Stylobasium spathulatum	0.5	0.7
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	0.5	0.6

Name	Cover (%)	Height (m)
Tribulus platypterus	0.5	0.7
Trichodesma zeylanicum var. *zeylanicum*	0.5	0.6
Triodia epactia	2	0.4
Triodia wiseana	15	0.4

* denotes weed species
? denotes unconfirmed ID

Site: MH377
Location: Map 9 **Type:** 50x50m Quadrat
Date: 2016-05-08 **Described by:** LV
MGA Zone: 50 **Easting:** 418820 **Northing:** 7591820
Habitat: Hillslope
Soil: Brown sandy clay loam
Rock type: Basalt
Vegetation: *Triodia wiseana* open hummock grassland.
Veg Condition: Excellent
Fire Age: 2-5 years

Species List

Name	Cover (%)	Height (m)
Acacia bivenosa	0.5	0.3
Acacia inaequilatera	0.5	0.5
Corchorus lasiocarpus subsp. *parvus*	0.5	0.3
Hibiscus coatesii	0.5	0.6
Ptilotus nobilis subsp. *nobilis*	0.5	0.08
Senna glutinosa subsp. *pruinosa*	0.5	0.6
Senna glutinosa subsp. *x luerssenii*	0.5	0.45
Sida sp. Pilbara (A.A. Mitchell PRP 1543)	0.5	0.4
Triodia wiseana	20	0.3

* denotes weed species
? denotes unconfirmed ID

Site: MH392
Location: NA **Type:** 50x50m Quadrat
Date: 2016-05-10 **Described by:** JA/DR
MGA Zone: 50 **Easting:** 424829 **Northing:** 7592502
Habitat: Major creek
Soil: Red brown sandy clay loam
Rock type: NA
Vegetation: *Eucalyptus victrix* open woodland over *Acacia trachycarpa* tall open shrubland over *Triodia wiseana* very open hummock grassland and **Cenchrus ciliaris* very open tussock grassland.
Veg Condition: Good
Fire Age: >10 years

Species List

Name	Cover (%)	Height (m)
**Cenchrus ciliaris*	3	0.25
**Malvastrum americanum*	0.5	0.1
**Passiflora foetida* var. *hispida*	0.5	0.1
Abutilon sp. Dioicum (A.A. Mitchell PRP 1618)	0.5	0.5
Acacia bivenosa	0.5	1.1
Acacia pyrifolia var. *pyrifolia*	0.5	1.6
Acacia trachycarpa	7	2.1
Boerhavia coccinea	0.5	0.1
Capparis spinosa var. *nummularia*	0.5	0.4
Cleome viscosa	0.5	0.2
Corchorus lasiocarpus subsp. *parvus*	0.5	0.5
Cymbopogon ambiguus	0.5	0.8
Cyperus vaginatus	0.5	0.6
Eucalyptus victrix	6	14.0
Euphorbia biconvexa	0.5	0.15
Euphorbia schultzii	0.5	0.05
Evolvulus alsinoides var. *villosicalyx*	0.5	0.1
Flueggea virosa subsp. *melanthesoides*	0.5	3.8
Gomphrena cunninghamii	0.5	0.05
Gossypium australe	0.5	0.4
Gossypium robinsonii	0.5	1.0
Grevillea wickhamii	0.5	0.7
Hybanthus aurantiacus	0.5	0.1
Indigofera monophylla	0.5	0.15
Notoleptopus decaisnei var. Orbicularis (A.B. Craig 428)	0.5	0.1

Name	Cover (%)	Height (m)
Phyllanthus maderaspatensis	0.5	0.3
Pterocaulon sphaeranthoides	0.5	0.1
Ptilotus appendiculatus	0.5	0.05
Ptilotus calostachyus	0.5	0.4
Ptilotus incanus	0.5	0.2
Ptilotus nobilis subsp. *nobilis*	0.5	0.1
Rhynchosia minima	0.5	0.05
Sida sp. Pilbara (A.A. Mitchell PRP 1543)	0.5	0.6
Solanum diversiflorum	0.5	0.1
Solanum horridum	0.5	0.15
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	0.5	0.6
Trianthema triquetrum	0.5	0.05
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	0.5	0.5
Triodia wiseana	3	0.6
Triumfetta appendiculata	0.5	0.3
Triumfetta clementii	0.5	0.1
Waltheria indica	0.5	0.2

* denotes weed species
? denotes unconfirmed ID

Site: MH393
Location: Map 11 **Type:** 25x100m Quadrat
Date: 2016-05-10 **Described by:** JA/DR
MGA Zone: 50 **Easting:** 424501 **Northing:** 7592735
Habitat: Major creek
Soil: Red brown sandy clay loam
Rock type: NA
Vegetation: *Eucalyptus victrix* low open woodland over *Acacia trachycarpa* tall open shrubland over *Triodia wiseana* very open hummock grassland and **Cenchrus ciliaris* very open tussock grassland.
Veg Condition: Good
Fire Age: >10 years

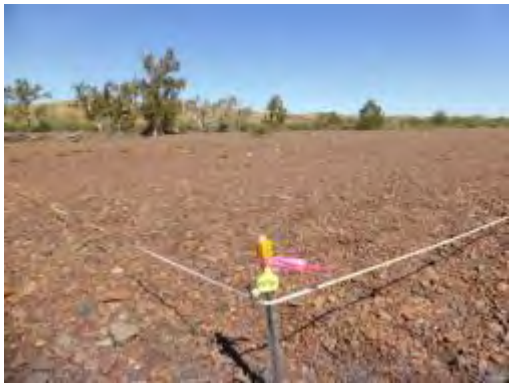
Species List

Name	Cover (%)	Height (m)
**Cenchrus ciliaris*	3	0.2
**Malvastrum americanum*	0.5	0.3
Abutilon sp. Dioicum (A.A. Mitchell PRP 1618)	0.5	0.2
Acacia bivenosa	0.5	2.1
Acacia colei var. *ileocarpa*	0.5	0.6
Acacia pyrifolia var. *pyrifolia*	0.5	2.1
Acacia synchronicia	0.5	2.2
Acacia trachycarpa	9	2.7
Acacia tumida var. *pilbarensis*	0.5	1.3
Boerhavia coccinea	0.5	0.1
Cleome viscosa	0.5	0.2
Corchorus lasiocarpus subsp. *parvus*	0.5	0.2
Cucumis variabilis	0.5	0.2
Cymbopogon ambiguus	0.5	0.3
Eriachne mucronata	0.5	0.4
Eriachne tenuiculmis	0.5	0.3
Eucalyptus victrix	2	8.0
Euphorbia australis	0.5	0.05
Euphorbia biconvexa	0.5	0.1
Euphorbia schultzii	0.5	0.02
Gossypium australe	0.5	0.3
Gossypium robinsonii	0.5	0.6
Hybanthus aurantiacus	0.5	0.1
Notoleptopus decaisnei var. Orbicularis (A.B. Craig 428)	0.5	0.1
Phyllanthus maderaspatensis	0.5	0.2

Name	Cover (%)	Height (m)
Pterocaulon sp.	0.5	0.2
Ptilotus appendiculatus	0.5	0.1
Ptilotus auriculifolius	0.5	0.1
Rhynchosia minima	0.5	0.1
Senna ferraria	0.5	1.1
Senna notabilis	0.5	0.2
Solanum diversiflorum	0.5	0.2
Solanum horridum	0.5	0.2
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	0.5	0.2
Triodia wiseana	7	0.6
Waltheria indica	0.5	0.2

* denotes weed species
? denotes unconfirmed ID

Site: MH394
Location: SW corner Map 6 **Type:** 50x50m Quadrat
Date: 2016-05-11 **Described by:** KMc/LV
MGA Zone: 50 **Easting:** 414348 **Northing:** 7595672
Habitat: Major creek
Soil: Brown sand
Rock type: Ironstone
Vegetation: *Acacia trachycarpa* very scattered shrub over *Euphorbia schultzii* very scattered low shrubs.
Veg Condition: Excellent
Fire Age: >10 years



Species List

Name	Cover (%)	Height (m)
**Argemone ochroleuca* subsp. *ochroleuca*	0.5	0.3
Acacia trachycarpa	0.5	2.5
Cleome viscosa	0.5	0.01
Corchorus ?crozophorifolius	0.5	0.4
Euphorbia schultzii	0.5	0.15
Hybanthus aurantiacus	0.5	0.15
Ptilotus incanus	0.5	0.3
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	0.5	0.35

* denotes weed species
? denotes unconfirmed ID

Site: MH395
Location: Map 4 **Type:** 50x50m Quadrat
Date: 2016-05-13 **Described by:** JA/DR
MGA Zone: 50 **Easting:** 419057 **Northing:** 7598866
Habitat: Floodplain
Soil: Red brown sandy clay loam
Rock type: NA
Vegetation: *Corymbia candida* low open woodland over *Acacia synchronicia*, *A. trachycarpa* tall open shrubland over *Triodia wiseana* and *T. epactia* open hummock grassland.
Veg Condition: Very Good
Fire Age: >10 years

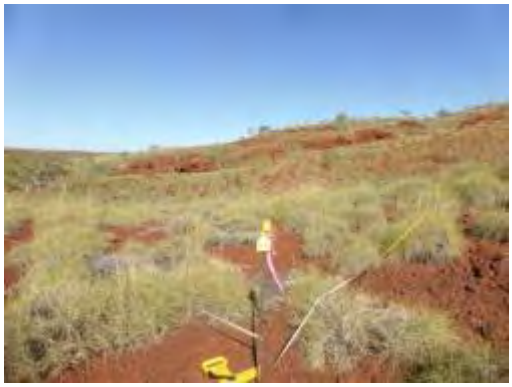
Species List

Name	Cover (%)	Height (m)
**Cenchrus ciliaris*	0.5	0.3
**Cenchrus setiger*	0.5	0.5
Acacia ancistrocarpa	0.5	2.2
Acacia atkinsiana	0.5	1.9
Acacia bivenosa	0.5	0.9
Acacia synchronicia	3	3.2
Acacia trachycarpa	1	3.5
Acacia tumida var. *pilbarensis*	0.5	2.0
Aristida holathera var. *holathera*	0.5	0.2
Corchorus lasiocarpus subsp. *parvus*	0.5	0.2
Corymbia candida	2	9.0
Euphorbia biconvexa	0.5	0.5
Euphorbia boopthona/tannensis	0.5	0.2
Goodenia forrestii	0.5	0.1
Gossypium australe	0.5	0.3
Grevillea pyramidalis subsp. *leucadendron*	0.5	2.6
Hakea lorea subsp. *lorea*	0.5	1.8
Petalostylis labicheoides	0.5	2.6
Ptilotus astrolasius	0.5	0.2
Ptilotus nobilis subsp. *nobilis*	0.5	0.1
Salsola australis	0.5	0.1
Sclerolaena costata	0.5	0.1
Senna artemisioides subsp. *oligophylla*	0.5	2.0
Sida arsiniata	0.5	0.1
Sida rohlenae subsp. *rohlenae*	0.5	0.1

Name	Cover (%)	Height (m)
Tribulus macrocarpus	0.5	0.1
Trichodesma zeylanicum var. *zeylanicum*	0.5	0.1
Triodia epactia	2	0.4
Triodia wiseana	20	0.7

* denotes weed species
? denotes unconfirmed ID

Site: MH396
Location: Bottom of Map 7 **Type:** 50x50m Quadrat
Date: 2016-05-12 **Described by:** KMc/LV
MGA Zone: 50 **Easting:** 417275 **Northing:** 7593400
Habitat: Hillslope
Soil: Red brown clay loam
Rock type: Ironstone
Vegetation: *Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Triodia wiseana* and *T.* sp. Robe River (M.E. Trudgen et al. MET 12367) P3 open hummock grassland.
Veg Condition: Excellent
Fire Age: 2-5 years

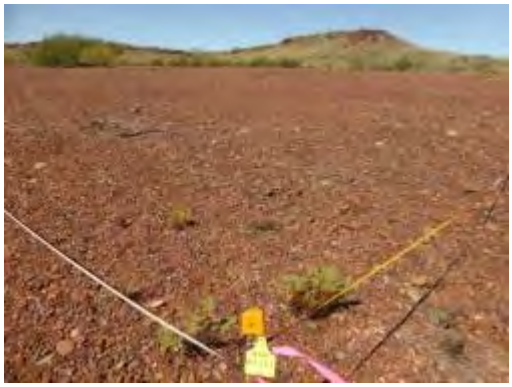


Species List

Name	Cover (%)	Height (m)
Acacia inaequilatera	0.5	2.2
Acacia orthocarpa	0.5	0.25
Corchorus lasiocarpus subsp. *parvus*	0.5	0.6
Eucalyptus leucophloia subsp. *leucophloia*	1	4.5
Ptilotus calostachyus	0.5	0.3
Senna glutinosa subsp. *glutinosa*	0.5	1.2
Sida sp. Articulation below (A.A. Mitchell PRP 1605)	0.5	1.6
Stylobasium spathulatum	0.5	1.8
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	2	0.3
Triodia wiseana	23	0.3
Triumfetta johnstonii	0.5	0.5

* denotes weed species
? denotes unconfirmed ID

Site: MH397
Location: Map 3 **Type:** 50x50m Quadrat
Date: 2016-05-12 **Described by:** DR
MGA Zone: 50 **Easting:** 416275 **Northing:** 7597984
Habitat: Major creek
Soil: Brown sandy clay loam
Rock type: NA
Vegetation: *Acacia trachycarpa* and *Petalostylis labicheoides* very scattered tall shrubs over *Euphorbia schultzii* very scattered herbs.
Veg Condition: Very Good
Fire Age: No fire evident



Species List

Name	Cover (%)	Height (m)
Acacia trachycarpa	0.5	2.8
Euphorbia schultzii	0.5	0.2
Ipomoea muelleri	0.5	0.1
Petalostylis labicheoides	0.5	2.5
Phyllanthus maderaspatensis	0.5	0.2

* denotes weed species
? denotes unconfirmed ID

Site: MH398
Location: NA **Type:** 60x42m Quadrat
Date: 2016-05-12 **Described by:** JA
MGA Zone: 50 **Easting:** 417606 **Northing:** 7597831
Habitat: Channel
Soil: Brown loamy sand
Rock type: NA
Vegetation: *Acacia trachycarpa* scattered tall shrubs to tall open shrubland (over *Euphorbia schultzii* very scattered herbs).
Veg Condition: Excellent
Fire Age: >10 years

Species List

Name	Cover (%)	Height (m)
Acacia trachycarpa	2	3.7
Euphorbia schultzii	0.5	0.15
Hybanthus aurantiacus	0.5	0.2
Ipomoea muelleri	0.5	0.05
Ptilotus incanus	0.5	0.2

* denotes weed species
? denotes unconfirmed ID

Site: MH399r
Location: Map 3, edge of Mesa h and Robe River **Type:** 10x200m Relevé
Date: 2016-05-13 **Described by:** KMc/LV
MGA Zone: 50 **Easting:** 414722 **Northing:** 7597221
Habitat: Breakaway
Soil: Red brown silty clay loam
Rock type: Ironstone
Vegetation: *Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Acacia bivenosa* scattered shrubs over *Triodia wiseana* very open hummock grassland.
Veg Condition: Excellent
Fire Age: >10 years

Species List

Name	Cover (%)	Height (m)
Abutilon lepidum	0.5	0.25
Acacia acradenia	0.5	2.5
Acacia bivenosa	1	1.5
Acacia trachycarpa	0.5	1.3
Capparis spinosa var. *nummularia*	0.5	0.4
Cymbopogon ambiguus	0.5	0.4
Cyperus cunninghamii subsp. *cunninghamii*	0.5	0.1
Eriachne mucronata	0.5	0.3
Eucalyptus leucophloia subsp. *leucophloia*	1	7.0
Flueggea virosa subsp. *melanthesoides*	0.5	3.0
Hibiscus goldsworthii	0.5	0.25
Hybanthus aurantiacus	0.5	0.6
Ptilotus obovatus	0.5	0.2
Senna glutinosa subsp. *glutinosa*	0.5	0.15
Triodia wiseana	5	0.6

* denotes weed species
? denotes unconfirmed ID

Site: MH400
Location: NA **Type:** 50x50m Quadrat
Date: 2016-05-12 **Described by:** JA
MGA Zone: 50 **Easting:** 417372 **Northing:** 7599213
Habitat: Gully
Soil: Brown sandy clay loam
Rock type: Ironstone
Vegetation: *Eucalyptus leucophloia* subsp*. leucophloia* scattered low trees over *Acacia tumida* var. *pilbarensis, Grevillea wickhamii*, *A. acradenia* tall open shrubland over *Triodia wiseana* open hummock grassland.
Veg Condition: Excellent
Fire Age: >10 years

Species List

Name	Cover (%)	Height (m)
Acacia acradenia	1	2.1
Acacia tumida var. *pilbarensis*	5	4.0
Bonamia pilbarensis	0.5	0.05
Corchorus lasiocarpus subsp. *parvus*	0.5	0.1
Dampiera candicans	0.5	0.4
Eucalyptus leucophloia subsp. *leucophloia*	1	6.0
Euphorbia australis var. *subtomentosa*	0.5	0.4
Grevillea wickhamii	1	3.7
Indigofera monophylla	0.5	0.4
Mollugo molluginea	0.5	0.1
Petalostylis labicheoides	0.5	1.7
Ptilotus astrolasius	0.5	0.2
Ptilotus calostachyus	0.5	1.0
Triodia wiseana	12	0.6

* denotes weed species
? denotes unconfirmed ID

Site: MH401
Location: Map 11 just NE of creek **Type:** 50x50m Quadrat
Date: 2016-05-10 **Described by:** KMc
MGA Zone: 50 **Easting:** 424035 **Northing:** 7592626
Habitat: Floodplain
Soil: Light reddish brown silty clay
Rock type: NA
Vegetation: *Eucalyptus victrix* low open woodland over *Acacia trachycarpa* and *Melaleuca glomerata* tall open shrubland over *Triodia wiseana* open hummock grassland with **Cenchrus ciliaris* open tussock grassland.
Veg Condition: Good
Fire Age: No fire evident

Species List

Name	Cover (%)	Height (m)
**Cenchrus ciliaris*	12	0.1
**Malvastrum americanum*	0.5	0.2
**Passiflora foetida* var. *hispida*	0.5	0.1
**Vachellia farnesiana*	0.5	0.6
Abutilon sp.	0.5	0.2
Acacia bivenosa	0.5	1.2
Acacia colei var. *ileocarpa*	0.5	0.6
Acacia pyrifolia var. *pyrifolia*	0.5	3.0
Acacia sclerosperma subsp. *sclerosperma*	0.5	1.3
Acacia trachycarpa	7	2.5
Eucalyptus victrix	7	8.0
Euphorbia biconvexa	0.5	0.1
Gossypium robinsonii	0.5	0.25
Indigofera boviperda	0.5	0.1
Melaleuca glomerata	2	2.2
Pterocaulon sp.	0.5	0.05
Rhynchosia minima	0.5	0.1
Sida fibulifera	0.5	0.05
Triodia wiseana	14	0.6

* denotes weed species
? denotes unconfirmed ID

Site: MH402
Location: additional area **Type:** 50x50m Quadrat
Date: 2016-07-20 **Described by:** JA
MGA Zone: 50 **Easting:** 424901 **Northing:** 7591093
Habitat: Floodplain
Soil: Orange brown silty clay
Rock type: NA
Vegetation: *Corymbia candida* scattered low trees to low open woodland over *Acacia synchronicia* tall open shrubland over *Triodia epactia* hummock grassland with **Cenchrus setiger*, **C. ciliaris* open tussock grassland.
Veg Condition: Good
Fire Age: >10 years

Species List

Name	Cover (%)	Height (m)
**Cenchrus ciliaris*	3	0.4
**Cenchrus setiger*	15	0.4
**Lactuca serriola*	0.5	0.1
Abutilon sp.	0.5	0.15
Acacia synchronicia	3	4.0
Acacia xiphophylla	0.5	2.2
Amaranthus cuspidifolius	0.5	0.1
Cynodon prostrata	0.5	0.05
Calotis hispidula	0.5	0.1
Corymbia candida	2	8.0
Dactyloctenium radulans	0.5	0.1
Dysphania rhadinostachya subsp. *rhadinostachya*	0.5	0.1
Eremophila longifolia	0.5	3.4
Euphorbia boophthona	0.5	0.3
Hibiscus sturtii	0.5	0.2
Indigofera linnaei	0.5	0.3
Indigofera trita	0.5	0.15
Ipomoea polymorpha	0.5	0.05
Lepidium pholidogynum	0.5	0.1
Nicotiana occidentalis	0.5	0.2
Phyllanthus erwinii	0.5	0.1
Pterocaulon sphacelatum	0.5	0.05
Ptilotus appendiculatus	0.5	0.05
Ptilotus nobilis subsp. *nobilis*	0.5	0.05

Name	Cover (%)	Height (m)
Rhagodia eremaea	0.5	0.1
Rhynchosia minima	0.5	0.3
Salsola australis	0.5	0.2
Sclerolaena costata	0.5	0.2
Sclerolaena sp.	0.5	0.05
Senna artemisioides subsp. *oligophylla*	0.5	1.7
Senna notabilis	0.5	0.1
Sida arsiniata	0.5	0.3
Sida fibulifera	0.5	0.15
Solanum cleistogamum	0.5	0.2
Solanum diversiflorum	0.5	0.15
Sporobolus australasicus	0.5	0.1
Stemodia grossa	0.5	0.05
Streptoglossa decurrens	0.5	0.1
Trianthema triquetrum	0.5	0.1
Triodia epactia	32	0.8

* denotes weed species
? denotes unconfirmed ID

Site: MH403
Location: Figure1 **Type:** 50x50m Quadrat
Date: 2016-07-20 **Described by:** DR
MGA Zone: 50 **Easting:** 424600 **Northing:** 7590603
Habitat: Plain
Soil: Red brown sandy clay loam
Rock type: NA
Vegetation: *Corymbia candida* low open woodland over *Acacia synchronicia* scattered tall shrubs over *Triodia epactia* hummock grassland over *Ptilotus nobilis* subsp. *nobilis* scattered herbs.
Veg Condition: Very Good
Fire Age: >10 years

Species List

Name	Cover (%)	Height (m)
**Cenchrus ciliaris*	0.5	0.3
Abutilon sp. Pilbara (W.R. Barker 2025)	0.5	0.2
Acacia bivenosa	0.5	1.3
Acacia synchronicia	1	2.1
Amaranthus cuspidifolius	0.5	0.2
Boerhavia coccinea	0.5	0.1
Boerhavia repleta	0.5	0.1
Bulbostylis barbata	0.5	0.05
Cheilanthes sieberi subsp. *sieberi*	0.5	0.2
Cleome viscosa	0.5	0.2
Corchorus lasiocarpus subsp. *parvus*	0.5	0.2
Corymbia candida	2	5.0
Dactyloctenium radulans	0.5	0.05
Dysphania rhadinostachya subsp. *rhadinostachya*	0.5	0.1
Eragrostis pergracilis	0.5	0.05
Euphorbia australis var. *subtomentosa*	0.5	0.1
Euphorbia biconvexa	0.5	0.2
Euphorbia boophthona	0.5	0.3
Evolvulus alsinoides var. *villosicalyx*	0.5	0.1
Gomphrena cunninghamii	0.5	0.1
Goodenia forrestii	0.5	0.2
Goodenia microptera	0.5	0.1
Hakea lorea subsp. *lorea*	0.5	1.0
Hibiscus sturtii var. *grandiflorus*	0.5	0.2
Ipomoea muelleri	0.5	0.1

Name	Cover (%)	Height (m)
Maireana planifolia	0.5	0.5
Notoleptopus decaisnei var. Orbicularis (A.B. Craig 428)	0.5	0.1
Paspalidium clementii	0.5	0.2
Ptilotus appendiculatus	0.5	0.2
Ptilotus astrolasius	0.5	0.1
Ptilotus axillaris	0.5	0.1
Ptilotus nobilis subsp. *nobilis*	1	0.7
Rhynchosia minima	0.5	0.4
Sclerolaena costata	0.5	0.3
Senna artemisioides subsp. *oligophylla*	0.5	1.0
Senna notabilis	0.5	0.1
Sida arsiniata	0.5	0.2
Sida fibulifera	0.5	0.2
Solanum diversiflorum	0.5	0.3
Sporobolus australasicus	0.5	0.05
Streptoglossa decurrens	0.5	0.2
Trianthema pilosum	0.5	0.05
Trianthema triquetrum	0.5	0.1
Tribulus macrocarpus	0.5	0.05
Trichodesma zeylanicum var. *zeylanicum*	0.5	0.2
Triodia epactia	35	0.6

* denotes weed species
? denotes unconfirmed ID

Site: MH404
Location: figure 1 **Type:** 50x50m Quadrat
Date: 2016-07-21 **Described by:** DR
MGA Zone: 50 **Easting:** 424538 **Northing:** 7590215
Habitat: Plain
Soil: Red brown clay loam
Rock type: NA
Vegetation: *Corymbia candida* low open woodland over *Acacia ancistrocarpa* scattered tall shrubs to tall open shrubland over *Triodia epactia* hummock grassland.
Veg Condition: Excellent
Fire Age: >10 years

Species List

Name	Cover (%)	Height (m)
**Malvastrum americanum*	0.5	0.3
Acacia ancistrocarpa	2	2.1
Acacia pyrifolia var. *pyrifolia*	0.5	3.3
Acacia tumida var. *pilbarensis*	0.5	0.5
Alternanthera nana	0.5	0.1
Boerhavia coccinea	0.5	0.1
Cleome viscosa	0.5	0.1
Corchorus lasiocarpus subsp. *parvus*	0.5	0.5
Corymbia candida	3	7.0
Crotalaria medicaginea var. *neglecta*	0.5	0.1
Cucumis variabilis	0.5	0.2
Cullen martinii	0.5	0.3
Dysphania rhadinostachya subsp. *rhadinostachya*	0.5	0.1
Eremophila forrestii	0.5	0.3
Eremophila longifolia	0.5	0.7
Euphorbia biconvexa	0.5	0.1
Euphorbia boophthona	0.5	0.2
Evolvulus alsinoides var. *villosicalyx*	0.5	0.1
Goodenia forrestii	0.5	0.2
Goodenia microptera	0.5	0.1
Gossypium australe	0.5	0.3
Grevillea wickhamii	0.5	0.5
Heliotropium ovalifolium	0.5	0.3
Heliotropium tanythrix	0.5	0.3
Hibiscus sturtii var. *grandiflorus*	0.5	0.3

Name	Cover (%)	Height (m)
Hybanthus aurantiacus	0.5	0.1
Indigofera monophylla	0.5	0.4
Ipomoea muelleri	0.5	0.1
Isotropis atropurpurea	0.5	0.5
Mollugo molluginea	0.5	0.1
Notoleptopus decaisnei var. Orbicularis (A.B. Craig 428)	0.5	0.1
Polymeria ambigua	0.5	0.1
Pterocaulon sphaeranthoides	0.5	0.8
Ptilotus appendiculatus	0.5	0.2
Ptilotus astrolasius	0.5	0.4
Ptilotus axillaris	0.5	0.1
Rhynchosia minima	0.5	0.3
Senna artemisioides subsp. *oligophylla*	0.5	0.6
Sida arsiniata	0.5	0.3
Sida fibulifera	0.5	0.2
Sida sp. Articulation below (A.A. Mitchell PRP 1605)	0.5	0.8
Solanum diversiflorum	0.5	0.3
Solanum horridum	0.5	0.2
Stylobasium spathulatum	0.5	0.7
Trachymene oleracea subsp. *oleracea*	0.5	0.05
Tribulus macrocarpus	0.5	0.05
Trichodesma zeylanicum var. *zeylanicum*	0.5	0.4
Triodia epactia	40	0.7
Triumfetta chaetocarpa	0.5	0.2
Waltheria indica	0.5	0.4

* denotes weed species
? denotes unconfirmed ID

Site: MH405
Location: figure 1 **Type:** 25x100m Quadrat
Date: 2016-07-21 **Described by:** DR
MGA Zone: 50 **Easting:** 423437 **Northing:** 7589806
Habitat: Minor creek
Soil: Red brown sandy clay loam
Rock type: NA
Vegetation: *Corymbia hamersleyana* scattered low trees over *Acacia tumida* var. *pilbarensis* and *Grevillea wickhamii* tall shrubland over *Triodia epactia* open hummock grassland.
Veg Condition: Excellent
Fire Age: >10 years

Species List

Name	Cover (%)	Height (m)
Acacia ancistrocarpa	0.5	1.3
Acacia tumida var. *pilbarensis*	22	4.0
Aristida holathera var. *holathera*	0.5	0.2
Bonamia pilbarensis	0.5	0.05
Corchorus lasiocarpus subsp. *parvus*	0.5	0.5
Corymbia hamersleyana	1	4.2
Cucumis variabilis	0.5	0.5
Eriachne mucronata	0.5	0.3
Euphorbia australis	0.5	0.05
Euphorbia boopthona/tannensis	0.5	0.1
Goodenia stobbsiana	0.5	0.4
Gossypium robinsonii	0.5	3.5
Grevillea wickhamii	3	3.5
Heliotropium ovalifolium	0.5	0.2
Indigofera monophylla	0.5	0.5
Isotropis atropurpurea	0.5	0.6
Jasminum didymum subsp. *lineare*	0.5	0.8
Mollugo molluginea	0.5	0.1
Paraneurachne muelleri	0.5	0.3
Petalostylis labicheoides	0.5	2.0
Pluchea sp.	0.5	0.1
Pterocaulon sphaeranthoides	0.5	0.7
Ptilotus astrolasius	0.5	0.3
Ptilotus calostachyus	0.5	0.8
Ptilotus nobilis subsp. *nobilis*	0.5	0.5

Name	Cover (%)	Height (m)
Rhynchosia minima	0.5	0.4
Solanum diversiflorum	0.5	0.3
Stylobasium spathulatum	0.5	1.0
Tephrosia uniovulata	0.5	0.4
Trachymene oleracea subsp. *oleracea*	0.5	0.1
Trichodesma zeylanicum var. *zeylanicum*	0.5	2.1
Triodia epactia	25	0.7
Triodia wiseana	0.5	0.7
Triumfetta chaetocarpa	0.5	0.3
Waltheria indica	0.5	0.4

* denotes weed species
? denotes unconfirmed ID

Site: MH406
Location: Additional area **Type:** 30x84m Quadrat
Date: 2016-07-21 **Described by:** JA
MGA Zone: 50 **Easting:** 423564 **Northing:** 7590341
Habitat: Drainage depression
Soil: Red brown sandy clay loam
Rock type: NA
Vegetation: *Corymbia hamersleyana* low open woodland over *Acacia tumida* var. *pilbarensis*, *Acacia ancistrocarpa* tall shrubland over *Triodia epactia* hummock grassland.
Veg Condition: Excellent
Fire Age: >10 years

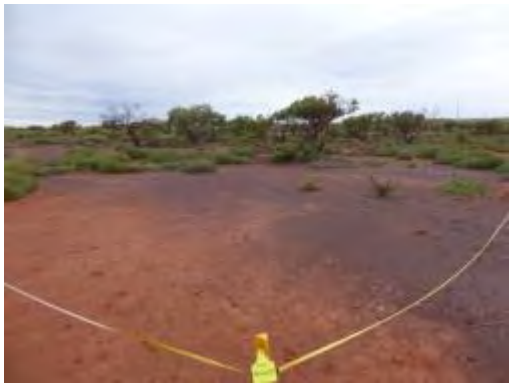
Species List

Name	Cover (%)	Height (m)
Abutilon sp. Pilbara (W.R. Barker 2025)	0.5	0.25
Acacia ancistrocarpa	14	3.0
Acacia inaequilatera	0.5	1.3
Acacia pyrifolia var. *pyrifolia*	0.5	2.0
Acacia tumida var. *pilbarensis*	14	4.0
Bonamia erecta	0.5	0.4
Corchorus lasiocarpus subsp. *parvus*	0.5	1.0
Corymbia hamersleyana	3	6.0
Cucumis variabilis	0.5	
Cullen martinii	0.5	0.2
Cymbopogon ambiguus	0.5	1.1
Dysphania rhadinostachya subsp. *rhadinostachya*	0.5	0.1
Euphorbia australis var. *subtomentosa*	0.5	0.1
Goodenia microptera	0.5	0.2
Gossypium australe	0.5	0.5
Grevillea wickhamii	0.5	2.0
Hibiscus sturtii var. *campylochlamys*	0.5	0.3
Hybanthus aurantiacus	0.5	0.15
Isotropis atropurpurea	0.5	0.3
Mollugo molluginea	0.5	0.1
Petalostylis labicheoides	0.5	2.8
Phyllanthus erwinii	0.5	0.15
Polymeria sp.	0.5	0.05
Ptilotus astrolasius	0.5	0.4
Ptilotus axillaris	0.5	0.1

Name	Cover (%)	Height (m)
Ptilotus calostachyus	0.5	1.2
Rhynchosia minima	0.5	0.5
Senna glutinosa subsp. *glutinosa*	0.5	1.5
Solanum ?*cleistigamum*	0.5	0.4
Stylobasium spathulatum	0.5	1.4
Tephrosia uniovulata	0.5	0.3
Trachymene oleracea subsp. *oleracea*	0.5	0.05
Trichodesma zeylanicum var. *zeylanicum*	0.5	1.3
Triodia epactia	45	0.9
Triumfetta chaetocarpa	0.5	0.6

* denotes weed species
? denotes unconfirmed ID

Site: MH407
Location: figure 2 **Type:** 50x50m Quadrat
Date: 2016-07-22 **Described by:** DR
MGA Zone: 50 **Easting:** 423814 **Northing:** 7591389
Habitat: Plain
Soil: Red brown clay
Rock type: NA
Vegetation: *Acacia xiphophylla* tall open shrubland over *Triodia epactia* open hummock grassland with **Cenchrus setiger* scattered tussock grasses.
Veg Condition: Very Good
Fire Age: >10 years



Species List

Name	Cover (%)	Height (m)
**Cenchrus ciliaris*	0.5	0.3
**Cenchrus setiger*	1	0.3
**Lactuca serriola*	0.5	0.05
**Malvastrum americanum*	0.5	0.1
**Rumex vesicaria*	0.5	0.2
**Vachellia farnesiana*	0.5	0.05
Abutilon sp. Pilbara (W.R. Barker 2025)	0.5	0.2
Acacia xiphophylla	8	4.0
Amaranthus cuspidifolius	0.5	0.3
Boerhavia coccinea	0.5	0.05
Boerhavia repleta	0.5	0.05
Cynodon prostrata	0.5	0.05
Calotis plumulifera	0.5	0.1
Cleome viscosa	0.5	0.1
Cyperus squarrosus	0.5	0.05
Dactyloctenium radulans	0.5	0.05
Dysphania rhadinostachya subsp. *rhadinostachya*	0.5	0.1
Euphorbia biconvexa	0.5	0.2
Euphorbia boophthona	0.5	0.2
Maireana planifolia	0.5	0.3
Paspalidium clementii	0.5	0.1
Portulaca cyclophylla	0.5	0.05
Portulaca oleracea	0.5	0.05
Ptilotus axillaris	0.5	0.05
Ptilotus nobilis subsp. *nobilis*	0.5	0.4

Name	Cover (%)	Height (m)
Sclerolaena costata	0.5	0.2
Senna artemisioides subsp. *oligophylla*	0.5	0.5
Senna notabilis	0.5	0.3
Senna sp. Meekatharra (E. Bailey 1-26)	0.5	
Sida fibulifera	0.5	0.2
Streptoglossa sp.	0.5	0.05
Trianthema triquetrum	0.5	0.05
Triodia epactia	12	0.5

* denotes weed species
? denotes unconfirmed ID

Site: MH408
Location: Additional area **Type:** 50x50m Quadrat
Date: 2016-07-21 **Described by:** JA
MGA Zone: 50 **Easting:** 424862 **Northing:** 7591915
Habitat: Floodplain
Soil: Brown sandy clay loam
Rock type: NA
Vegetation: *Acacia synchonicia* tall open shrubland over *Triodia epactia* open hummock grassland with **Cenchrus setiger*, **C. ciliaris* very open tussock grassland.
Veg Condition: Good
Fire Age: >10 years

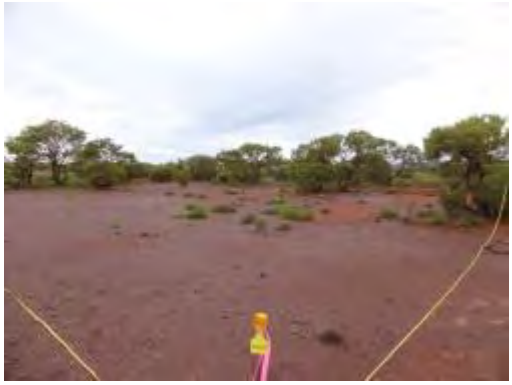
Species List

Name	Cover (%)	Height (m)
**Cenchrus ciliaris*	0.5	0.3
**Cenchrus setiger*	2	0.3
**Lactuca serriola*	0.5	0.1
Acacia synchronicia	2	2.0
Centipeda minima subsp. *macrocephala*	0.5	0.1
Dactyloctenium radulans	0.5	0.05
Dysphania rhadinostachya subsp. *rhadinostachya*	0.5	0.1
Euphorbia biconvexa	0.5	0.15
Euphorbia boophthona	0.5	0.5
Hibiscus brachychlaenus	0.5	0.5
Hybanthus aurantiacus	0.5	0.2
Lepidium pholidogynum	0.5	0.1
Phyllanthus erwinii	0.5	0.1
Pterocaulon sphacelatum	0.5	0.1
Pterocaulon sphaeranthoides	0.5	0.2
Ptilotus astrolasius	0.5	0.3
Ptilotus nobilis subsp. *nobilis*	0.5	0.05
Sclerolaena costata	0.5	0.15
Sclerolaena sp.	0.5	0.05
Senna notabilis	0.5	0.15
Sida arsiniata	0.5	0.15
Solanum cleistogamum	0.5	0.4
Sporobolus australasicus	0.5	0.1
Trianthema triquetrum	0.5	0.05
Triodia epactia	18	0.7

Name	Cover (%)	Height (m)
Triodia longiceps	0.5	0.8

* denotes weed species
? denotes unconfirmed ID

Site: MH409
Location: Additional area **Type:** 50x50m Quadrat
Date: 2016-07-22 **Described by:** JA
MGA Zone: 50 **Easting:** 423776 **Northing:** 7591914
Habitat: Plain
Soil: Reddish brown sandy clay loam
Rock type: Ironstone
Vegetation: *Acacia xiphophylla* tall shrubland over *Triodia epactia* very open hummock grassland with **Cenchrus* sp. very open tussock grassland.
Veg Condition: Very Good
Fire Age: >10 years



Species List

Name	Cover (%)	Height (m)
**Cenchrus ciliaris*	0.5	0.4
**Cenchrus setiger*	2	0.5
**Lactuca serriola*	0.5	0.85
**Malvastrum americanum*	0.5	0.4
**Rumex vesicaria*	0.5	0.15
**Vachellia farnesiana*	0.5	0.3
Abutilon sp. Pilbara (W.R. Barker 2025)	0.5	0.2
Acacia synchronicia	0.5	0.5
Acacia xiphophylla	15	4.5
Amaranthus cuspidifolius	0.5	0.1
Boerhavia coccinea	0.5	0.05
Bulbostylis barbata	0.5	0.1
Calandrinia sp.	0.5	0.05
Cucumis variabilis	0.5	0.15
Cyperus iria	0.5	0.1
Dactyloctenium radulans	0.5	0.1
Dysphania rhadinostachya subsp. *rhadinostachya*	0.5	0.1
Enchylaena tomentosa var. *tomentosa*	0.5	0.3
Enteropogon ramosus	0.5	0.4
Eragrostis leptocarpa	0.5	0.1
Eremophila forrestii subsp. *forrestii*	0.5	0.6
Euphorbia boophthona	0.5	0.1
Evolvulus alsinoides var. *villosicalyx*	0.5	0.15
Goodenia forrestii	0.5	0.15
Hibiscus sturtii var. *campylochlamys*	0.5	0.2

Name	Cover (%)	Height (m)
Ipomoea polymorpha	0.5	0.1
Lepidium pholidogynum	0.5	0.1
Phyllanthus erwinii	0.5	0.1
Portulaca oleracea	0.5	0.05
Ptilotus axillaris	0.5	0.05
Ptilotus gomphrenoides var. *gomphrenoides*	0.5	0.05
Ptilotus nobilis subsp. *nobilis*	0.5	0.4
Sclerolaena costata	0.5	0.2
Sclerolaena sp.	0.5	0.05
Senna artemisioides subsp. *oligophylla*	0.5	0.8
Sida fibulifera	0.5	0.1
Solanum cleistogamum	0.5	0.3
Sporobolus australasicus	0.5	0.1
Trianthema triquetrum	0.5	0.05
Triodia epactia	9	0.45
Triodia wiseana	0.5	0.4

* denotes weed species
? denotes unconfirmed ID

Site: MHJ301r
Location: North MJ **Type:** 50x50m Relevé
Date: 2016-05-08 **Described by:** DR/KMc
MGA Zone: 50 **Easting:** 419409 **Northing:** 7593550
Habitat: Hillslope
Soil: Red brown silty clay loam
Rock type: Ironstone
Vegetation: *Acacia bivenosa* open shrubland over *Triodia wiseana* open hummock grassland with *Cassytha capillaris* very open herbland.
Veg Condition: Very Good
Fire Age: >10 years

Species List

Name	Cover (%)	Height (m)
Acacia bivenosa	2	1.8
Acacia inaequilatera	0.5	1.8
Acacia ptychophylla	0.5	1.0
Aristida holathera var. *holathera*	0.5	0.4
Bonamia pilbarensis	0.5	0.1
Cassytha capillaris	3	
Cleome viscosa	0.5	0.1
Corchorus lasiocarpus subsp. *parvus*	0.5	0.1
Corymbia hamersleyana	0.5	4.5
Cymbopogon ambiguus	0.5	0.7
Dodonaea coriacea	0.5	0.4
Dysphania rhadinostachya subsp. *rhadinostachya*	0.5	0.1
Euphorbia australis var. *subtomentosa*	0.5	0.1
Gomphrena cunninghamii	0.5	0.25
Goodenia microptera	0.5	0.1
Goodenia stobbsiana	0.5	0.7
Gossypium australe	0.5	0.8
Grevillea wickhamii	0.5	3.0
Hakea chordophylla	0.5	2.1
Hybanthus aurantiacus	0.5	0.2
Mollugo molluginea	0.5	0.1
Oldenlandia crouchiana	0.5	0.15
Petalostylis labicheoides	0.5	1.0
Polygala glaucifolia	0.5	0.05
Ptilotus astrolasius	0.5	0.6

Name	Cover (%)	Height (m)
Ptilotus auriculifolius	0.5	0.6
Ptilotus axillaris	0.5	
Ptilotus calostachyus	0.5	1.0
Ptilotus fusiformis	0.5	0.4
Ptilotus nobilis subsp. *nobilis*	0.5	0.6
Senna glutinosa subsp. *glutinosa*	0.5	0.1
Senna notabilis	0.5	0.5
Sida sp. Pilbara (A.A. Mitchell PRP 1543)	0.5	0.5
Solanum cleistogamum	0.5	0.3
Solanum diversiflorum	0.5	0.35
Solanum horridum	0.5	0.35
Trachymene oleracea subsp. *oleracea*	0.5	0.8
Trichodesma zeylanicum var. *zeylanicum*	0.5	1.0
Triodia wiseana	25	0.4
Triumfetta clementii	0.5	0.5
Triumfetta maconochieana	0.5	0.8
Waltheria indica	0.5	0.5

* denotes weed species
? denotes unconfirmed ID

Site: MHJ302
Location: East side of Mesa J **Type:** 20x125m Quadrat
Date: 2016-04-29 **Described by:** JA/KMc
MGA Zone: 50 **Easting:** 419850 **Northing:** 7592641
Habitat: Plain
Soil: Red brown sandy loam
Rock type: Ironstone
Vegetation: *Corymbia hamersleyana* low open woodland over *Acacia bivenosa* tall open shrubland over *Triodia wiseana* and *T. epactia* hummock grassland.
Veg Condition: Excellent
Fire Age: >10 years

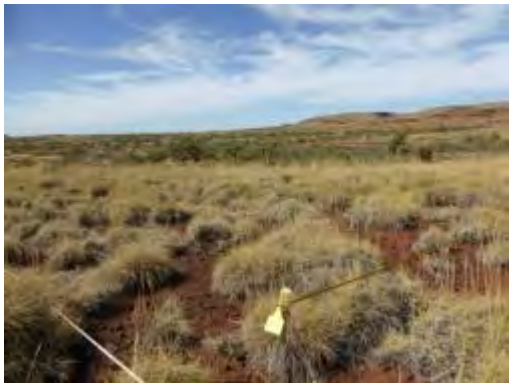
Species List

Name	Cover (%)	Height (m)
Abutilon sp. Pilbara (W.R. Barker 2025)	0.5	0.9
Acacia ancistrocarpa	0.5	1.1
Acacia bivenosa	5	2.2
Acacia inaequilatera	0.5	2.1
Acacia pyrifolia var. *pyrifolia*	0.5	2.5
Acacia trachycarpa	0.5	2.8
Bonamia erecta	0.5	0.3
Bulbostylis barbata	0.5	0.05
Cassytha capillaris	0.5	
Corchorus parviflorus	0.5	0.4
Corymbia hamersleyana	3	3.0
Cucumis variabilis	0.5	
Dysphania rhadinostachya subsp. *rhadinostachya*	0.5	0.3
Euphorbia australis var. *subtomentosa*	0.5	0.1
Euphorbia biconvexa	0.5	0.5
Euphorbia boophthona	0.5	0.25
Evolvulus alsinoides var. *villosicalyx*	0.5	0.15
Gomphrena cunninghamii	0.5	0.15
Goodenia forrestii	0.5	0.1
Goodenia microptera	0.5	0.4
Goodenia stobbsiana	0.5	0.15
Gossypium australe	0.5	0.7
Grevillea pyramidalis subsp. *leucadendron*	0.5	0.5
Grevillea wickhamii	0.5	0.6
Hakea chordophylla	0.5	1.8

Name	Cover (%)	Height (m)
Heliotropium tanythrix	0.5	0.1
Hibiscus sturtii var. *grandiflorus*	0.5	0.25
Indigofera monophylla	0.5	0.55
Isotropis atropurpurea	0.5	0.45
Jasminum didymum subsp. *lineare*	0.5	
Mollugo molluginea	0.5	0.05
Notoleptopus decaisnei var. Orbicularis (A.B. Craig 428)	0.5	0.15
Pentalepis trichodesmoides	0.5	0.25
Phyllanthus erwinii	0.5	0.15
Phyllanthus maderaspatensis	0.5	0.3
Polycarpaea longiflora	0.5	0.2
Pterocaulon sphaeranthoides	0.5	0.5
Ptilotus astrolasius	0.5	0.45
Ptilotus calostachyus	0.5	0.7
Ptilotus fusiformis	0.5	0.45
Ptilotus nobilis subsp. *nobilis*	0.5	1.1
Rhynchosia minima	0.5	
Scaevola spinescens	0.5	0.9
Senna notabilis	0.5	0.25
Sida sp. Pilbara (A.A. Mitchell PRP 1543)	0.5	0.3
Solanum cleistogamum	0.5	0.4
Solanum diversiflorum	0.5	0.3
Solanum horridum	0.5	0.15
Streptoglossa decurrens	0.5	0.5
Stylobasium spathulatum	0.5	1.0
Swainsona formosa	0.5	0.3
Trachymene oleracea subsp. *oleracea*	0.5	0.8
Tribulus macrocarpus	0.5	0.15
Trichodesma zeylanicum var. *zeylanicum*	0.5	1.2
Triodia epactia	2	0.6
Triodia wiseana	50	0.6
Triumfetta clementii	0.5	0.2

* denotes weed species
? denotes unconfirmed ID

Site: MHJ303
Location: Mesa J extension **Type:** 50x50m Quadrat
Date: 2016-04-29 **Described by:** DR/LV
MGA Zone: 50 **Easting:** 419455 **Northing:** 7592293
Habitat: Hillslope
Soil: Red brown silty clay loam
Rock type: CID
Vegetation: *Acacia bivenosa* scattered tall shrubs over *Senna notabilis* scattered low shrubs over *Triodia wiseana* and *T.* sp. Robe River (M.E. Trudgen et al. MET 12367) open hummock grassland.
Veg Condition: Very Good
Fire Age: No fire evident



Species List

Name	Cover (%)	Height (m)
Abutilon sp.	0.5	0.8
Acacia ancistrocarpa	0.5	0.5
Acacia bivenosa	1	2.1
Acacia inaequilatera	0.5	1.9
Acacia ptychophylla	0.5	0.9
Acacia tumida var. *pilbarensis*	0.5	0.8
Bonamia pilbarensis	0.5	0.01
Cleome viscosa	0.5	0.3
Corchorus lasiocarpus subsp. *parvus*	0.5	0.1
Corymbia hamersleyana	0.5	1.7
Dodonaea coriacea	0.5	0.3
Dysphania rhadinostachya subsp. *rhadinostachya*	0.5	0.1
Enneapogon caerulescens	0.5	0.3
Goodenia stobbsiana	0.5	1.2
Grevillea wickhamii	0.5	3.0
Hibiscus sturtii var. *campylochlamys*	0.5	0.1
Mollugo molluginea	0.5	0.1
Paspalidium clementii	0.5	0.1
Pentalepis trichodesmoides	0.5	0.3
Petalostylis labicheoides	0.5	1.5
Polycarpaea holtzei	0.5	0.02
Pterocaulon sp.	0.5	0.3
Ptilotus astrolasius	0.5	0.3
Ptilotus auriculifolius	0.5	0.4
Ptilotus axillaris	0.5	0.1

Name	Cover (%)	Height (m)
Ptilotus calostachyus	0.5	1.3
Ptilotus fusiformis	0.5	0.3
Ptilotus nobilis subsp. *nobilis*	0.5	0.6
Ptilotus obovatus	0.5	0.4
Rhynchosia minima	0.5	0.3
Senna notabilis	1	0.9
Senna venusta	1	0.6
Solanum horridum	0.5	0.1
Trachymene oleracea subsp. *oleracea*	0.5	0.8
Trichodesma zeylanicum var. *zeylanicum*	0.5	0.5
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	3	0.5
Triodia wiseana	25	0.6

* denotes weed species
? denotes unconfirmed ID

Site: MHJ304
Location: Mesa J extension **Type:** 50x50m Quadrat
Date: 2016-04-29 **Described by:** DR/LV
MGA Zone: 50 **Easting:** 419900 **Northing:** 7591977
Habitat: Hillslope
Soil: Red brown silty clay loam
Rock type: CID
Vegetation: *Acacia bivenosa* scattered shrubs over *Senna notabilis* scattered low shrubs *Triodia wiseana* open hummock grassland.
Veg Condition: Very Good
Fire Age: No fire evident

Species List

Name	Cover (%)	Height (m)
**Lactuca serriola*	0.5	0.6
Abutilon sp. Pilbara (W.R. Barker 2025)	0.5	0.4
Acacia ancistrocarpa	0.5	0.1
Acacia bivenosa	1	1.8
Acacia inaequilatera	0.5	2.8
Acacia tumida var. *pilbarensis*	0.5	0.1
Cassytha capillaris	0.5	0.5
Corymbia hamersleyana	0.5	0.35
Cymbopogon ambiguus	0.5	0.4
Dampiera candicans	0.5	0.4
Dysphania rhadinostachya subsp. *rhadinostachya*	0.5	0.2
Euphorbia schultzii	0.5	0.1
Goodenia microptera	0.5	0.15
Goodenia stobbsiana	0.5	0.25
Keraudrenia velutina subsp. *elliptica*	0.5	0.3
Lysiana casuarinae	0.5	2.0
Mollugo molluginea	0.5	0.1
Notoleptopus decaisnei var. Orbicularis (A.B. Craig 428)	0.5	0.15
Oldenlandia crouchiana	0.5	0.25
Petalostylis labicheoides	0.5	1.8
Ptilotus astrolasius	0.5	0.5
Ptilotus axillaris	0.5	0.1
Ptilotus fusiformis	0.5	0.3
Ptilotus nobilis subsp. *nobilis*	0.5	0.6
Ptilotus obovatus	0.5	0.5

Name	Cover (%)	Height (m)
Senna notabilis	1	0.5
Senna venusta	1	0.7
Solanum horridum	0.5	0.25
Streptoglossa bubakii	0.5	0.8
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	0.5	0.25
Trachymene oleracea subsp. *oleracea*	0.5	0.5
Trichodesma zeylanicum var. *zeylanicum*	0.5	0.4
Triodia wiseana	26	0.6
Triumfetta chaetocarpa	0.5	0.4

* denotes weed species
? denotes unconfirmed ID

Site: MHJ305
Location: Creek line in Mesa J **Type:** 20x125m Quadrat
Date: 2016-04-29 **Described by:** JA/KMc
MGA Zone: 50 **Easting:** 419638 **Northing:** 7592816
Habitat: Minor creek
Soil: Red brown sandy clay loam
Rock type: Shale
Vegetation: *Acacia pyrifolia* var. *pyrifolia* scattered tall shrubs over *Tephrosia rosea* var. Fortescue creeks (M.I.H. Brooker 2186) low shrubland over *Triodia epactia* scattered hummock grasses with *Ptilotus incanus* very open herbland.
Veg Condition: Very Good
Fire Age: >10 years

Species List

Name	Cover (%)	Height (m)
**Argemone ochroleuca* subsp. *ochroleuca*	0.5	0.8
**Cenchrus ciliaris*	0.5	0.45
Acacia bivenosa	0.5	1.8
Acacia pyrifolia var. *pyrifolia*	1	2.2
Alternanthera nana	0.5	0.15
Amaranthus undulatus	0.5	0.1
Boerhavia coccinea	0.5	0.1
Bulbostylis barbata	0.5	0.1
Capparis spinosa var. *nummularia*	0.5	0.45
Cleome viscosa	0.5	0.05
Corchorus lasiocarpus subsp. *parvus*	0.5	1.3
Cucumis variabilis	0.5	
Cymbopogon ambiguus	0.5	0.9
Cyperus cunninghamii subsp. *cunninghamii*	0.5	0.2
Dysphania rhadinostachya subsp. *rhadinostachya*	0.5	0.1
Eremophila longifolia	0.5	1.3
Eriachne aristidea	0.5	0.1
Eriachne mucronata	0.5	0.45
Eriachne pulchella subsp. *dominii*	0.5	0.5
Eriachne pulchella subsp. *pulchella*	0.5	0.5
Eulalia aurea	0.5	0.8
Euphorbia schultzii	0.5	0.1
Evolvulus alsinoides var. *villosicalyx*	0.5	0.2
Gomphrena cunninghamii	0.5	0.15

Name	Cover (%)	Height (m)
Goodenia forrestii	0.5	0.25
Grevillea pyramidalis subsp. *leucadendron*	0.5	4.0
Grevillea wickhamii	0.5	2.5
Hybanthus aurantiacus	0.5	0.25
Indigofera monophylla	0.5	0.65
Ipomoea muelleri	0.5	
Notoleptopus decaisnei var. Orbicularis (A.B. Craig 428)	0.5	0.1
Paspalidium clementii	0.5	0.15
Paspalidium tabulatum	0.5	0.4
Pentalepis trichodesmoides	0.5	0.1
Perotis rara	0.5	0.1
Petalostylis labicheoides	0.5	1.3
Phyllanthus maderaspatensis	0.5	0.15
Pluchea rubelliflora	0.5	0.2
Polycarpaea longiflora	0.5	0.15
Portulaca oleracea	0.5	0.1
Pterocaulon sphaeranthoides	0.5	0.3
Ptilotus astrolasius	0.5	0.4
Ptilotus fusiformis	0.5	0.2
Ptilotus incanus	5	0.3
Ptilotus nobilis subsp. *nobilis*	0.5	0.8
Scaevola spinescens	0.5	1.2
Sporobolus australasicus	0.5	0.15
Striga curviflora	0.5	0.15
Stylobasium spathulatum	0.5	1.1
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	8	0.8
Trachymene oleracea subsp. *oleracea*	1	0.65
Tribulus macrocarpus	0.5	0.2
Trichodesma zeylanicum var. *zeylanicum*	0.5	0.45
Triodia epactia	1	0.35
Triumfetta appendiculata	0.5	0.5
Waltheria indica	0.5	0.3

* denotes weed species
? denotes unconfirmed ID

Site: MHJ306
Location: Mesa J extension **Type:** 50x50m Quadrat
Date: 2016-04-29 **Described by:** DR/LV
MGA Zone: 50 **Easting:** 419181 **Northing:** 7592620
Habitat: Major creek
Soil: Red brown clay loam
Rock type: Ironstone
Vegetation: *Corymbia hamersleyana* scattered low trees over *Grevillea wickhamii* subsp. *hispidula* scattered tall shrubs over *Tephrosia rosea* var. Fortescue creeks (M.I.H. Brooker 2186) low open shrubland over *Triodia epactia* very open hummock grassland with **Cenchrus ciliaris* scattered tussock grasses.
Veg Condition: Good
Fire Age: No fire evident

Species List

Name	Cover (%)	Height (m)
**Argemone ochroleuca* subsp. *ochroleuca*	0.5	0.7
**Cenchrus ciliaris*	1	0.6
**Cenchrus setiger*	0.5	0.4
**Flaveria trinervia*	0.5	0.8
**Malvastrum americanum*	0.5	0.7
**Setaria verticillata*	0.5	0.4
Abutilon sp. Dioicum (A.A. Mitchell PRP 1618)	0.5	1.8
Acacia pyrifolia var. *pyrifolia*	0.5	1.6
Amaranthus mitchellii	0.5	0.4
Boerhavia coccinea	0.5	0.1
Boerhavia sp.	0.5	0.1
Bulbostylis barbata	0.5	0.1
Calocephalus knappii	0.5	0.2
Cleome viscosa	0.5	0.6
Corchorus lasiocarpus subsp. *parvus*	0.5	0.6
Corymbia hamersleyana	1	4.5
Cucumis melo	0.5	0.1
Cucumis variabilis	0.5	0.8
Cyperus vaginatus	0.5	0.3
Dysphania rhadinostachya subsp. *rhadinostachya*	0.5	0.1
Eriachne mucronata	0.5	0.3
Eriachne pulchella subsp. *dominii*	0.5	0.1
Eriachne tenuiculmis	0.5	0.7
Euphorbia schultzii	0.5	0.1

Name	Cover (%)	Height (m)
Evolvulus alsinoides var. *villosicalyx*	0.5	0.2
Gomphrena cunninghamii	0.5	0.3
Gossypium robinsonii	0.5	2.5
Grevillea pyramidalis subsp. *leucadendron*	0.5	2.1
Grevillea wickhamii	1	2.6
Hybanthus aurantiacus	0.5	0.3
Indigofera monophylla	0.5	0.5
Ipomoea muelleri	0.5	0.2
Jasminum didymum subsp. *lineare*	0.5	0.8
Mollugo molluginea	0.5	0.1
Notoleptopus decaisnei var. Orbicularis (A.B. Craig 428)	0.5	0.3
Paspalidium tabulatum	0.5	0.4
Pentalepis trichodesmoides	0.5	1.0
Phyllanthus maderaspatensis	0.5	0.5
Polycarpaea longiflora	0.5	0.2
Portulaca oleracea	0.5	0.1
Pterocaulon sphaeranthoides	0.5	0.8
Ptilotus astrolasius	0.5	0.4
Ptilotus axillaris	0.5	0.1
Ptilotus nobilis subsp. *nobilis*	0.5	0.9
Ptilotus obovatus	0.5	0.3
Rhynchosia bungarensis P4	0.5	0.4
Senna artemisioides subsp. *oligophylla*	0.5	1.3
Sporobolus australasicus	0.5	0.1
Streptoglossa adscendens	0.5	0.2
Stylobasium spathulatum	0.5	1.4
Swainsona formosa	0.5	0.3
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	7	0.8
Trachymene oleracea subsp. *oleracea*	0.5	0.5
Tribulus sp.	0.5	0.1
Trichodesma zeylanicum var. *zeylanicum*	0.5	1.2
Triodia epactia	7	0.5
Triumfetta appendiculata	0.5	1.1
Waltheria indica	0.5	0.5

* denotes weed species
? denotes unconfirmed ID

Site: MHJ309r
Location: Mesa J extension **Type:** 50x50m Relevé
Date: 2016-05-09 **Described by:** KMc/LV
MGA Zone: 50 **Easting:** 419307 **Northing:** 7593552
Habitat: Hillcrest
Soil: Red brown silty clay loam
Rock type: CID
Vegetation: *Acacia pruinocarpa* tall open shrubland over *Triodia wiseana* and *T.* sp. Robe River (M.E. Trudgen et al. MET 12367) open hummock grassland.
Veg Condition: Very Good
Fire Age: No fire evident

Species List

Name	Cover (%)	Height (m)
Acacia bivenosa	0.5	1.9
Acacia pruinocarpa	4	4.5
Dysphania rhadinostachya subsp. *rhadinostachya*	0.5	0.15
Eremophila fraseri subsp. *fraseri*	0.5	1.2
Eriachne pulchella subsp. *dominii*	0.5	0.1
Hibiscus coatesii	0.5	0.1
Jasminum didymum subsp. *lineare*	0.5	2.0
Mollugo molluginea	0.5	0.15
Petalostylis labicheoides	0.5	1.0
Ptilotus astrolasius	0.5	0.4
Ptilotus axillaris	0.5	0.1
Ptilotus calostachyus	0.5	1.2
Ptilotus nobilis subsp. *nobilis*	1	0.8
Sarcostemma viminale	0.5	1.1
Senna glutinosa subsp. *pruinosa*	0.5	0.8
Senna glutinosa subsp. *x luerssenii*	0.5	0.6
Sida sp. Pilbara (A.A. Mitchell PRP 1543)	0.5	0.5
Solanum horridum	0.5	0.2
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	3	0.4
Triodia wiseana	16	0.4

* denotes weed species
? denotes unconfirmed ID

Site: MHJr02
Location: Just south of mining ops **Type:** 50x50m Relevé
Date: 2016-05-08 **Described by:** DR
MGA Zone: 50 **Easting:** 419436 **Northing:** 7592984
Habitat: Plain
Soil: Red brown sandy loam
Rock type: Ironstone
Vegetation: *Corymbia hamersleyana* low open woodland over *Triodia wiseana* and *T. epactia* open hummock grassland.
Veg Condition: Excellent
Fire Age: >10 years

Species List

Name	Cover (%)	Height (m)
Acacia bivenosa	0.5	0.9
Acacia inaequilatera	0.5	2.2
Cleome viscosa	0.5	0.15
Corymbia hamersleyana	5	4.0
Eremophila longifolia	0.5	1.8
Grevillea pyramidalis subsp. *leucadendron*	0.5	2.5
Jasminum didymum subsp. *lineare*	0.5	
Paraneurachne muelleri	0.5	0.5
Phyllanthus maderaspatensis	0.5	0.5
Pterocaulon sp.	0.5	0.2
Ptilotus astrolasius	0.5	0.5
Ptilotus nobilis subsp. *nobilis*	0.5	0.8
Scaevola spinescens	0.5	0.7
Senna notabilis	0.5	0.2
Stylobasium spathulatum	0.5	1.5
Themeda triandra	0.5	0.9
Trichodesma zeylanicum var. *zeylanicum*	0.5	0.6
Triodia epactia	1	0.55
Triodia wiseana	17	0.5

* denotes weed species
? denotes unconfirmed ID

Site: MHJr04
Location: Southern end of Mesa J **Type:** 50x50m Relevé
Date: 2016-05-08 **Described by:** DR
MGA Zone: 50 **Easting:** 419835 **Northing:** 7591617
Habitat: Hillcrest
Soil: Red brown sandy loam
Rock type: Ironstone
Vegetation: *Acacia inaequilatera* scattered shrubs over *Triodia wiseana* open hummock grassland.
Veg Condition: Excellent
Fire Age: 2-5 years

Species List

Name	Cover (%)	Height (m)
Acacia inaequilatera	1	2.0
Bonamia pilbarensis	0.5	0.1
Corchorus lasiocarpus subsp. *parvus*	0.5	0.8
Corymbia hamersleyana	0.5	2.1
Dampiera candicans	0.5	0.3
Dysphania rhadinostachya subsp. *rhadinostachya*	0.5	0.1
Goodenia stobbsiana	0.5	0.6
Mollugo molluginea	0.5	0.05
Oldenlandia crouchiana	0.5	0.05
Petalostylis labicheoides	0.5	1.5
Ptilotus astrolasius	0.5	0.4
Ptilotus calostachyus	0.5	0.6
Ptilotus clementii	0.5	0.55
Ptilotus fusiformis	0.5	0.3
Ptilotus nobilis subsp. *nobilis*	0.5	0.15
Senna glutinosa subsp. *glutinosa*	0.5	1.3
Senna glutinosa subsp. *pruinosa*	0.5	1.0
Triodia wiseana	20	0.3

* denotes weed species
? denotes unconfirmed ID

Site: MHJr06
Location: Map 9 **Type:** 50x50m Relevé
Date: 2016-05-08 **Described by:** DR
MGA Zone: 50 **Easting:** 419716 **Northing:** 7591944
Habitat: Plain
Soil: Red brown sandy loam
Rock type: Ironstone
Vegetation: *Corymbia hamersleyana* low open woodland over *Acacia bivenosa* tall open shrubland over *Triodia wiseana* hummock grassland.
Veg Condition: Excellent
Fire Age: >10 years

Species List

Name	Cover (%)	Height (m)
Acacia bivenosa	9	2.2
Cassytha capillaris	0.5	0.5
Corchorus crozophorifolius	0.5	0.7
Corymbia hamersleyana	2	4.5
Dysphania rhadinostachya subsp. *rhadinostachya*	0.5	0.1
Gossypium australe	0.5	0.8
Hybanthus aurantiacus	0.5	0.3
Indigofera monophylla	0.5	0.6
Isotropis atropurpurea	0.5	0.6
Jasminum didymum subsp. *lineare*	0.5	1.5
Phyllanthus maderaspatensis	0.5	0.3
Pterocaulon sp.	0.5	0.3
Ptilotus clementii	0.5	0.5
Ptilotus fusiformis	0.5	0.5
Ptilotus nobilis subsp. *nobilis*	0.5	0.6
Rhynchosia minima	0.5	0.5
Scaevola spinescens	0.5	0.7
Senna glutinosa subsp. *glutinosa*	0.5	0.8
Senna notabilis	0.5	0.1
Trachymene oleracea subsp. *oleracea*	0.5	0.6
Trichodesma zeylanicum var. *zeylanicum*	0.5	1.1
Triodia wiseana	55	0.4

* denotes weed species
? denotes unconfirmed ID

Site: MHr200
Location: Map 7 **Type:** 50x50m Relevé
Date: 2016-05-09 **Described by:** DR
MGA Zone: NA **Easting:** 416632 **Northing:** 7593573
Habitat: Hillslope
Soil: Red brown clay loam
Rock type: Ironstone
Vegetation: *Acacia inaequilatera, Hakea chordophylla* tall open shrubland over *Triodia wiseana* and *T.* sp. Robe River (M.E. Trudgen et al. MET 12367) P3 open hummock grassland.
Veg Condition: Excellent
Fire Age: 5-10 years

Species List

Name	Cover (%)	Height (m)
Acacia bivenosa	0.5	0.6
Acacia inaequilatera	2	2.2
Corchorus lasiocarpus subsp. *parvus*	0.5	0.3
Dampiera candicans	0.5	0.3
Goodenia stobbsiana	0.5	0.2
Grevillea wickhamii	0.5	0.4
Hakea chordophylla	1	3.0
Senna glutinosa subsp. *glutinosa*	0.5	1.0
Sida sp. Pilbara (A.A. Mitchell PRP 1543)	0.5	0.4
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	1	0.6
Triodia wiseana	25	0.5

* denotes weed species
? denotes unconfirmed ID

Project: 14269-15 **Site:** Opportunistic

Species List

Name	Cover (%)	Height (m)
**Rumex vesicarius*	0.5	
**Argemone ochroleuca* subsp. *ochroleuca*	0.5	
**Cenchrus ciliaris*	0.5	
**Cenchrus setiger*	0.5	
**Chloris barbata*	0.5	
**Echinochloa colona*	0.5	
**Malvastrum americanum*	0.5	
**Ocimum basilicum*	0.5	
**Phoenix dactylifera*	0.5	
**Setaria verticillata*	0.5	
?*Ehretia saligna*	0.5	
Abutilon sp. Dioicum (A.A. Mitchell PRP 1618)	0.5	
Abutilon sp. Pilbara (W.R. Barker 2025)	0.5	
Acacia ampliceps	0.5	
Acacia ancistrocarpa	0.5	
Acacia colei var. *ileocarpa*	0.5	
Acacia elachantha	0.5	
Acacia inaequilatera	0.5	
Acacia maitlandii	0.5	
Acacia monticola	0.5	
Acacia orthocarpa	0.5	
Acacia pruinocarpa	0.5	
Acacia ptychophylla	0.5	
Acacia pyrifolia var. *pyrifolia*	0.5	
Acacia sclerosperma subsp. *sclerosperma*	0.5	
Acacia trachycarpa	0.5	
Acacia tumida var. *pilbarensis*	0.5	
Alternanthera nodiflora	0.5	
Amaranthus mitchellii	0.5	
Amaranthus undulatus	0.5	
Amphipogon sericeus	0.5	
Aristida holathera var. *holathera*	0.5	
Boerhavia paludosa	0.5	
Bonamia erecta	0.5	
Bonamia pilbarensis	0.5	
Cynodon prostrata	0.5	
Cajanus cinereus	0.5	
Capparis spinosa var. *nummularia*	0.5	
Carissa lanceolata	0.5	
Cheilanthes brownii	0.5	
Clerodendrum floribundum var. *angustifolium*	0.5	
Clerodendrum tomentosum var. *lanceolatum*	0.5	
Codonocarpus cotinifolius	0.5	

Name	Cover (%)	Height (m)
Corchorus tridens	0.5	
Corymbia candida	0.5	
Corymbia ferriticola	0.5	
Corymbia hamersleyana	0.5	
Crotalaria medicaginea var. *neglecta*	0.5	
Cullen pogonocarpum	0.5	
Cymbopogon ambiguus	0.5	
Cyperus hesperius	0.5	
Dampiera candicans	0.5	
Dodonaea coriacea	0.5	
Duperreya commixta	0.5	
Dysphania kalpari	0.5	
Dysphania rhadinostachya subsp. *rhadinostachya*	0.5	
Ehretia saligna	0.5	
Eragrostis dielsii	0.5	
Eremophila forrestii	0.5	
Eremophila fraseri subsp. *fraseri*	0.5	
Eremophila longifolia	0.5	
Eriachne aristidea	0.5	
Euphorbia australis var. *subtomentosa*	0.5	
Euphorbia boophthona	0.5	
Euphorbia schultzii	0.5	
Evolvulus alsinoides var. *villosicalyx*	0.5	
Ficus aculeata var. *aculeata*	0.5	
Ficus brachypoda	0.5	
Flueggea virosa	0.5	
Flueggea virosa subsp. *melanthesoides*	0.5	
Gomphrena cunninghamii	0.5	
Goodenia forrestii	0.5	
Goodenia lamprosperma	0.5	
Goodenia microptera	0.5	
Gossypium australe	0.5	
Gossypium robinsonii	0.5	
Heliotropium heteranthum	0.5	
Hibiscus coatesii	0.5	
Hibiscus goldsworthii	0.5	
Hibiscus sturtii var. *grandiflorus*	0.5	
Indigofera colutea	0.5	
Indigofera monophylla	0.5	
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301) P3	0.5	
Isotropis atropurpurea	0.5	
Jasminum didymum subsp. *lineare*	0.5	
Lobelia arnhemiaca	0.5	
Lobelia heterophylla	0.5	
Melaleuca linophylla	0.5	

Name	Cover (%)	Height (m)
Neptunia dimorphantha	0.5	
Nicotiana benthamiana	0.5	
Nicotiana occidentalis	0.5	
Paraneurachne muelleri	0.5	
Paspalidium tabulatum	0.5	
Pentalepis trichodesmoides	0.5	
Petalostylis labicheoides	0.5	
Polycarpaea corymbosa	0.5	
Polycarpaea holtzei	0.5	
Polycarpaea longiflora	0.5	
Pterocaulon sphaeranthoides	0.5	
Ptilotus aervoides	0.5	
Ptilotus auriculifolius	0.5	
Ptilotus calostachyus	0.5	
Ptilotus clementii	0.5	
Ptilotus fusiformis	0.5	
Ptilotus incanus	0.5	
Ptilotus nobilis subsp. *nobilis*	0.5	
Rhodanthe margarethae	0.5	
Rhynchosia bungarensis P4	0.5	
Rhynchosia minima	0.5	
Salsola australis	0.5	
Sarcostemma viminale	0.5	
Sauropus crassifolius	0.5	
Schizachyrium fragile	0.5	
Schoenoplectus subulatus	0.5	
Senna artemisioides subsp. *helmsii*	0.5	
Senna artemisioides subsp. *oligophylla*	0.5	
Senna glutinosa subsp. *pruinosa*	0.5	
Senna sp. Meekatharra (E. Bailey 1-26)	0.5	
Senna venusta	0.5	
Sesbania formosa	0.5	
Sida echinocarpa	0.5	
Sida sp. Articulation below (A.A. Mitchell PRP 1605)	0.5	
Sida sp. Pilbara (A.A. Mitchell PRP 1543)	0.5	
Sporobolus australasicus	0.5	
Stemodia grossa	0.5	
Streptoglossa decurrens	0.5	
Swainsona formosa	0.5	
Tephrosia sp. Bungaroo Creek (M.E. Trudgen 11601)	0.5	
Tephrosia supina	0.5	
Tephrosia uniovulata	0.5	
Tinospora smilacina	0.5	
Trianthema triquetrum	0.5	
Tribulus hirsutus	0.5	

Name	Cover (%)	Height (m)
Tribulus macrocarpus	0.5	
Tribulus platypterus	0.5	
Tribulus suberosus	0.5	
Triodia angusta	0.5	
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	0.5	
Triumfetta johnstonii	0.5	
Typha domingensis	0.5	
Vigna lanceolata var. *lanceolata*	0.5	
Waltheria indica	0.5	

* denotes weed species
? denotes unconfirmed ID

Appendix K: Vegetation Condition Mapping

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414000 415000 416000 417000 418000 419000 420000 421000

7600000 7599000 7598000 7597000 7596000

Legend

- Survey Site
- Railway
- Main Road
- River/Creek
- Mesa H Survey Area

Vegetation Condition

- Excellent
- Very Good
- Good
- Poor
- Very Poor
- Disturbed

K.1A
K.1B
K.1C

MH358 MH333r MH336 MH310 MH309r MH306 MH368 MH331 MH400 MH307 MH343 MH308 MH395 MH05 MH21 MH20 MH361 MH359 MH22 MH06 MH100 MH31 MH203 MH39 MH40 MH200 MH32 MH363 MH342 MH204 MH397 MH337r MH398 MH324 MH354 MH01 MH345 MH305 MH329 MH325 MH327 MH300 MH29 MH346 MH399r MH326 MH332 MH335 MH02 MH328 MH26 MH330 MH353 MH370 MH321 MH18 MH44 MH318 MH313 MH19 MH41 MH311r MH43 MH38 MH360r MH07 MH316

Robe River Mining Co. Pty Ltd

Mesa H – Level 2 Vegetation and Flora Assessment, May 2016

Figure K.1A: Vegetation Condition Mapping

Datum: GDA 1994 - Projection: MGA Zone 50

0 200 400 600 800 1,000 metres

N

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Author: D. Roocke | Drawn: T. Pedersen | Date: 09-08-2017 | Figure Ref: 14269-16-BIDR-2Rev1_170809_FigK1_VegCond

414000 415000 416000 417000 418000 419000 420000 421000

7596000 7595000 7594000 7593000 7592000 7591000

MH316 MH394 MH322 MH319 MH07 MH357 MH106 MH303 MH301 MH37 MH104 MH103 MH317 MH27 MH35 MH34 MH33 MH36 MH315 MH365 MH42 MH17 MH312 MH101 MH11 MH302 MH356 MH320 MH12 MH09 MH10 MH105 MHr200 MHJ309r MHJ301r MH396 MHJr02 MH25 MH314 MHJ305 MHJ306 MHJ302 MH334r MH30 MH24 MH28 MHJ303 MH364 MH352 MHJr06 MHJ304 MH377 MH374 MH338 MHJr04 MH376 MH375r BA10

K.1A K.1B K.1C

Legend

- Survey Site
- Railway
- Main Road
- River/Creek
- Mesa H Survey Area

Vegetation Condition

- Excellent
- Very Good
- Good
- Poor
- Very Poor
- Disturbed

Robe River Mining Co. Pty Ltd

Mesa H – Level 2 Vegetation and Flora Assessment, May 2016

Figure K.1B: Vegetation Condition Mapping

Datum: GDA 1994 - Projection: MGA Zone 50

0 200 400 600 800 1,000 metres

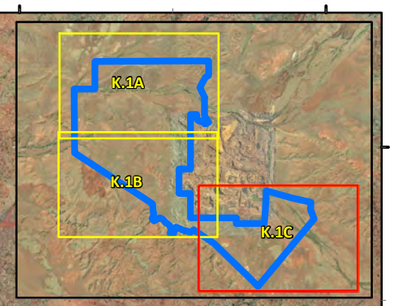
N

astron delivering environmental intelligence™

Author: D. Roocke | Drawn: T. Pedersen | Date: 09-08-2017 | Figure Ref: 14269-16-BIDR-2Rev1_170809_FigK1_VegCond

421000 422000 423000 424000 425000 426000 427000 428000

7593000 7592000 7591000 7590000 7589000



MH393 MH401 MH392 MH371 MH373 MH409 MH408 MH344 MH338 BA32 BA21 BA07 BA22 MH407 BA18 BA111 MH350 BA10 MH402 BA42A BA219 MH348 BA210 BA209 MH403 MH406 MH404 BADRr05 BUN06 BAKM15 MH405 MH339 GBR23

Legend

- Survey Site
- Railway
- Main Road
- River/Creek
- Mesa H Survey Area

Vegetation Condition

- Excellent
- Very Good
- Good
- Poor
- Very Poor
- Disturbed

Robe River Mining Co. Pty Ltd

Mesa H – Level 2 Vegetation and Flora Assessment, May 2016

Figure K.1C: Vegetation Condition Mapping

Datum: GDA 1994 - Projection: MGA Zone 50

0 200 400 600 800 1,000 metres

N

astron delivering environmental intelligence™

Author: D. Roocke | Drawn: T. Pedersen | Date: 09-08-2017 | Figure Ref: 14269-16-BIDR-2Rev1_170809_FigK1_VegCond

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Appendix L: Floristic Analysis

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1 Floristic Analysis

1.1 Sampling Effort

Sampling effort was assessed using a species accumulation curve and modelled estimates of the total species pool. Species accumulation curves are created by randomly sampling an incremental number of samples, and plotting the mean number of species sampled at each sample size. Species estimators are particular statistical models of species accumulation which are employed to estimate the total species pool available. Four different species estimators were compared: Chao 2, Jackknife 1, Jacknife 2, and Bootstrap (Colwell and Coddington 1994). All analysis was performed in R 3.2.1 (R Development Core Team 2015) using the package "Vegan".

1.2 Vegetation Classification

Similarity amongst vegetation quadrats was assessed using a dendogram which was based on Sorensen's index of Similarity. The dendogram was constructed using the UPGMA (Unweighted Pair Group Method with Arithmetic Mean) method, within Primer. Significant clusters of samples were identified using the Simprof test (Clarke, Somerfield, and Gorley 2008). In order to understand the regional context of the current survey, a separate analysis was carried out to include the following surveys: Astron Environmental Services (2016a, 2016b) and Biota Environmental Sciences (2006, 2007, 2012). Owing to the size of the larger dendogram illustrating broader context, it is not displayed here.

1.3 Floristic Community Groups

1.3.1 Sampling Effort

A total of 254 species from the current survey were included in the floristic analysis. Only quadrat and relevé data was included (opportunistic records were excluded) and names not confirmed to species level were removed from the analysis. The species accumulation curve indicates that the total number of species has reached an asymptote, and that sampling has been near-exhaustive (Figure L.1). This is highlighted by the fact that the final 10% increase in sampling effort only led to a 2% increase in species sampled.

The species estimators suggest that there were between 276 and 308 species available in the pool at the time of the surveys. This suggests that between 83% and 92% of the total species pool has been sampled from quadrats and relevés (Table L.1). Including opportunistic observations, 310 species were recorded, indicating that 100% of the potential total species pool available at the time of the surveys was observed. Given the dry conditions for some of the surveys it is possible that the entire species pool may be higher in better seasonal conditions.

Table L.1: Total number of taxa sampled in comparison to estimates of the total species pool based on several models.

Observed		Estimated			
		Chao2	Jackknife 1	Jackknife 2	Bootstrap
Species	254	282.7	296.7	307.8	275.6
Est. % sampled		89.8	85.6	82.5	92.2

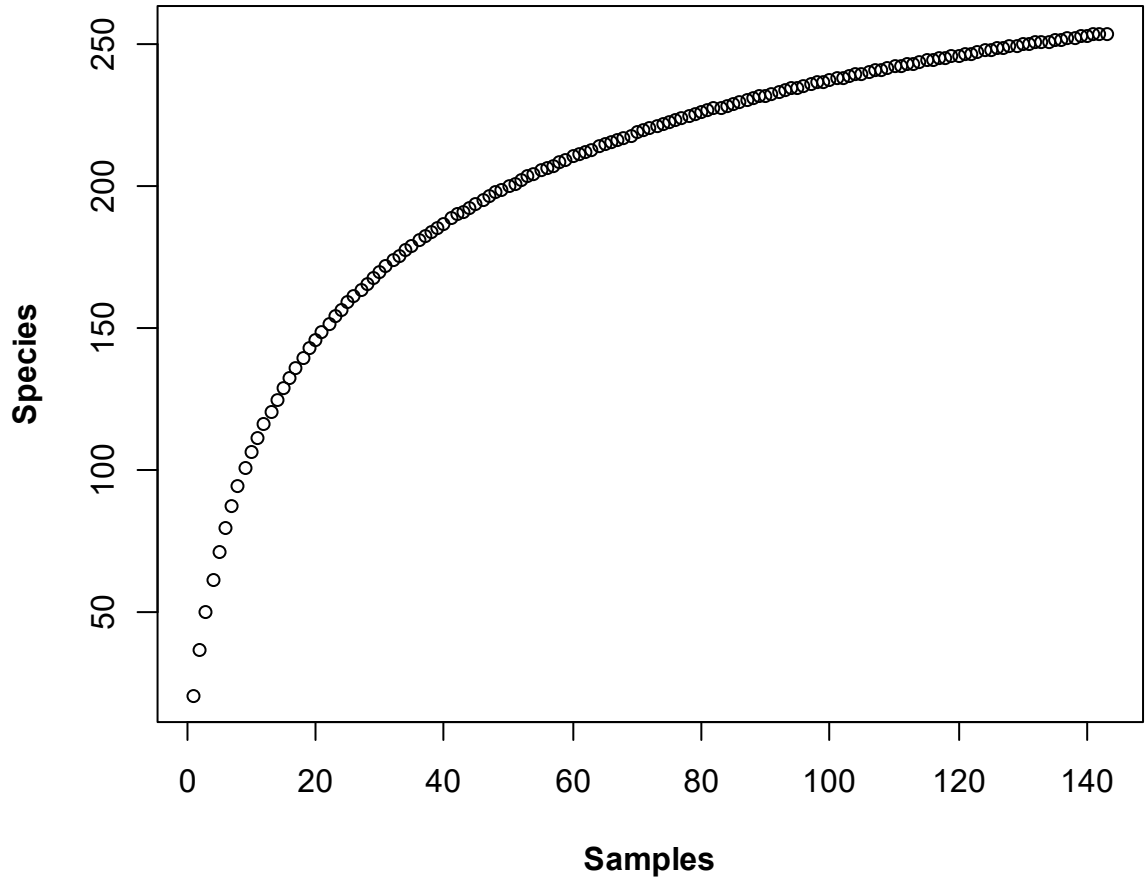

Figure L.1: Species accumulation curve for all Astron quadrats and relevés employed in the 2016 survey.

1.3.2 Vegetation Classification

Dendogram production combined with the Simprof statistical test for the current survey led to the identification of 32 distinct floristic clusters (Figure L2). Of these clusters, six were formed by individual samples from the current survey: MH27, MH302, MH325, MH350, MH357 and MH375r. Clusters showed some pattern of grouping according to the structural vegetation associations, as well as similar landforms.

Analysis of the clusters within a regional context led to identification of 110 significant clusters. Twenty two other significant clusters which were made up only of quadrats/relevés from the current survey were also identified. Of these clusters, four were formed by individual samples from the current survey: MH18, MH203, MH302 and MH315. Most of these clusters aligned with the structural vegetation associations; where they differed it was typically due to structural differences between the survey sites. As nearly half of the significant clusters were from the current survey it indicates that the survey area may be somewhat unique regionally, with vegetation that is floristically different to that in the broader region.

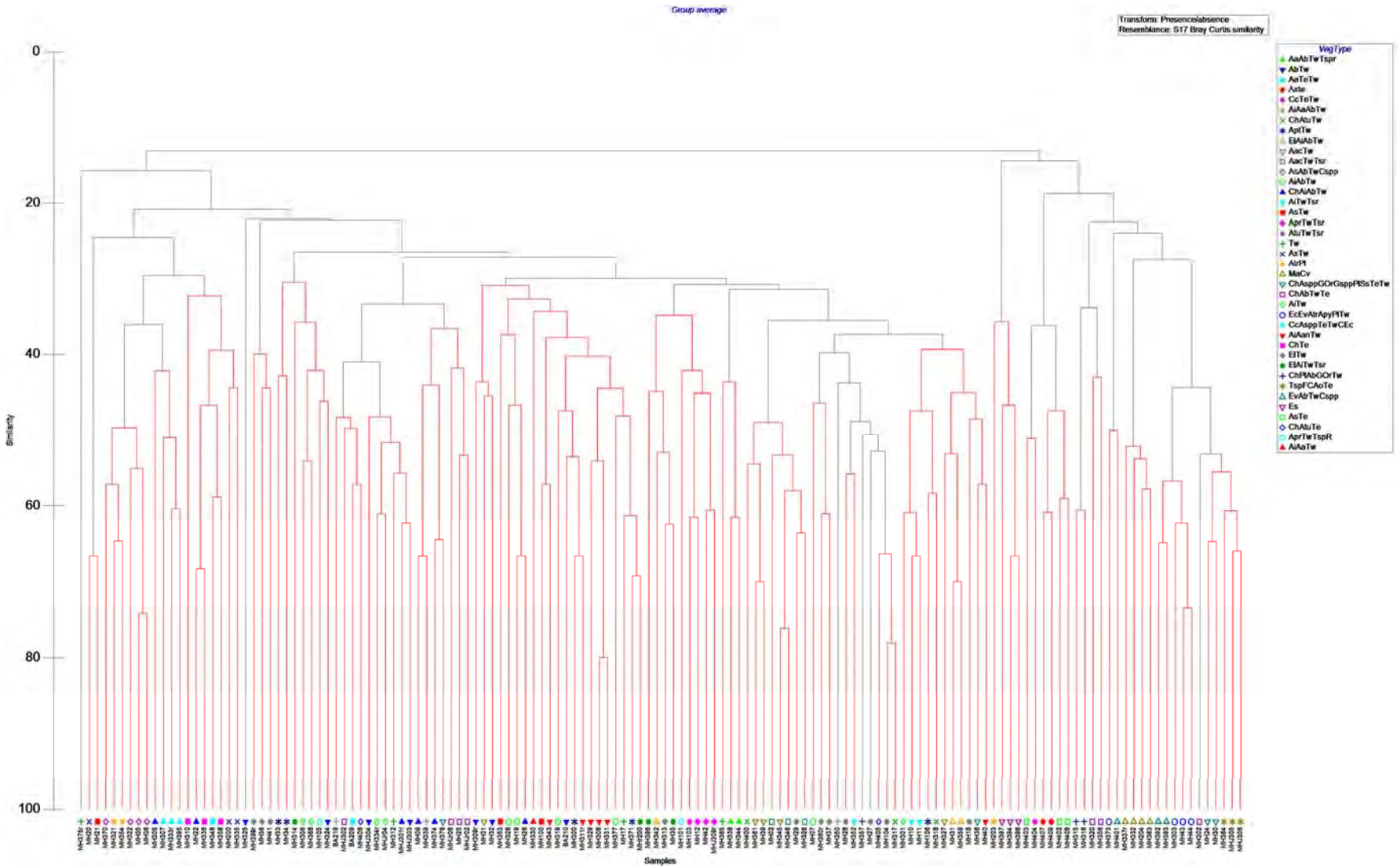

Figure L2: Dendrogram showing relationship between current survey quadrats and relevés according to the degree of shared species (Sorensen's Index). Significant clusters are distinguished by solid black lines.

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Appendix M: Vascular Flora Species List and Site x Species Matrix

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Table M.1: Vascular flora species list for the survey area.

Family	Species Name	Conservation Status	Weed
Aizoaceae	*Trianthema cusackianum*		
	Trianthema pilosum		
	Trianthema triquetrum		
Amaranthaceae	*Aerva javanica*		*
	Alternanthera nana		
	Alternanthera nodiflora		
	Amaranthus cuspidifolius		
	Amaranthus mitchellii		
	Amaranthus undulatus		
	Gomphrena cunninghamii		
	Ptilotus aervoides		
	Ptilotus appendiculatus		
	Ptilotus astrolasius		
	Ptilotus auriculifolius		
	Ptilotus axillaris		
	Ptilotus calostachyus		
	Ptilotus clementii		
	Ptilotus fusiformis		
	Ptilotus gomphrenoides var. *gomphrenoides*		
	Ptilotus incanus		
	Ptilotus nobilis subsp. *nobilis*		
	Ptilotus obovatus		
	Ptilotus sp.		
Apocynaceae	*Carissa lanceolata*		
	Cynanchum floribundum		
	Cynanchum pedunculatum		
	Rhyncharrhena linearis		
	Sarcostemma viminale		
Araliaceae	*Trachymene oleracea* subsp. *oleracea*		
Arecaceae	*Phoenix dactylifera*		*
Asteraceae	*Bidens bipinnata*		*
	Calocephalus knappii		
	Calotis hispidula		
	Calotis plumulifera		
	Centipeda minima subsp. *macrocephala*		
	Flaveria trinervia		*
	Helichrysum luteoalbum		
	Ixiochlamys cuneifolia		

Family	Species Name	Conservation Status	Weed
Asteraceae	*Lactuca serriola*		*
	Pentalepis trichodesmoides		
	Pluchea dentex		
	Pluchea rubelliflora		
	Pluchea sp.		
	Pterocaulon sp.		
	Pterocaulon sphacelatum		
	Pterocaulon sphaeranthoides		
	Rhodanthe margarethae		
	Sonchus oleraceus		*
	Streptoglossa adscendens		
	Streptoglossa bubakii		
	Streptoglossa decurrens		
	Streptoglossa liatroides		
	Streptoglossa sp.		
Boraginaceae	*?Ehretia saligna*		
	Ehretia saligna		
	Heliotropium heteranthum		
	Heliotropium ovalifolium		
	Heliotropium pachyphyllum		
	Heliotropium tanythrix		
	Trichodesma zeylanicum var. *zeylanicum*		
Brassicaceae	*Lepidium pholidogynum*		
Campanulaceae	*Lobelia arnhemiaca*		
	Lobelia heterophylla		
	Lobelia sp.		
	Wahlenbergia tumidifructa		
Capparaceae	*Capparis spinosa* var. *nummularia*		
Caryophyllaceae	*Polycarpaea corymbosa*		
	Polycarpaea holtzei		
	Polycarpaea longiflora		
Celastraceae	*Stackhousia muricata*		
	Stackhousia muricata subsp. annual (W.R. Barker 2172)		
Chenopodiaceae	*Dysphania kalpari*		
	Dysphania melanocarpa		
	Dysphania rhadinostachya subsp. *rhadinostachya*		
	Dysphania sp.		
	Enchylaena tomentosa var. *tomentosa*		
	Maireana melanocoma		

Family	Species Name	Conservation Status	Weed
Chenopodiaceae	*Maireana planifolia*		
	Rhagodia eremaea		
	Salsola australis		
	Sclerolaena costata		
	Sclerolaena sp.		
Cleomaceae	*Cleome viscosa*		
Combretaceae	*Terminalia canescens*		
Convolvulaceae	*Bonamia erecta*		
	Bonamia pilbarensis		
	Duperreya commixta		
	Evolvulus alsinoides var. *villosicalyx*		
	Ipomoea muelleri		
	Ipomoea polymorpha		
	Polymeria ambigua		
	Polymeria sp.		
Cucurbitaceae	*Citrullus colocynthis*		*
	Cucumis melo		
	Cucumis variabilis		
Cyperaceae	*Bulbostylis barbata*		
	Cyperus cunninghamii subsp. *cunninghamii*		
	Cyperus hesperius		
	Cyperus iria		
	Cyperus squarrosus		
	Cyperus vaginatus		
	Eleocharis geniculata		
	Fimbristylis dichotoma		
	Schoenoplectus subulatus		
Euphorbiaceae	*Adriana tomentosa*		
	Euphorbia australis		
	Euphorbia australis var. *hispidula*		
	Euphorbia australis var. *subtomentosa*		
	Euphorbia biconvexa		
	Euphorbia boophthona		
	Euphorbia boophthona / tannensis		
	Euphorbia careyi		
	Euphorbia hirta		*
	Euphorbia schultzii		
	Euphorbia sp.		
	Euphorbia tannensis		

Family	Species Name	Conservation Status	Weed
Euphorbiaceae	*Euphorbia vaccaria var. vaccaria*		
Fabaceae	*Acacia ?elachantha*		
	Acacia ?orthocarpa		
	Acacia acradenia		
	Acacia ampliceps		
	Acacia ancistrocarpa		
	Acacia ancistrocarpa x *ptychophylla*		
	Acacia atkinsiana		
	Acacia bivenosa		
	Acacia colei var. *ileocarpa*		
	Acacia elachantha		
	Acacia inaequilatera		
	Acacia maitlandii		
	Acacia monticola		
	Acacia orthocarpa		
	Acacia pruinocarpa		
	Acacia ptychophylla		
	Acacia pyrifolia var. *pyrifolia*		
	Acacia sclerosperma subsp. *sclerosperma*		
	Acacia sp.		
	Acacia synchronicia		
	Acacia trachycarpa		
	Acacia trachycarpa x *tumida* var. *pilbarensis*		
	Acacia tumida var. *pilbarensis*		
	Acacia xiphophylla		
	Cajanus cinereus		
	Crotalaria ?novae-hollandiae		
	Crotalaria medicaginea var. *neglecta*		
	Cullen leucochaites		
	Cullen martinii		
	Cullen pogonocarpum		
	Indigofera boviperda		
	Indigofera colutea		
	Indigofera linnaei		
	Indigofera monophylla		
	Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	P3	
	Indigofera trita		
	Isotropis atropurpurea		
	Neptunia dimorphantha		

Family	Species Name	Conservation Status	Weed
Fabaceae	*Petalostylis labicheoides*		
	Rhynchosia bungarensis	P4	
	Rhynchosia minima		
	Senna artemisioides subsp. *helmsii*		
	Senna artemisioides subsp. *oligophylla*		
	Senna ferraria		
	Senna glutinosa subsp. *glutinosa*		
	Senna glutinosa subsp. *pruinosa*		
	Senna glutinosa subsp. x *luerssenii*		
	Senna notabilis		
	Senna sp. Meekatharra (E. Bailey 1-26)		
	Senna stricta		
	Senna venusta		
	Sesbania formosa		
	Swainsona formosa		
	Swainsona sp.		
	Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)		
	Tephrosia sp. B Kimberley Flora (C.A. Gardner 7300)		
	Tephrosia sp. Bungaroo Creek (M.E. Trudgen 11601)		
	Tephrosia sp. Fortescue (A.A. Mitchell 606)		
	Tephrosia supina		
	Tephrosia uniovulata		
	Tephrosia virens		
	Vigna lanceolata var. *lanceolata*		
	Vachellia farnesiana		*
Goodeniaceae	*Dampiera candicans*		
	Goodenia forrestii		
	Goodenia lamprosperma		
	Goodenia microptera		
	Goodenia stobbsiana		
	Scaevola ?parvifolia		
	Scaevola spinescens		
Gyrostemonaceae	*Codonocarpus cotinifolius*		
Lamiaceae	*Ocimum basilicum*		*
	Clerodendrum floribundum var. *angustifolium*		
	Clerodendrum sp.		
	Clerodendrum tomentosum var. *lanceolatum*		

Family	Species Name	Conservation Status	Weed
Lauraceae	*Cassytha capillaris*		
Loranthaceae	*Amyema preissii*		
	Lysiana casuarinae		
Malvaceae	*Abutilon lepidum*		
	Abutilon leucopetalum		
	Abutilon sp.		
	Abutilon sp. Dioicum (A.A. Mitchell PRP 1618)		
	Abutilon sp. Pilbara (W.R. Barker 2025)		
	Corchorus ?crozophorifolius		
	Corchorus crozophorifolius		
	Corchorus lasiocarpus subsp. *parvus*		
	Corchorus parviflorus		
	Corchorus sidoides		
	Corchorus sp.		
	Corchorus tridens		
	Gossypium australe		
	Gossypium robinsonii		
	Hibiscus brachychlaenus		
	Hibiscus coatesii		
	Hibiscus goldsworthii		
	Hibiscus leptocladus		
	Hibiscus sp.		
	Hibiscus sturtii		
	Hibiscus sturtii var. *campylochlamys*		
	Hibiscus sturtii var. *grandiflorus*		
	Keraudrenia sp.		
	Keraudrenia velutina subsp. *elliptica*		
	Malvastrum americanum		*
	Melhania oblongifolia		
	Sida arenicola		
	Sida arsiniata		
	Sida cardiophylla		
	Sida echinocarpa		
	Sida fibulifera		
	Sida rohlenae subsp. *rohlenae*		
	Sida sp. Articulation below (A.A. Mitchell PRP 1605)		
	Sida sp. Pilbara (A.A. Mitchell PRP 1543)		
	Triumfetta ?chaetocarpa		
	Triumfetta appendiculata		

Family	Species Name	Conservation Status	Weed
Malvaceae	*Triumfetta chaetocarpa*		
	Triumfetta clementii		
	Triumfetta johnstonii		
	Triumfetta maconochieana		
	Triumfetta sp.		
	Waltheria indica		
Marsileaceae	*Marsilea* sp.		
Menispermaceae	*Tinospora smilacina*		
Molluginaceae	*Mollugo molluginea*		
Moraceae	*Ficus aculeata* var. *indecora*		
	Ficus brachypoda		
Myrtaceae	*Corymbia candida*		
	Corymbia ferriticola		
	Corymbia hamersleyana		
	Eucalyptus camaldulensis subsp. *refulgens*		
	Eucalyptus leucophloia subsp. *leucophloia*		
	Eucalyptus sp.		
	Eucalyptus victrix		
	Melaleuca argentea		
	Melaleuca glomerata		
	Melaleuca linophylla		
Nyctaginaceae	*Boerhavia coccinea*		
	Boerhavia paludosa		
	Boerhavia repleta		
	Boerhavia sp.		
Oleaceae	*Jasminum didymum* subsp. *lineare*		
Orobanchaceae	*Striga curviflora*		
Papaveraceae	*Argemone ochroleuca* subsp. *ochroleuca*		*
Passifloraceae	*Passiflora foetida* var. *hispida*		*
Phyllanthaceae	*Flueggea virosa*		
	Flueggea virosa subsp. melanthesoides		
	Notoleptopus decaisnei var. Orbicularis (A.B. Craig 428)		
	Phyllanthus erwinii		
	Phyllanthus maderaspatensis		
	Phyllanthus sp.		
	Sauropus crassifolius		
Plantaginaceae	*Stemodia grossa*		
Poaceae	*Amphipogon sericeus*		
	Aristida contorta		

Family	Species Name	Conservation Status	Weed
Poaceae	*Aristida holathera* var. *holathera*		
	Brachyachne prostrata		
	Cenchrus ciliaris		*
	Cenchrus setiger		*
	Cenchrus sp.		
	Chloris barbata		*
	Cymbopogon ambiguus		
	Cynodon dactylon		*
	Dactyloctenium radulans		
	Echinochloa colona		*
	Enneapogon caerulescens		
	Enteropogon ramosus		
	Eragrostis dielsii		
	Eragrostis eriopoda		
	Eragrostis leptocarpa		
	Eragrostis pergracilis		
	Eriachne aristidea		
	Eriachne mucronata		
	Eriachne pulchella subsp. *dominii*		
	Eriachne pulchella subsp. *pulchella*		
	Eriachne sp.		
	Eriachne tenuiculmis		
	Eulalia aurea		
	Paraneurachne muelleri		
	Paspalidium ?clementii		
	Paspalidium clementii		
	Paspalidium sp.		
	Paspalidium tabulatum		
	Perotis rara		
	Schizachyrium fragile		
	Setaria verticillata		*
	Sporobolus australasicus		
	Themeda triandra		
	Triodia angusta		
	Triodia epactia		
	Triodia longiceps		
	Triodia sp. Robe River (M.E. Trudgen et al. MET 12367)	P3	
	Triodia wiseana		
Polygalaceae	*Polygala glaucifolia*		

Family	Species Name	Conservation Status	Weed
Polygonaceae	*Rumex vesicaria*		*
Portulacaceae	*Calandrinia* sp.		
	Portulaca cyclophylla		
	Portulaca oleracea		
Proteaceae	*Grevillea pyramidalis* subsp. *leucadendron*		
	Grevillea wickhamii		
	Hakea chordophylla		
	Hakea lorea subsp. *lorea*		
Pteridaceae	*Cheilanthes brownii*		
	Cheilanthes sieberi subsp. *sieberi*		
Rubiaceae	*Oldenlandia crouchiana*		
	Synaptantha tillaeacea		
Sapindaceae	*Dodonaea coriacea*		
Scrophulariaceae	*Eremophila forrestii*		
	Eremophila forrestii subsp. *forrestii*		
	Eremophila fraseri subsp. *fraseri*		
	Eremophila longifolia		
Solanaceae	*Nicotiana benthamiana*		
	Nicotiana occidentalis		
	Solanum ?cleistogamum		
	Solanum cleistogamum		
	Solanum diversiflorum		
	Solanum elatius		
	Solanum gabrielae		
	Solanum horridum		
	Solanum lasiophyllum		
Surianaceae	*Stylobasium spathulatum*		
Thymelaeaceae	*Pimelea ammocharis*		
Typhaceae	*Typha domingensis*		
Violaceae	*Hybanthus aurantiacus*		
Zygophyllaceae	*Tribulus ?occidentalis*		
	Tribulus hirsutus		
	Tribulus macrocarpus		
	Tribulus platypterus		
	Tribulus sp.		
	Tribulus suberosus		
	Tribulus terrestris		*

Table M.2: Site by species matrix for the survey area.

Species	BA209	BA210	BA219	MH01	MH02	MH05	MH06	MH07	MH09	MH10	MH100	MH101	MH103	MH104	MH105	MH106	MH11	MH12	MH17	MH18	MH19	MH20	MH200	MH203	MH204	MH21	MH22	MH24	MH25	MH26	MH27	MH28	MH29	MH30	MH300	MH301	MH302	MH303	MH305	MH306	MH307	MH308	MH309r	MH31	MH310	MH311r	MH312	MH313	MH314	MH315	MH316	MH317
**Argemone ochroleuca* subsp. *ochroleuca*																												0.5									0.5																
**Cenchrus ciliaris*						1	2				0.5												0.5		0.5		0.5	0.5						2			0.5	0.5			0.5				0.5							
**Cenchrus setiger*						0.5	0.5															0.5		0.5		0.5								0.5			1	32			0.5											
**Chloris barbata*																																																				
**Citrullus colocynthis*																																																				
**Cynodon dactylon*																																																				
**Echinochloa colona*																																						0.5															
**Euphorbia hirta*																									0.5													0.5															
**Flaveria trinervia*																																					0.5															
**Lactuca serriola*																																																				
**Malvastrum americanum*																																					0.5	0.5															
**Ocimum basilicum*																																																				
**Passiflora foetida* var. *hispida*																									0.5																												
**Phoenix dactylifera*																																																				
**Rumex vesicaria*																																																				
**Setaria verticillata*																												0.5									1	0.5															
**Sonchus oleraceus*																																						0.5															
**Tribulus terrestris*																												0.5									0.5																
**Vachellia farnesiana*							0.5																															0.5															
?Ehretia saligna																																						0.5															
Abutilon lepidum																																						0.5															
Abutilon leucopetalum																																																				
Abutilon sp.																																		0.5																			
Abutilon sp. Dioicum (A.A. Mitchell PRP 1618)			0.5												0.5					0.5																1	0.5						0.5										
Abutilon sp. Pilbara (W.R. Barker 2025)																																																	0.5				
Acacia ?elacantha																																																				
Acacia acradenia				12	15																												0.5									0.5	0.5								
Acacia ampliceps																																																				
Acacia ancistrocarpa	12	0.5	1					0.5	0.5	0.5	0.5			0.5		0.5	0.5			0.5			0.5				0.5					0.5			0.5	0.5			4	3			0.5	0.5						1
Acacia ancistrocarpa x *ptychophylla*																0.5																																					
Acacia atkinsiana																																										0.5		0.5									
Acacia bivenosa		3	1	0.5		1	0.5	0.5	1	0.5	0.5	0.5			0.5	1	0.5		0.5	0.5	3	0.5	0.5	1	0.5		0.5	0.5	0.5	1			0.5			0.5	1		1		0.5	1		3	5		0.5	0.5	0.5		3	55	0.5
Acacia colei var. *ileocarpa*																																					0.5															
Acacia elachantha																																																				
Acacia inaequilatera	0.5	0.5	0.5					1	3	2	0.5	0.5		0.5	0.5		1	0.5	0.5		1						0.5		1	4		0.5	0.5		0.5	1			1	2	0.5	1		0.5		0.5	0.5	0.5	0.5			0.5
Acacia maitlandii																																																				
Acacia monticola																																																				
Acacia orthocarpa															0.5																																				2				

Species	BA209	BA210	BA219	MH01	MH02	MH05	MH06	MH07	MH09	MH10	MH100	MH101	MH103	MH104	MH105	MH106	MH11	MH12	MH17	MH18	MH19	MH20	MH200	MH203	MH204	MH21	MH22	MH24	MH25	MH26	MH27	MH28	MH29	MH30	MH300	MH301	MH302	MH303	MH305	MH306	MH307	MH308	MH309r	MH31	MH310	MH311r	MH312	MH313	MH314	MH315	MH316	MH317
Acacia pruinocarpa												7	6		1			6																																		
Acacia ptychophylla		0.5													0.5	3															0.5			3	1				0.5												0.5
Acacia pyrifolia var. *pyrifolia*									0.5															0.5				4						1			1	0.5													0.5
Acacia sclerosperma subsp. *sclerosperma*						0.5																																													
Acacia sp.																																																			
Acacia synchronicia			1			4	1				2											0.5	1		0.5	4	0.5		0.5										1		0.5				0.5							
Acacia trachycarpa				0.5		0.5	0.5																0.5	35	3										0.5		2	1			4			0.5		0.5				0.5	
Acacia trachycarpa x tumida var. *pilbarensis*																																								0.5											
Acacia tumida var. *pilbarensis*	0.5												0.5	32				0.5	0.5	15											35	9	25					0.5		0.5			0.5			0.5	0.5				5
Acacia xiphophylla																						4	8																													
Adriana tomentosa																								0.5																										0.5	0.5	
Alternanthera nana																																																			
Alternanthera nodiflora																																																			
Amaranthus cuspidifolius																																																			
Amaranthus mitchellii																																					0.5														
Amaranthus undulatus																																																			
Amphipogon sericeus																																											0.5								
Amyema preissii																	0.5																			0.5									0.5						
Aristida contorta																											0.5																								
Aristida holathera var. *holathera*											0.5																		0.5			0.5								0.5											
Boerhavia coccinea																												0.5									0.5	0.5												
Boerhavia paludosa																																																		
Boerhavia repleta																																																		
Boerhavia sp.																																																		
Bonamia erecta	0.5		0.5																																						0.5	0.5			0.5						
Bonamia pilbarensis					0.5									0.5	0.5				0.5												0.5	0.5				0.5			0.5						0.5					0.5
Brachyachne prostrata																																																		
Bulbostylis barbata																							0.5														0.5		0.5		0.5										
Cajanus cinereus																																																		
Calandrinia sp.																																																		
Calocephalus knappii																																																		
Calotis hispidula																																																		
Calotis plumulifera																																																		
Capparis spinosa var. *nummularia*																																							0.5										0.5	
Carissa lanceolata																																																		
Cassytha capillaris				0.5	0.5					0.5			0.5	0.5		0.5	0.5	0.5		0.5	0.5									0.5	0.5					0.5					0.5			0.5				0.5	0.5	0.5
Cenchrus sp.																																																		
Centipeda minima subsp. *macrocephala*																																																		
Cheilanthes brownii																																																		
Cheilanthes sieberi subsp. *sieberi*																																																		

Species	BA209	BA210	BA219	MH01	MH02	MH05	MH06	MH07	MH09	MH10	MH100	MH101	MH103	MH104	MH105	MH106	MH11	MH12	MH17	MH18	MH19	MH20	MH200	MH203	MH204	MH21	MH22	MH24	MH25	MH26	MH27	MH28	MH29	MH30	MH300	MH301	MH302	MH303	MH305	MH306	MH307	MH308	MH309r	MH31	MH310	MH311r	MH312	MH313	MH314	MH315	MH316	MH317
Cleome viscosa			0.5																					0.5	0.5			0.5						0.5			0.5	0.5														
Clerodendrum floribundum var. *angustifolium*									0.5						0.5													0.5																									
Clerodendrum sp.																																																				
Clerodendrum tomentosum var. *lanceolatum*																																																			
Codonocarpus cotinifolius																																																		1	
Corchorus ?crozophorifolius																																																			
Corchorus crozophorifolius																																					0.5													0.5		
Corchorus lasiocarpus subsp. *parvus*	0.5					0.5		0.5				0.5		0.5					0.5					0.5				0.5	0.5		0.5	1		0.5			0.5	0.5			0.5					0.5			0.5		0.5
Corchorus parviflorus																																																			
Corchorus sp.																							0.5																													
Corchorus tridens																																																			
Corymbia candida																																										2									
Corymbia ferriticola																																																			
Corymbia hamersleyana	0.5	0.5						3	1					1		0.5				5							2		12	1							1		0.5						0.5	4	0.5	0.5			2	9	4
Crotalaria ?novae-hollindae																																																			
Crotalaria medicaginea var. *neglecta*																																																			
Cucumis melo																																																			
Cucumis variabilis			0.5						0.5																			0.5	0.5		0.5			0.5			0.5	0.5			0.5									
Cullen leucochaites																																																			
Cullen martinii																																																	0.5			
Cullen pogonocarpum																																																			
Cymbopogon ambiguus															0.5					0.5			0.5								0.5					0.5		0.5						0.5							0.5
Cynanchum floribundum																												0.5																							
Cynanchum pedunculatum																																																			
Cyperus cunninghamii subsp. *cunninghamii*															0.5																																			0.5			
Cyperus hesperius																																																			
Cyperus iria																																																			
Cyperus squarrosus																																																			
Cyperus vaginatus																									1													1														
Dactyloctenium radulans																																						0.5														
Dampiera candicans																																																		0.5		
Dodonaea coriacea																															0.5														0.5			0.5				
Duperreya commixta																				0.5																																
Dysphania kalpari			0.5																																																
Dysphania melanocarpa																																																			
Dysphania rhadinostachya subsp. *rhadinostachya*	0.5	0.5	0.5																																0.5		0.5		0.5	0.5	0.5						0.5		0.5			0.5

Species	BA209	BA210	BA219	MH01	MH02	MH05	MH06	MH07	MH09	MH10	MH100	MH101	MH103	MH104	MH105	MH106	MH11	MH12	MH17	MH18	MH19	MH20	MH200	MH203	MH204	MH21	MH22	MH24	MH25	MH26	MH27	MH28	MH29	MH30	MH300	MH301	MH302	MH303	MH305	MH306	MH307	MH308	MH309r	MH31	MH310	MH311r	MH312	MH313	MH314	MH315	MH316	MH317
Dysphania sp.																																																				
Ehretia saligna																																																				
Eleocharis geniculata																																																			
Enchylaena tomentosa var. *tomentosa*																																																			
Enneapogon caerulescens																																					0.5														
Enteropogon ramosus																																																			
Eragrostis dielsii																																																			
Eragrostis eriopoda																											0.5														0.5				0.5							
Eragrostis leptocarpa																																																			
Eragrostis pergracilis																																																			
Eremophila forrestii																																																			
Eremophila forrestii subsp. *forrestii*																																																			
Eremophila fraseri subsp. *fraseri*												1	0.5																																									
Eremophila longifolia																												0.5																										
Eriachne aristidea																																																			
Eriachne mucronata										0.5		0.5			0.5		0.5	0.5		0.5			0.5													0.5		0.5			0.5		0.5	0.5	0.5							
Eriachne pulchella subsp. *dominii*																																										0.5											
Eriachne pulchella subsp. *pulchella*										0.5							0.5																		0.5				0.5	0.5						0.5		0.5	0.5			
Eriachne sp.																											0.5																										
Eriachne tenuiculmis																																																			
Eucalyptus camaldulensis subsp. *refulgens*																									10												40															
Eucalyptus leucophloia subsp. *leucophloia*													1		2			0.5														0.5												1				4	1				
Eucalyptus sp.																																			0.5	0.5															
Eucalyptus victrix																																																			
Eulalia aurea																																					0.5														
Euphorbia australis	0.5		0.5											0.5											0.5																												
Euphorbia australis var. *hispidula*																														0.5																					
Euphorbia australis var. *subtomentosa*																	0.5																				0.5		0.5		0.5		0.5								0.5
Euphorbia biconvexa																									0.5			0.5						0.5												0.5						
Euphorbia boophthona	0.5		0.5																									0.5									0.5														
Euphorbia boopthona/tannensis																													0.5																					0.5
Euphorbia schultzii															0.5								0.5	0.5	0.5												0.5				0.5										
Euphorbia sp.																																																			
Euphorbia tannensis																																																	0.5		
Evolvulus alsinoides var. *villosicalyx*						0.5																					0.5	0.5						0.5																	
Ficus aculeata var. *aculeata*																																																			
Ficus aculeata var. *indecora*																				0.5																		0.5														
Ficus brachypoda																																																			

Species	BA209	BA210	BA219	MH01	MH02	MH05	MH06	MH07	MH09	MH10	MH100	MH101	MH103	MH104	MH105	MH106	MH11	MH12	MH17	MH18	MH19	MH20	MH200	MH203	MH204	MH21	MH22	MH24	MH25	MH26	MH27	MH28	MH29	MH30	MH300	MH301	MH302	MH303	MH305	MH306	MH307	MH308	MH309r	MH31	MH310	MH311r	MH312	MH313	MH314	MH315	MH316	MH317
Fimbristylis dichotoma																																																			
Flueggea virosa																																																			
Flueggea virosa subsp. *melanthesoides*																																	0.5				0.5														
Gomphrena cunninghamii																												0.5									0.5			0.5										
Goodenia forrestii																											0.5													0.5										
Goodenia lamprosperma																																																		
Goodenia microptera	0.5		0.5							0.5						0.5	0.5										0.5												0.5	0.5										
Goodenia stobbsiana		0.5								0.5						0.5	0.5												0.5		0.5		0.5			0.5			0.5							0.5					0.5
Gossypium australe			0.5			0.5		0.5	0.5																				0.5			0.5		0.5			0.5							0.5					
Gossypium robinsonii						0.5	0.5	0.5						0.5														1			2		2			0.5	0.5											1	0.5	0.5
Grevillea pyramidalis subsp. *leucadendron*										2			0.5															0.5	0.5				0.5			1			0.5										
Grevillea wickhamii				0.5	2				0.5					0.5		0.5	0.5		0.5	0.5								2			1	2	1	1							0.5		0.5			0.5					0.5
Hakea chordophylla		0.5		0.5													0.5		0.5								0.5		0.5						0.5	0.5				0.5			0.5	0.5	0.5			0.5		
Hakea lorea subsp. *lorea*	0.5																																																	
Helichrysum luteoalbum																																																		
Heliotropium heteranthum																																																		
Heliotropium ovalifolium																																																		
Heliotropium pachyphyllum																																															0.5			0.5		
Heliotropium tanythrix																																																		
Hibiscus brachychlaenus																																																		
Hibiscus coatesii																																0.5																			
Hibiscus goldsworthii																																																		
Hibiscus leptocladus																													0.5																						
Hibiscus sp.																																																		
Hibiscus sturtii																																																		
Hibiscus sturtii var. *campylochlamys*	0.5					0.5	0.5	0.5						0.5																	0.5	0.5								0.5			0.5							0.5
Hibiscus sturtii var. *grandiflorus*																																																		
Hybanthus aurantiacus																				0.5				0.5				0.5			0.5		0.5				0.5	0.5						0.5				0.5	0.5	0.5
Indigofera boviperda																																																		
Indigofera colutea																																																		
Indigofera linnaei																																																		
Indigofera monophylla		0.5							0.5					0.5														0.5			0.5	1		0.5			0.5				0.5									0.5
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301) P3																																																		
Indigofera trita																																																		
Ipomoea muelleri																									0.5			0.5					0.5				0.5											0.5			
Ipomoea polymorpha																																																		
Isotropis atropurpurea																																																		
Ixiochlamys cuneifolia																																																		

Species	BA209	BA210	BA219	MH01	MH02	MH05	MH06	MH07	MH09	MH10	MH100	MH101	MH103	MH104	MH105	MH106	MH11	MH12	MH17	MH18	MH19	MH20	MH200	MH203	MH204	MH21	MH22	MH24	MH25	MH26	MH27	MH28	MH29	MH30	MH300	MH301	MH302	MH303	MH305	MH306	MH307	MH308	MH309r	MH31	MH310	MH311r	MH312	MH313	MH314	MH315	MH316	MH317
Jasminum didymum subsp. *lineare*	0.5	0.5											0.5	0.5	0.5			0.5										0.5	0.5		0.5		0.5	0.5			0.5			0.5			0.5	0.5					0.5	0.5
Keraudrenia velutina subsp. *elliptica*				0.5																											0.5			0.5																
Lepidium pholidogynum																																					0.5														
Lobelia arnhemiaca																																					0.5														
Lobelia heterophylla																																																			
Lobelia sp.																									0.5																												
Lysiana casuarinae								0.5	0.5			0.5									0.5								0.5	0.5																								
Maireana melanocoma																						0.5																																
Maireana planifolia																																																				
Marsilea sp.																																																				
Melaleuca argentea																									40																												
Melaleuca glomerata																																					1														
Melaleuca linophylla																																																			
Melhania oblongifolia																																					0.5														
Mollugo molluginea	0.5		0.5										0.5	0.5														0.5	0.5					0.5				0.5		0.5											0.5
Neptunia dimorphantha																																																			
Nicotiana benthamiana																																																			
Nicotiana occidentalis																																																			
Notoleptopus decaisnei var. *Orbicularis* (A.B. Craig 428)																												0.5						0.5			0.5	0.5													0.5
Oldenlandia crouchiana										0.5							0.5	0.5																															0.5			
Paraneurachne muelleri											0.5			0.5						0.5											0.5						0.5	0.5		0.5										0.5
Paspalidium ?clementii																																	0.5																	
Paspalidium clementii																																				0.5	0.5													
Paspalidium sp.																																																			
Paspalidium tabulatum	0.5																																																			
Pentalepis trichodesmoides																												0.5					1																	
Perotis rara																																																			
Petalostylis labicheoides						0.5	1							0.5	0.5	0.5				0.5				25	0.5			0.5			1	2	0.5					1	0.5		0.5	0.5						3	3	0.5
Phyllanthus erwinii																												0.5																							
Phyllanthus maderaspatensis	0.5																								0.5			0.5						0.5			0.5	0.5												
Phyllanthus sp.																																																			
Pimelea ammocharis																																																	0.5	0.5	
Pluchea dentex																																																		
Pluchea rubelliflora																									0.5																											
Pluchea sp.																																																			
Polycarpaea corymbosa																																										0.5									
Polycarpaea holtzei		0.5																																	0.5				0.5	0.5							0.5			
Polycarpaea longiflora															0.5													0.5								0.5														
Polygala glaucifolia																																																	0.5			

Species	BA209	BA210	BA219	MH01	MH02	MH05	MH06	MH07	MH09	MH10	MH100	MH101	MH103	MH104	MH105	MH106	MH11	MH12	MH17	MH18	MH19	MH20	MH200	MH203	MH204	MH21	MH22	MH24	MH25	MH26	MH27	MH28	MH29	MH30	MH300	MH301	MH302	MH303	MH305	MH306	MH307	MH308	MH309r	MH31	MH310	MH311r	MH312	MH313	MH314	MH315	MH316	MH317
Polymeria ambigua																																																			
Polymeria sp.																																																			
Portulaca cyclophylla																																																		
Portulaca oleracea																																																		
Pterocaulon sp.			0.5						0.5					0.5															0.5	0.5				0.5																		
Pterocaulon sphacelatum																												0.5																								0.5
Pterocaulon sphaeranthoides							0.5																					0.5									0.5													0.5
Ptilotus aervoides		0.5																																		0.5														
Ptilotus appendiculatus																																				0.5	0.5			0.5										
Ptilotus astrolasius	0.5		0.5		0.5			0.5			0.5			0.5	0.5												0.5		0.5		0.5	0.5					0.5		0.5		0.5			0.5	0.5		0.5		0.5			0.5
Ptilotus auriculifolius											0.5							0.5				0.5		0.5		0.5																					0.5					
Ptilotus axillaris	0.5		0.5																														0.5			0.5									0.5			0.5			
Ptilotus calostachyus	0.5			0.5										0.5	0.5	0.5	0.5		0.5	0.5							0.5			0.5	0.5	0.5	0.5		0.5	0.5			0.5	0.5	0.5	0.5		0.5		0.5	0.5					0.5
Ptilotus clementii																																							0.5												
Ptilotus fusiformis	0.5	0.5	0.5																												0.5					0.5									0.5					0.5
Ptilotus gomphrenoides var. *gomphrenoides*																																																		
Ptilotus incanus															0.5					0.5								0.5												0.5											
Ptilotus nobilis subsp. *nobilis*	0.5	0.5	0.5			0.5								0.5			0.5			0.5			0.5				0.5		0.5					0.5	0.5		0.5		0.5	0.5	0.5	0.5			0.5	0.5		0.5	0.5		0.5
Ptilotus obovatus																																				0.5											0.5				
Ptilotus sp.																																					0.5													
Rhagodia eremaea																																																		
Rhodanthe margarethae																																																		
Rhynchosia bungarensis P4																								0.5	0.5																											
Rhynchosia minima	0.5																			0.5									0.5												0.5										0.5
Salsola australis																																																				
Sarcostemma viminale													1																																							
Sauropus crassifolius																																																			
Scaevola ?parviflolia																																																		
Scaevola spinescens																													0.5																							
Schizachyrium fragile																																																		
Schoenoplectus subulatus																																																		
Sclerolaena costata						0.5	0.5																																													
Sclerolaena sp.																																																			
Senna artemisioides subsp. *helmsii*																																																		
Senna artemisioides subsp. *oligophylla*			0.5						1																			0.5	0.5					0.5				0.5		0.5										
Senna ferraria																																																		
Senna glutinosa subsp. *glutinosa*								0.5							0.5												0.5			0.5					0.5					0.5								0.5		
Senna glutinosa subsp. *pruinosa*																																						0.5	0.5	0.5		0.5								
Senna glutinosa subsp. x *luerssenii*												0.5	0.5									0.5	0.5																				0.5				0.5					

Species	BA209	BA210	BA219	MH01	MH02	MH05	MH06	MH07	MH09	MH10	MH100	MH101	MH103	MH104	MH105	MH106	MH11	MH12	MH17	MH18	MH19	MH20	MH200	MH203	MH204	MH21	MH22	MH24	MH25	MH26	MH27	MH28	MH29	MH30	MH300	MH301	MH302	MH303	MH305	MH306	MH307	MH308	MH309r	MH31	MH310	MH311r	MH312	MH313	MH314	MH315	MH316	MH317
Senna notabilis	0.5		0.5				0.5																						0.5										0.5													
Senna sp. Meekatharra (E. Bailey 1-26)																																																			
Senna stricta																		0.5																																					
Senna venusta																																																				
Sesbania formosa																									0.5																														
Sida arsiniata																															0.5																						
Sida cardiophylla			0.5																																																		
Sida echinocarpa																											0.5	0.5													0.5						0.5							
Sida fibulifera																																																				
Sida rohlenae subsp. rohlenae																																																				
Sida sp. Articulation below (A.A. Mitchell PRP 1605)																																					0.5															
Sida sp. Pilbara (A.A. Mitchell PRP 1543)								0.5				0.5							0.5												0.5	0.5				0.5											0.5					
Solanum ?cleistigamum																																																			
Solanum cleistogamum														0.5						0.5									0.5		0.5																						0.5
Solanum diversiflorum	0.5		0.5											0.5																							0.5	0.5			0.5										0.5
Solanum elatius																																																			
Solanum gabrielae																																																			
Solanum horridum					0.5							0.5					0.5											0.5		0.5			0.5				0.5	0.5										0.5			0.5
Solanum lasiophyllum																																																			
Sporobolus australasicus	0.5																																						0.5		0.5										
Stackhousia muricata																																								0.5											
Stackhousia muricata subsp. annual (W.R. Barker 2172)																																																	0.5			
Stemodia grossa		0.5																							0.5			0.5																								
Streptoglossa adscendens																																																			
Streptoglossa bubakii			0.5																																																	
Streptoglossa decurrens																																																			
Streptoglossa liatroides																									0.5																												
Streptoglossa sp.																																																			
Striga curviflora																																																			
Stylobasium spathulatum			0.5			0.5	0.5		0.5																				0.5	0.5				1			3	0.5										0.5	0.5	
Swainsona formosa																												0.5																							
Swainsona sp.																																																			
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)																									0.5			0.5							0.5			0.5	0.5												
Tephrosia sp. B Kimberley Flora (C.A. Gardner 7300)																																																			
Tephrosia sp. Bungaroo Creek (M.E. Trudgen 11601)	0.5																																																		
Tephrosia sp.																									0.5																												

Species	BA209	BA210	BA219	MH01	MH02	MH05	MH06	MH07	MH09	MH10	MH100	MH101	MH103	MH104	MH105	MH106	MH11	MH12	MH17	MH18	MH19	MH20	MH200	MH203	MH204	MH21	MH22	MH24	MH25	MH26	MH27	MH28	MH29	MH30	MH300	MH301	MH302	MH303	MH305	MH306	MH307	MH308	MH309r	MH31	MH310	MH311r	MH312	MH313	MH314	MH315	MH316	MH317
Fortescue (A.A. Mitchell 606)																																																			
Tephrosia supina																																																			
Tephrosia uniovulata								0.5		0.5				0.5						0.5											0.5																		0.5		0.5
Tephrosia virens												0.5																			0.5																			
Themeda triandra																				0.5																	0.5															
Tinospora smilacina																																																		
Trachymene oleracea subsp. *oleracea*	0.5																0.5																				0.5	0.5		0.5								0.5				
Trianthema cusackianum																																																		0.5
Trianthema pilosum																																																		
Trianthema triquetrum						0.5																																												
Tribulus ?occidentalis																																																		
Tribulus hirsutus																																																		
Tribulus macrocarpus			0.5			0.5	0.5																																0.5		0.5					0.5				
Tribulus platypterus																												0.5																		0.5				
Tribulus sp.																																																		
Tribulus suberosus												0.5																																						
Trichodesma zeylanicum var. *zeylanicum*	0.5								0.5			0.5	0.5	0.5				0.5										0.5			0.5	0.5		0.5		0.5		0.5	0.5						0.5			0.5		0.5
Triodia angusta																																																		
Triodia epactia	12		18			0.5	0.5																				0.5	25	40					15			25				3				32						
Triodia longiceps																																																		
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3					2					7		0.5	1	12	0.5	4	11	5		6										0.5	5	1			3				0.5						0.5	4			0.5
Triodia wiseana	25	45	22	22	25	2	2	25	40	20	19	9	15	12	12	25	10	12	20	8	60	23	20			20	35	0.5	5	32	35	10	6		20	29		0.5	25	33	5	11	35	40		28	18	25	20	8	65	12
Triumfetta ?chaetocarpa																																																		
Triumfetta appendiculata															1																							0.5													
Triumfetta chaetocarpa																																																		
Triumfetta clementii												0.5																									0.5	1			0.5									
Triumfetta johnstonii												0.5																			0.5																0.5		0.5			
Triumfetta maconochieana					0.5										0.5															0.5																	0.5			
Triumfetta sp.																																						0.5												
Typha domingensis																																																		
Vigna lanceolata var. *lanceolata*																				0.5					0.5																											
Wahlenbergia tumidifructa																																																		
Waltheria indica																									0.5			0.5									0.5	0.5														

? denotes unconfirmed ID

Species	MH318	MH319	MH32	MH320	MH321	MH322	MH324	MH325	MH326	MH327	MH328	MH329	MH33	MH330	MH331	MH332	MH333r	MH334r	MH335	MH336	MH337r	MH338	MH339	MH34	MH342	MH343	MH344	MH345	MH346	MH348	MH35	MH350	MH352	MH353	MH354	MH356	MH357	MH358	MH359	MH36	MH360r	MH361	MH363	MH364	MH365	MH368	MH37	MH370	MH371	MH373	MH374	MH375r
**Argemone ochroleuca* subsp. *ochroleuca*																					0.5																						0.5	0.5									
**Cenchrus ciliaris*				0.5	0.5	0.5										0.5	0.5			0.5															0.5									0.5				0.5				
**Cenchrus setiger*					0.5	0.5											1				0.5														0.5														0.5				
**Chloris barbata*																																																					
**Citrullus colocynthis*																																																					
**Cynodon dactylon*					0.5											0.5																												0.5									
**Echinochloa colona*																																																			0.5			
**Euphorbia hirta*																																														0.5				0.5			
**Flaveria trinervia*																																														0.5							
**Lactuca serriola*																0.5																																						
**Malvastrum americanum*																																																			0.5			
**Ocimum basilicum*																																																					
**Passiflora foetida* var. *hispida*																0.5					0.5																									0.5									
**Phoenix dactylifera*																																																					
**Rumex vesicaria*																																																					
**Setaria verticillata*				0.5																																																	
**Sonchus oleraceus*				0.5																																																	
**Tribulus terrestris*																																																					
**Vachellia farnesiana*																0.5																																					0.5			
?Ehretia saligna																																																					
Abutilon lepidum																																					0.5																
Abutilon leucopetalum				0.5																																																	
Abutilon sp.																																															0.5						0.5		
Abutilon sp. Dioicum (A.A. Mitchell PRP 1618)																0.5																														0.5				0.5				
Abutilon sp. Pilbara (W.R. Barker 2025)																																																					
Acacia ?elacantha																																																				0.5		
Acacia acradenia			3					0.5	9	5	0.5														0.5		12	8										1			3												
Acacia ampliceps																																																					
Acacia ancistrocarpa		0.5										2		0.5	1		0.5			0.5		0.5	1		0.5	1	0.5			17		5				0.5		3				1				0.5		0.5		0.5		
Acacia ancistrocarpa x ptychophylla																																																				
Acacia atkinsiana															0.5		0.5																																				
Acacia bivenosa		1	6	20	0.5	1	4	4		0.5	1	0.5			0.5	0.5	0.5	0.5	0.5	0.5		1	4		5	1	2			0.5	0.5	4			0.5	26	0.5		4	0.5				0.5	0.5		2	0.5		0.5		
Acacia colei var. *ileocarpa*				0.5																																0.5													0.5			
Acacia elachantha		0.5		0.5																																															
Acacia inaequilatera		1					0.5		0.5	0.5	3	2	0.5	1	1			2		0.5			1			0.5		1	0.5		1	1	0.5	1					1		0.5					1	0.5		0.5		1		
Acacia maitlandii		0.5																																																	
Acacia monticola																																																				
Acacia orthocarpa																																																			0.5			
Acacia pruinocarpa														4																				0.5																	
Acacia ptychophylla													1											0.5								0.5																	8			0.5			

Species	MH318	MH319	MH32	MH320	MH321	MH322	MH324	MH325	MH326	MH327	MH328	MH329	MH33	MH330	MH331	MH332	MH333r	MH334r	MH335	MH336	MH337r	MH338	MH339	MH34	MH342	MH343	MH344	MH345	MH346	MH348	MH35	MH350	MH352	MH353	MH354	MH356	MH357	MH358	MH359	MH36	MH360r	MH361	MH363	MH364	MH365	MH368	MH37	MH370	MH371	MH373	MH374	MH375r
Acacia pyrifolia var. *pyrifolia*																0.5							0.5														0.5	0.5				0.5		0.5					0.5	1	
Acacia sclerosperma subsp. *sclerosperma*																	0.5																																				
Acacia sp.			0.5																																																
Acacia synchronicia					0.5	0.5	0.5										1		0.5	0.5									0.5					6				0.5											3				
Acacia trachycarpa				0.5	6	0.5	0.5									2	3				0.5													32			0.5	0.5			0.5	1			0.5		0.5		0.5		0.5		
Acacia trachycarpa x *tumida* var. *pilbarensis*					0.5																																														
Acacia tumida var. *pilbarensis*	15																											0.5	0.5			0.5	0.5				0.5		0.5	0.5	0.5	0.5		0.5			3				0.5	
Acacia xiphophylla																			1																																		
Adriana tomentosa																																																			
Alternanthera nana																																																			
Alternanthera nodiflora																																																			
Amaranthus cuspidifolius																																																			
Amaranthus mitchellii																																																			
Amaranthus undulatus																																																0.5				
Amphipogon sericeus																																																0.5				
Amyema preissii														0.5														0.5	0.5			0.5																0.5				
Aristida contorta																				0.5																																	
Aristida holathera var. *holathera*				0.5																						0.5																								0.5	
Boerhavia coccinea																																															0.5					
Boerhavia paludosa																																																				
Boerhavia repleta																																																				
Boerhavia sp.																	0.5			0.5																																	
Bonamia erecta																				0.5																																	
Bonamia pilbarensis											0.5		0.5									0.5				0.5	0.5	0.5	0.5				0.5								0.5				0.5	0.5	0.5	0.5			0.5	
Brachyachne prostrata																			0.5																																		
Bulbostylis barbata													0.5				0.5																																			
Cajanus cinereus																																																				
Calandrinia sp.																																																				
Calocephalus knappii																																																				
Calotis hispidula																																																				
Calotis plumulifera																																																				
Capparis spinosa var. *nummularia*																0.5																																				0.5	
Carissa lanceolata																																																				
Cassytha capillaris	0.5																		0.5								0.5		0.5		0.5	0.5		0.5		0.5			0.5								0.5		0.5			
Cenchrus sp.																																					0.5												25			
Centipeda minima subsp. *macrocephala*																																																			
Cheilanthes brownii																																																			
Cheilanthes sieberi subsp. *sieberi*																																																			
Cleome viscosa					0.5											0.5								0.5										0.5	0.5					0.5				0.5	0.5							

Species	MH318	MH319	MH32	MH320	MH321	MH322	MH324	MH325	MH326	MH327	MH328	MH329	MH33	MH330	MH331	MH332	MH333r	MH334r	MH335	MH336	MH337r	MH338	MH339	MH34	MH342	MH343	MH344	MH345	MH346	MH348	MH35	MH350	MH352	MH353	MH354	MH356	MH357	MH358	MH359	MH36	MH360r	MH361	MH363	MH364	MH365	MH368	MH37	MH370	MH371	MH373	MH374	MH375r
Clerodendrum floribundum var. *angustifolium*	0.5	0.5																																													0.5				0.5	
Clerodendrum sp.			0.5																																																
Clerodendrum tomentosum var. *lanceolatum*																																																			
Codonocarpus cotinifolius																																			3																	
Corchorus ?crozophorifolius																																																			
Corchorus crozophorifolius																0.5																																					
Corchorus lasiocarpus subsp. *parvus*				0.5	0.5							0.5		0.5				0.5				0.5		0.5			0.5				0.5	0.5	0.5		0.5	0.5	0.5			0.5	0.5		0.5	0.5	0.5		0.5	0.5	0.5		1	
Corchorus parviflorus																																																			
Corchorus sp.																																																			
Corchorus tridens				0.5																																															
Corymbia candida																	0.5																																				
Corymbia ferriticola																																																			
Corymbia hamersleyana	1	0.5	0.5	4				0.5		0.5								0.5		1																	3	4	1	0.5		1						0.5				1	
Crotalaria ?novae-hollindae																																													0.5							
Crotalaria medicaginea var. *neglecta*																																												0.5							
Cucumis melo																																												0.5							
Cucumis variabilis				0.5																	0.5																			0.5						0.5					
Cullen leucochaites																																													0.5					
Cullen martinii																																																		
Cullen pogonocarpum																																																		
Cymbopogon ambiguus										0.5									0.5		0.5				0.5										0.5				0.5	0.5				0.5							
Cynanchum floribundum																																													0.5							
Cynanchum pedunculatum				0.5																																															
Cyperus cunninghamii subsp. *cunninghamii*																																									0.5	0.5			0.5							
Cyperus hesperius																																																			
Cyperus iria																																																			
Cyperus squarrosus																																																			
Cyperus vaginatus																1					1															0.5							1							0.5		
Dactyloctenium radulans																																																			
Dampiera candicans													0.5									0.5		0.5																0.5										0.5			
Dodonaea coriacea																				0.5		0.5					0.5																			0.5						
Duperreya commixta																																																			
Dysphania kalpari				0.5																																															
Dysphania melanocarpa																																																			
Dysphania rhadinostachya subsp. *rhadinostachya*										0.5	0.5	0.5		0.5			0.5	0.5		0.5																																		
Dysphania sp.																															0.5			0.5																		

Species	MH318	MH319	MH32	MH320	MH321	MH322	MH324	MH325	MH326	MH327	MH328	MH329	MH33	MH330	MH331	MH332	MH333r	MH334r	MH335	MH336	MH337r	MH338	MH339	MH34	MH342	MH343	MH344	MH345	MH346	MH348	MH35	MH350	MH352	MH353	MH354	MH356	MH357	MH358	MH359	MH36	MH360r	MH361	MH363	MH364	MH365	MH368	MH37	MH370	MH371	MH373	MH374	MH375r
Ehretia saligna																																																				
Eleocharis geniculata																0.5																																							
Enchylaena tomentosa var. *tomentosa*																																																				
Enneapogon caerulescens																																		0.5																			
Enteropogon ramosus																																																				
Eragrostis dielsii																																																				
Eragrostis eriopoda				0.5																0.5																0.5																		
Eragrostis leptocarpa																																																				
Eragrostis pergracilis																																																			
Eremophila forrestii																																																			
Eremophila forrestii subsp. *forrestii*																																																			
Eremophila fraseri subsp. *fraseri*																																																			
Eremophila longifolia				0.5																																									0.5								
Eriachne aristidea																	0.5			0.5																																		
Eriachne mucronata	0.5		0.5				0.5																	0.5	0.5							0.5	0.5							0.5	0.5	0.5			0.5		0.5	0.5					
Eriachne pulchella subsp. *dominii*																																																				
Eriachne pulchella subsp. *pulchella*																																																		0.5			
Eriachne sp.																																																				
Eriachne tenuiculmis																																																				
Eucalyptus camaldulensis subsp. *refulgens*																																		0.5	0.5									2						6		
Eucalyptus leucophloia subsp. *leucophloia*						0.5				0.5															1						2										1	4	1	1					0.5		0.5			
Eucalyptus sp.						0.5										0.5																																	0.5				
Eucalyptus victrix																0.5																																			6		
Eulalia aurea																																																		0.5				
Euphorbia australis																																																				
Euphorbia australis var. *hispidula*																																																			
Euphorbia australis var. *subtomentosa*				0.5																																												0.5				
Euphorbia biconvexa																																				0.5														
Euphorbia boophthona																																																			
Euphorbia boopthona/tannensis																																			0.5									0.5				0.5				
Euphorbia schultzii					0.5											0.5																			0.5									0.5				0.5				
Euphorbia sp.																																																		0.5				
Euphorbia tannensis				0.5																																															
Evolvulus alsinoides var. *villosicalyx*				0.5																																0.5															
Ficus aculeata var. *aculeata*																																																				
Ficus aculeata var. *indecora*																																																				
Ficus brachypoda																																																				
Fimbristylis dichotoma								0.5																0.5																													0.5

Species	MH318	MH319	MH32	MH320	MH321	MH322	MH324	MH325	MH326	MH327	MH328	MH329	MH33	MH330	MH331	MH332	MH333r	MH334r	MH335	MH336	MH337r	MH338	MH339	MH34	MH342	MH343	MH344	MH345	MH346	MH348	MH35	MH350	MH352	MH353	MH354	MH356	MH357	MH358	MH359	MH36	MH360r	MH361	MH363	MH364	MH365	MH368	MH37	MH370	MH371	MH373	MH374	MH375r
Flueggea virosa																																																					
Flueggea virosa subsp. *melanthesoides*																																							0.5													
Gomphrena cunninghamii					0.5																																					0.5									
Goodenia forrestii				0.5													0.5		0.5	0.5																																	
Goodenia lamprosperma																																																				
Goodenia microptera				0.5																0.5							0.5			0.5		0.5																					
Goodenia stobbsiana	0.5																					0.5								0.5							0.5																
Gossypium australe																	0.5															0.5							0.5													
Gossypium robinsonii				0.5												0.5																					2						0.5	1				0.5		0.5	0.5	
Grevillea pyramidalis subsp. *leucadendron*		0.5	0.5				0.5				0.5																	0.5	0.5							0.5							0.5						0.5		
Grevillea wickhamii	0.5								0.5	0.5		0.5	0.5		0.5							0.5				1		0.5	0.5				0.5						0.5	0.5		1							0.5			
Hakea chordophylla		0.5	0.5										0.5		0.5			0.5	0.5	0.5									0.5					0.5				0.5								0.5	0.5	0.5		
Hakea lorea subsp. *lorea*																															0.5																				
Helichrysum luteoalbum																0.5																																				
Heliotropium heteranthum																																																			
Heliotropium ovalifolium																																																			
Heliotropium pachyphyllum																																				0.5							0.5		0.5							
Heliotropium tanythrix																																																			
Hibiscus brachychlaenus																																					0.5															
Hibiscus coatesii								0.5																																												
Hibiscus goldsworthii																																															0.5					
Hibiscus leptocladus																																																			
Hibiscus sp.																				0.5																																	
Hibiscus sturtii																																																			
Hibiscus sturtii var. *campylochlamys*				0.5																													0.5			0.5				0.5							0.5			0.5	
Hibiscus sturtii var. *grandiflorus*																																																			
Hybanthus aurantiacus				0.5																																	0.5							0.5				0.5	0.5	
Indigofera boviperda																																																		0.5		
Indigofera colutea																																																			
Indigofera linnaei																																																			
Indigofera monophylla													0.5										0.5	0.5								0.5			0.5			0.5							0.5		0.5				1	
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301) P3																																																			
Indigofera trita																																																			
Ipomoea muelleri																0.5					0.5																																
Ipomoea polymorpha																																																		0.5		
Isotropis atropurpurea																																																			
Ixiochlamys cuneifolia								0.5																																												
Jasminum didymum subsp. *lineare*	0.5	0.5		0.5						0.5						0.5																				0.5	0.5			0.5							0.5				0.5	

Species	MH318	MH319	MH32	MH320	MH321	MH322	MH324	MH325	MH326	MH327	MH328	MH329	MH33	MH330	MH331	MH332	MH333r	MH334r	MH335	MH336	MH337r	MH338	MH339	MH34	MH342	MH343	MH344	MH345	MH346	MH348	MH35	MH350	MH352	MH353	MH354	MH356	MH357	MH358	MH359	MH36	MH360r	MH361	MH363	MH364	MH365	MH368	MH37	MH370	MH371	MH373	MH374	MH375r
Keraudrenia velutina subsp. *elliptica*																						0.5																																	
Lepidium pholidogynum																			0.5																																			
Lobelia arnhemiaca																0.5					0.5																																		
Lobelia heterophylla																																																													
Lobelia sp.																																																													
Lysiana casuarinae											0.5	0.5																						0.5																													
Maireana melanocoma																																																													
Maireana planifolia																																																													
Marsilea sp.																																																												0.5		
Melaleuca argentea																32					50																											62												
Melaleuca glomerata																																																													
Melaleuca linophylla																																																													
Melhania oblongifolia				0.5																																0.5																							
Mollugo molluginea			0.5														0.5							0.5		0.5																													0.5	0.5	
Neptunia dimorphantha																																																													
Nicotiana benthamiana																																																													
Nicotiana occidentalis																																																													
Notoleptopus decaisnei var. *Orbicularis* (A.B. Craig 428)				0.5																																0.5								0.5													
Oldenlandia crouchiana								0.5										0.5									0.5																																	
Paraneurachne muelleri			0.5	0.5																		0.5																																						
Paspalidium ?clementii																																																													
Paspalidium clementii																																																													
Paspalidium sp.																																																													
Paspalidium tabulatum																																																													
Pentalepis trichodesmoides																																																													
Perotis rara																																																													
Petalostylis labicheoides	0.5				8	0.5					0.5				0.5	1	0.5				0.5	0.5						0.5				0.5	0.5		1		6					0.5	0.5				0.5	0.5						
Phyllanthus erwinii																																																												
Phyllanthus maderaspatensis				0.5												0.5					0.5													0.5										0.5	0.5				0.5		0.5			
Phyllanthus sp.																																																										0.5		
Pimelea ammocharis				0.5																																0.5																							
Pluchea dentex																																																													
Pluchea rubelliflora								0.5								0.5																																0.5											
Pluchea sp.																																																												
Polycarpaea corymbosa																	0.5																																												
Polycarpaea holtzei								0.5										0.5																																												
Polycarpaea longiflora							0.5						0.5					0.5																																												
Polygala glaucifolia																																																												
Polymeria ambigua																																																												

Species	MH318	MH319	MH32	MH320	MH321	MH322	MH324	MH325	MH326	MH327	MH328	MH329	MH33	MH330	MH331	MH332	MH333r	MH334r	MH335	MH336	MH337r	MH338	MH339	MH34	MH342	MH343	MH344	MH345	MH346	MH348	MH35	MH350	MH352	MH353	MH354	MH356	MH357	MH358	MH359	MH36	MH360r	MH361	MH363	MH364	MH365	MH368	MH37	MH370	MH371	MH373	MH374	MH375r
Polymeria sp.																																																				
Portulaca cyclophylla																																																				
Portulaca oleracea																																																			
Pterocaulon sp.																			0.5																	0.5															0.5			
Pterocaulon sphacelatum																																																				
Pterocaulon sphaeranthoides				0.5																													0.5																		
Ptilotus aervoides																																																			
Ptilotus appendiculatus																																																			
Ptilotus astrolasius					0.5		0.5	0.5					0.5				0.5	0.5				0.5	0.5			0.5	0.5	0.5		0.5		0.5	0.5	0.5			0.5		0.5				0.5	0.5		0.5			0.5	
Ptilotus auriculifolius												0.5						0.5																																			
Ptilotus axillaris				0.5													0.5	0.5		0.5												0.5																				
Ptilotus calostachyus			0.5						0.5			0.5			0.5			0.5				0.5			0.5	0.5	0.5	0.5					0.5				0.5					0.5			0.5			0.5			
Ptilotus clementii																																																			
Ptilotus fusiformis																		0.5														0.5												0.5							
Ptilotus gomphrenoides var. *gomphrenoides*																																																			
Ptilotus incanus							0.5																				0.5																			0.5						
Ptilotus nobilis subsp. *nobilis*				0.5	0.5			0.5		0.5		0.5		0.5	0.5		0.5	0.5	0.5	0.5							0.5								0.5	0.5	0.5							0.5			0.5			0.5		
Ptilotus obovatus				0.5																					0.5																											
Ptilotus sp.																																	0.5										0.5								
Rhagodia eremaea																																																			
Rhodanthe margarethae																																																			
Rhynchosia bungarensis P4																0.5					0.5													0.5	0.5																	
Rhynchosia minima				0.5													0.5																0.5					0.5													
Salsola australis																			0.5																																	
Sarcostemma viminale																																																			
Sauropus crassifolius																																																			
Scaevola ?parviflolia																		0.5																																		
Scaevola spinescens				0.5																																0.5									0.5						
Schizachyrium fragile																																																			
Schoenoplectus subulatus																0.5																																				
Sclerolaena costata																																																			
Sclerolaena sp.																																																			
Senna artemisioides subsp. *helmsii*																																																			
Senna artemisioides subsp. *oligophylla*				0.5											0.5		0.5		0.5				0.5				0.5			0.5				1		0.5	0.5				0.5			0.5					0.5		
Senna ferraria				0.5																																															
Senna glutinosa subsp. *glutinosa*		0.5		0.5			0.5	0.5										0.5															0.5							0.5		0.5					0.5		0.5		0.5		
Senna glutinosa subsp. *pruinosa*								0.5				0.5															0.5															0.5					0.5				0.5		
Senna glutinosa subsp. *x luerssenii*			0.5																			0.5				0.5								0.5							0.5								0.5			
Senna notabilis				0.5													0.5																									0.5										

Species	MH318	MH319	MH32	MH320	MH321	MH322	MH324	MH325	MH326	MH327	MH328	MH329	MH33	MH330	MH331	MH332	MH333r	MH334r	MH335	MH336	MH337r	MH338	MH339	MH34	MH342	MH343	MH344	MH345	MH346	MH348	MH35	MH350	MH352	MH353	MH354	MH356	MH357	MH358	MH359	MH36	MH360r	MH361	MH363	MH364	MH365	MH368	MH37	MH370	MH371	MH373	MH374	MH375r
Senna sp. Meekatharra (E. Bailey 1-26)																																																				
Senna stricta														0.5																																								
Senna venusta				0.5																0.5																				0.5													
Sesbania formosa																0.5																												0.5										
Sida arsiniata				0.5																															0.5																0.5	
Sida cardiophylla																																																					
Sida echinocarpa																																		0.5																			
Sida fibulifera				0.5																															0.5																0.5		
Sida rohlenae subsp. *rohlenae*								0.5																																													
Sida sp. Articulation below (A.A. Mitchell PRP 1605)																																					0.5														0.5				
Sida sp. Pilbara (A.A. Mitchell PRP 1543)										0.5												0.5					0.5				0.5					0.5										0.5						
Solanum ?cleistigamum																																																				
Solanum cleistogamum																						0.5					0.5									0.5																0.5		
Solanum diversiflorum				0.5																		0.5										0.5														0.5						
Solanum elatius												0.5		0.5																																							
Solanum gabrielae								0.5																																													
Solanum horridum			0.5	0.5				0.5		0.5		0.5	0.5						0.5								0.5					0.5		0.5						0.5				0.5			0.5				0.5	
Solanum lasiophyllum								0.5																																												
Sporobolus australasicus				0.5																0.5																									0.5							
Stackhousia muricata																																																				
Stackhousia muricata subsp. annual (W.R. Barker 2172)																																																			
Stemodia grossa																0.5					0.5															0.5									0.5							
Streptoglossa adscendens																																																				
Streptoglossa bubakii																																																			
Streptoglossa decurrens																																																			
Streptoglossa liatroides																																																			
Streptoglossa sp.																																																			
Striga curviflora																																																				
Stylobasium spathulatum				1																			0.5													0.5	0.5			0.5				0.5				0.5			1	
Swainsona formosa				0.5																																								0.5							
Swainsona sp.																											0.5																									
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)					0.5											0.5					0.5			0.5										0.5									0.5	1					0.5	
Tephrosia sp. B Kimberley Flora (C.A. Gardner 7300)							0.5																																												
Tephrosia sp. Bungaroo Creek (M.E. Trudgen 11601)																						0.5																														
Tephrosia sp. Fortescue (A.A. Mitchell 606)																																																		

Species	MH318	MH319	MH32	MH320	MH321	MH322	MH324	MH325	MH326	MH327	MH328	MH329	MH33	MH330	MH331	MH332	MH333r	MH334r	MH335	MH336	MH337r	MH338	MH339	MH34	MH342	MH343	MH344	MH345	MH346	MH348	MH35	MH350	MH352	MH353	MH354	MH356	MH357	MH358	MH359	MH36	MH360r	MH361	MH363	MH364	MH365	MH368	MH37	MH370	MH371	MH373	MH374	MH375r
Tephrosia supina																																																				
Tephrosia uniovulata									0.5																												1				0.5	0.5					0.5					
Tephrosia virens																																																			
Themeda triandra																																																			
Tinospora smilacina																																																			
Trachymene oleracea subsp. *oleracea*	0.5						0.5						0.5	0.5		0.5					0.5			0.5																			0.5			0.5				0.5	
Trianthema cusackianum																																																			
Trianthema pilosum																																																			
Trianthema triquetrum																				0.5																																	
Tribulus ?occidentalis				0.5																																															
Tribulus hirsutus																																																			
Tribulus macrocarpus																																																			
Tribulus platypterus																																				0.5								0.5							
Tribulus sp.																				0.5																																
Tribulus suberosus																																																			
Trichodesma zeylanicum var. *zeylanicum*				0.5			0.5				0.5		0.5	0.5				0.5														0.5		0.5						0.5				0.5							
Triodia angusta																																					2															
Triodia epactia				18	0.5												12		0.5	20										54		0.5			0.5	1		30						1						
Triodia longiceps																																																			
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	0.5		1						1	0.5												2			0.5		4		2		0.5	0.5	12			0.5		0.5		2	0.5		0.5		0.5	0.5		2			1
Triodia wiseana	35	40	45		0.5	0.5	45	28	16	20	25	35	25	20	18		8	20	13	0.5		13	65	20	35	20	28	15	20	1	20	55	13	60		59	26	2	35	8	3	15			11	20	15	7	32		6	12
Triumfetta ?chaetocarpa					0.5																																														
Triumfetta appendiculata													0.5			0.5								0.5																0.5				0.5						0.5	
Triumfetta chaetocarpa																																																			
Triumfetta clementii													0.5																																							
Triumfetta johnstonii																0.5																					0.5														
Triumfetta maconochieana							0.5																																	0.5											
Triumfetta sp.																																																			
Typha domingensis																0.5																																				
Vigna lanceolata var. *lanceolata*																0.5					0.5																									0.5							
Wahlenbergia tumidifructa																																																			
Waltheria indica																																																			

? denotes unconfirmed ID

Species	MH376	MH377	MH38	MH39	MH392	MH393	MH394	MH395	MH396	MH397	MH398	MH399r	MH40	MH400	MH401	MH402	MH403	MH404	MH405	MH406	MH407	MH408	MH409	MH41	MH42	MH43	MH44	MHJ301r	MHJ302	MHJ303	MHJ304	MHJ305	MHJ306	MHJ307	MHJ309r	MHJr02	MHJr04	MHJr06	MHr200	OPPS
**Argemone ochroleuca* subsp. *ochroleuca*							0.5																									0.5	0.5	0.5						0.5
**Cenchrus ciliaris*					3	3		0.5							12	3	0.5				0.5	0.5	0.5			1	2					0.5	1	1						0.5
**Cenchrus setiger*								0.5								15					1	2	2			1	1						0.5	0.5						0.5
**Chloris barbata*																																								0.5
**Citrullus colocynthis*																										0.5														
**Cynodon dactylon*																																								
**Echinochloa colona*																																								0.5
**Euphorbia hirta*																																								
**Flaveria trinervia*																																	0.5	0.5						
**Lactuca serriola*																0.5					0.5	0.5	0.5								0.5									
**Malvastrum americanum*					0.5	0.5									0.5			0.5			0.5		0.5				0.5					0.5								0.5
**Ocimum basilicum*																																								0.5
**Passiflora foetida* var. *hispida*					0.5										0.5																									
**Phoenix dactylifera*																																								0.5
**Rumex vesicaria*																					0.5		0.5											0.5						0.5
**Setaria verticillata*																																	0.5	0.5						0.5
**Sonchus oleraceus*																																								
**Tribulus terrestris*																																								
**Vachellia farnesiana*															0.5						0.5		0.5				0.5													
?Ehretia saligna																																								0.5
Abutilon lepidum												0.5															0.5													
Abutilon leucopetalum																																								
Abutilon sp.															0.5	0.5														0.5										
Abutilon sp. Dioicum (A.A. Mitchell PRP 1618)					0.5	0.5																		0.5		0.5	0.5					0.5	0.5						0.5
Abutilon sp. Pilbara (W.R. Barker 2025)																	0.5			0.5	0.5		0.5						0.5		0.5		0.5						0.5
Acacia ?elacantha																																								
Acacia acradenia				3								0.5		1																										
Acacia ampliceps																																								0.5
Acacia ancistrocarpa	0.5		1					0.5					5					2	0.5	14									0.5	0.5	0.5								0.5
Acacia ancistrocarpa x *ptychophylla*																																								
Acacia atkinsiana								0.5																																
Acacia bivenosa	0.5	0.5	7		0.5	0.5		0.5				1	0.5		0.5		0.5									0.5	1	2	5	1	1	0.5		0.5	0.5	0.5		9	0.5	
Acacia colei var. *ileocarpa*	0.5					0.5									0.5											0.5													0.5
Acacia elachantha																										0.5													0.5
Acacia inaequilatera	0.5	0.5	0.5						0.5				0.5							0.5					0.5			0.5	0.5	0.5	0.5				0.5	1		2	0.5
Acacia maitlandii																																								0.5
Acacia monticola	0.5																																							0.5
Acacia orthocarpa	0.5								0.5																																0.5
Acacia pruinocarpa																									7										4						0.5
Acacia ptychophylla			0.5																									0.5		0.5									0.5
Acacia pyrifolia var. *pyrifolia*	0.5				0.5	0.5									0.5			0.5		0.5						0.5	0.5		0.5			1	0.5	4						0.5
Acacia sclerosperma subsp. *sclerosperma*															0.5																									0.5

Species	MH376	MH377	MH38	MH39	MH392	MH393	MH394	MH395	MH396	MH397	MH398	MH399r	MH40	MH400	MH401	MH402	MH403	MH404	MH405	MH406	MH407	MH408	MH409	MH41	MH42	MH43	MH44	MHJ301r	MHJ302	MHJ303	MHJ304	MHJ305	MHJ306	MHJ307	MHJ309r	MHJr02	MHJr04	MHJr06	MHr200	OPPS
Acacia sp.																																								
Acacia synchronicia						0.5		3								3	1					2	0.5																		
Acacia trachycarpa			0.5		7	9	0.5	1		0.5	2	0.5	0.5		7											1	2		0.5											0.5
Acacia trachycarpa x tumida var. *pilbarensis*																																								
Acacia tumida var. *pilbarensis*	0.5		2	1		0.5		0.5					6	5				0.5	22	14				4						0.5	0.5									0.5
Acacia xiphophylla																0.5					8		15																	
Adriana tomentosa																																								
Alternanthera nana																		0.5														0.5								
Alternanthera nodiflora																																								0.5
Amaranthus cuspidifolius																0.5	0.5				0.5		0.5																	
Amaranthus mitchellii																																	0.5	0.5						0.5
Amaranthus undulatus																																0.5								0.5
Amphipogon sericeus													0.5																											0.5
Amyema preissii																																		0.5						
Aristida contorta																																								
Aristida holathera var. *holathera*								0.5											0.5									0.5												0.5
Boerhavia coccinea					0.5	0.5											0.5	0.5			0.5		0.5									0.5	0.5							
Boerhavia paludosa																																								0.5
Boerhavia repleta																	0.5				0.5																			
Boerhavia sp.																																	0.5	0.5						
Bonamia erecta																				0.5									0.5											0.5
Bonamia pilbarensis	0.5		0.5										0.5	0.5					0.5									0.5		0.5						0.5			0.5
Brachyachne prostrata																0.5					0.5																			0.5
Bulbostylis barbata																	0.5						0.5						0.5			0.5	0.5	0.5					
Cajanus cinereus																																								0.5
Calandrinia sp.																							0.5																	
Calocephalus knappii																																	0.5							
Calotis hispidula																0.5																								
Calotis plumulifera																					0.5																			
Capparis spinosa var. *nummularia*					0.5							0.5												0.5		0.5						0.5								0.5
Carissa lanceolata																																								0.5
Cassytha capillaris			0.5																					0.5				3	0.5		0.5						0.5		
Cenchrus sp.																																								
Centipeda minima subsp. *macrocephala*																						0.5																		
Cheilanthes brownii																																								0.5
Cheilanthes sieberi subsp. *sieberi*																	0.5																							
Cleome viscosa			0.5		0.5	0.5	0.5										0.5	0.5			0.5			0.5		0.5	0.5	0.5		0.5		0.5	0.5	0.5		0.5			
Clerodendrum floribundum var. *angustifolium*	0.5																							0.5																0.5
Clerodendrum sp.																																								
Clerodendrum tomentosum var. *lanceolatum*																																								0.5
Codonocarpus cotinifolius																																								0.5
Corchorus ?crozophorifolius							0.5																																	

Species	MH376	MH377	MH38	MH39	MH392	MH393	MH394	MH395	MH396	MH397	MH398	MH399r	MH40	MH400	MH401	MH402	MH403	MH404	MH405	MH406	MH407	MH408	MH409	MH41	MH42	MH43	MH44	MHJ301r	MHJ302	MHJ303	MHJ304	MHJ305	MHJ306	MHJ307	MHJ309r	MHJr02	MHJr04	MHJr06	MHr200	OPPS
Corchorus crozophorifolius																																						0.5		
Corchorus lasiocarpus subsp. *parvus*	2	0.5			0.5	0.5		0.5	0.5					0.5			0.5	0.5	0.5	0.5						0.5	0.5	0.5		0.5		0.5	0.5	0.5			0.5		0.5	
Corchorus parviflorus																													0.5											
Corchorus sp.																																								
Corchorus tridens																																								0.5
Corymbia candida								2								2	2	3																						0.5
Corymbia ferriticola																																								0.5
Corymbia hamersleyana	2		9										0.5						1	3								0.5	3	0.5	0.5		1			5	0.5	2		0.5
Crotalaria ?novae-hollindae																																								
Crotalaria medicaginea var. *neglecta*																		0.5																						0.5
Cucumis melo																																	0.5							
Cucumis variabilis						0.5												0.5	0.5	0.5			0.5			0.5			0.5			0.5	0.5	0.5						
Cullen leucochaites																																								
Cullen martinii																		0.5		0.5																					
Cullen pogonocarpum																																								0.5
Cymbopogon ambiguus			0.5		0.5	0.5						0.5								0.5				0.5				0.5			0.5	0.5							0.5
Cynanchum floribundum																																								
Cynanchum pedunculatum																																								
Cyperus cunninghamii subsp. *cunninghamii*												0.5																				0.5								
Cyperus hesperius																																								0.5
Cyperus iria																							0.5																	
Cyperus squarrosus																					0.5																			
Cyperus vaginatus			0.5		0.5																					1	0.5					0.5								
Dactyloctenium radulans																0.5	0.5				0.5	0.5	0.5																	
Dampiera candicans													0.5	0.5																	0.5						0.5		0.5	0.5
Dodonaea coriacea																												0.5		0.5									0.5
Duperreya commixta																																	0.5						0.5
Dysphania kalpari																																							0.5
Dysphania melanocarpa																																	0.5						
Dysphania rhadinostachya subsp. *rhadinostachya*																0.5	0.5	0.5		0.5	0.5	0.5	0.5					0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5		0.5	0.5		0.5
Dysphania sp.																																								
Ehretia saligna																																								0.5
Eleocharis geniculata																																								
Enchylaena tomentosa var. *tomentosa*																							0.5																	
Enneapogon caerulescens																														0.5										
Enteropogon ramosus																							0.5																	
Eragrostis dielsii																																		0.5						0.5
Eragrostis eriopoda																																								
Eragrostis leptocarpa																							0.5																	
Eragrostis pergracilis																	0.5																							
Eremophila forrestii																		0.5																						0.5
Eremophila forrestii subsp. *forrestii*																							0.5																	

Species	MH376	MH377	MH38	MH39	MH392	MH393	MH394	MH395	MH396	MH397	MH398	MH399r	MH40	MH400	MH401	MH402	MH403	MH404	MH405	MH406	MH407	MH408	MH409	MH41	MH42	MH43	MH44	MHJ301r	MHJ302	MHJ303	MHJ304	MHJ305	MHJ306	MHJ307	MHJ309r	MHJr02	MHJr04	MHJr06	MHr200	OPPS
Eremophila fraseri subsp. *fraseri*																									2										0.5					0.5
Eremophila longifolia																0.5		0.5														0.5				0.5				0.5
Eriachne aristidea																																0.5								0.5
Eriachne mucronata	0.5		0.5			0.5						0.5							0.5					0.5		0.5					0.5	0.5							
Eriachne pulchella subsp. *dominii*																																0.5	0.5		0.5					
Eriachne pulchella subsp. *pulchella*																									0.5							0.5								
Eriachne sp.																																								
Eriachne tenuiculmis						0.5																											0.5							
Eucalyptus camaldulensis subsp. *refulgens*																										14	20													
Eucalyptus leucophloia subsp. *leucophloia*			0.5	1					1			1		1										25	1														
Eucalyptus sp.																																							
Eucalyptus victrix					6	2									7											14	7												
Eulalia aurea																																0.5							
Euphorbia australis						0.5													0.5																				
Euphorbia australis var. *hispidula*																																							
Euphorbia australis var. *subtomentosa*														0.5			0.5			0.5								0.5	0.5										0.5
Euphorbia biconvexa					0.5	0.5		0.5							0.5		0.5	0.5			0.5	0.5							0.5										
Euphorbia boophthona																0.5	0.5	0.5			0.5	0.5	0.5						0.5										0.5
Euphorbia boopthona/tannensis								0.5											0.5																				
Euphorbia schultzii					0.5	0.5	0.5			0.5	0.5															0.5					0.5	0.5	0.5						0.5
Euphorbia sp.																																							
Euphorbia tannensis																																		0.5					
Evolvulus alsinoides var. *villosicalyx*					0.5												0.5	0.5					0.5			0.5			0.5			0.5	0.5							0.5
Ficus aculeata var. *aculeata*																																								0.5
Ficus aculeata var. *indecora*																								0.5																
Ficus brachypoda																								0.5																0.5
Fimbristylis dichotoma																																								
Flueggea virosa																																								0.5
Flueggea virosa subsp. *melanthesoides*					0.5							0.5												0.5			0.5													0.5
Gomphrena cunninghamii					0.5												0.5											0.5	0.5			0.5	0.5	0.5						0.5
Goodenia forrestii								0.5									0.5	0.5					0.5						0.5			0.5								0.5
Goodenia lamprosperma																																								0.5
Goodenia microptera																	0.5	0.5		0.5								0.5	0.5		0.5									0.5
Goodenia stobbsiana																			0.5									0.5	0.5	0.5	0.5					0.5		0.5	
Gossypium australe					0.5	0.5		0.5										0.5		0.5								0.5	0.5					0.5			0.5		0.5	0.5
Gossypium robinsonii	0.5		0.5		0.5	0.5									0.5				0.5							0.5	0.5						0.5	0.5						0.5
Grevillea pyramidalis subsp. *leucadendron*	0.5							0.5																					0.5			0.5	0.5	0.5		0.5				
Grevillea wickhamii			0.5	2	0.5								1	1				0.5	3	0.5					0.5			0.5	0.5	0.5		0.5	1	1					0.5	
Hakea chordophylla																												0.5	0.5										1	
Hakea lorea subsp. *lorea*								0.5									0.5																							
Helichrysum luteoalbum																																								
Heliotropium heteranthum																																								0.5

Species	MH376	MH377	MH38	MH39	MH392	MH393	MH394	MH395	MH396	MH397	MH398	MH399r	MH40	MH400	MH401	MH402	MH403	MH404	MH405	MH406	MH407	MH408	MH409	MH41	MH42	MH43	MH44	MHJ301r	MHJ302	MHJ303	MHJ304	MHJ305	MHJ306	MHJ307	MHJ309r	MHJr02	MHJr04	MHJr06	MHr200	OPPS
Heliotropium ovalifolium																		0.5	0.5																					
Heliotropium pachyphyllum																																								
Heliotropium tanythrix																		0.5											0.5											
Hibiscus brachychlaenus																						0.5																		
Hibiscus coatesii		0.5																																	0.5					0.5
Hibiscus goldsworthii												0.5																												0.5
Hibiscus leptocladus																																								
Hibiscus sp.																																								
Hibiscus sturtii																0.5																								
Hibiscus sturtii var. *campylochlamys*	0.5																			0.5			0.5							0.5										
Hibiscus sturtii var. *grandiflorus*																	0.5	0.5											0.5										0.5
Hybanthus aurantiacus			0.5		0.5	0.5	0.5				0.5	0.5	0.5					0.5		0.5		0.5				0.5	0.5	0.5				0.5	0.5	0.5			0.5		
Indigofera boviperda															0.5																									
Indigofera colutea																																								0.5
Indigofera linnaei																0.5																								
Indigofera monophylla	0.5		0.5		0.5								0.5	0.5				0.5	0.5										0.5			0.5	0.5	0.5			0.5		0.5
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301) P3																																								0.5
Indigofera trita																0.5																								
Ipomoea muelleri										0.5	0.5						0.5	0.5														0.5	0.5	0.5					
Ipomoea polymorpha																0.5							0.5																	
Isotropis atropurpurea																		0.5	0.5	0.5									0.5								0.5		0.5
Ixiochlamys cuneifolia																																								
Jasminum didymum subsp. *lineare*	0.5																		0.5					0.5	0.5				0.5				0.5		0.5	0.5		0.5		0.5
Keraudrenia velutina subsp. *elliptica*													0.5																			0.5								
Lepidium pholidogynum																0.5						0.5	0.5																	
Lobelia arnhemiaca																																								0.5
Lobelia heterophylla																																								0.5
Lobelia sp.																																								
Lysiana casuarinae																																0.5								
Maireana melanocoma																																								
Maireana planifolia																	0.5				0.5																			
Marsilea sp.																																								
Melaleuca argentea																																								
Melaleuca glomerata															2											0.5	0.5													
Melaleuca linophylla																																								0.5
Melhania oblongifolia																																								
Mollugo molluginea	0.5													0.5				0.5	0.5	0.5								0.5	0.5	0.5	0.5		0.5	0.5	0.5		0.5			
Neptunia dimorphantha																																								0.5
Nicotiana benthamiana																																								0.5
Nicotiana occidentalis																0.5																		0.5					0.5
Notoleptopus decaisnei var. Orbicularis (A.B. Craig 428)					0.5	0.5											0.5	0.5								0.5	0.5		0.5		0.5	0.5	0.5	0.5					
Oldenlandia crouchiana																												0.5			0.5					0.5				

Species	MH376	MH377	MH38	MH39	MH392	MH393	MH394	MH395	MH396	MH397	MH398	MH399r	MH40	MH400	MH401	MH402	MH403	MH404	MH405	MH406	MH407	MH408	MH409	MH41	MH42	MH43	MH44	MHJ301r	MHJ302	MHJ303	MHJ304	MHJ305	MHJ306	MHJ307	MHJ309r	MHJr02	MHJr04	MHJr06	MHr200	OPPS
Paraneurachne muelleri																			0.5																	0.5				0.5
Paspalidium ?clementii																																							
Paspalidium clementii																	0.5				0.5									0.5		0.5							
Paspalidium sp.																								0.5															
Paspalidium tabulatum																																0.5	0.5						0.5
Pentalepis trichodesmoides	0.5																												0.5	0.5		0.5	0.5	0.5						0.5
Perotis rara																																0.5							
Petalostylis labicheoides			1	0.5				0.5		0.5			0.5	0.5					0.5	0.5				0.5		0.5	0.5	0.5		0.5	0.5	0.5		0.5	0.5		0.5			0.5
Phyllanthus erwinii																0.5				0.5		0.5	0.5						0.5										
Phyllanthus maderaspatensis			0.5		0.5	0.5				0.5														0.5		0.5	0.5		0.5			0.5	0.5	0.5		0.5		0.5		
Phyllanthus sp.																																							
Pimelea ammocharis																																							
Pluchea dentex																																		0.5					
Pluchea rubelliflora																																0.5							
Pluchea sp.																			0.5																					
Polycarpaea corymbosa																																							0.5
Polycarpaea holtzei																														0.5									0.5
Polycarpaea longiflora																													0.5			0.5	0.5	0.5					0.5
Polygala glaucifolia																												0.5											
Polymeria ambigua																		0.5																					
Polymeria sp.																				0.5																			
Portulaca cyclophylla																					0.5																		
Portulaca oleracea																					0.5		0.5									0.5	0.5						
Pterocaulon sp.						0.5									0.5											0.5				0.5						0.5		0.5		
Pterocaulon sphacelatum																0.5						0.5																	
Pterocaulon sphaeranthoides					0.5													0.5	0.5			0.5					0.5		0.5			0.5	0.5	0.5					0.5
Ptilotus aervoides																																							0.5
Ptilotus appendiculatus					0.5	0.5										0.5	0.5	0.5																					
Ptilotus astrolasius	0.5							0.5						0.5			0.5	0.5	0.5	0.5		0.5			0.5	0.5		0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5		
Ptilotus auriculifolius						0.5																						0.5		0.5				0.5					0.5
Ptilotus axillaris																	0.5	0.5		0.5	0.5		0.5			0.5		0.5		0.5	0.5		0.5	0.5	0.5				
Ptilotus calostachyus					0.5				0.5					0.5					0.5	0.5								0.5	0.5	0.5					0.5		0.5			0.5
Ptilotus clementii																																					0.5	0.5		0.5
Ptilotus fusiformis			0.5																									0.5	0.5	0.5	0.5	0.5					0.5	0.5		0.5
Ptilotus gomphrenoides var. *gomphrenoides*																							0.5																	
Ptilotus incanus					0.5		0.5				0.5																					5								0.5
Ptilotus nobilis subsp. *nobilis*		0.5			0.5			0.5								0.5	1		0.5		0.5	0.5	0.5		0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	0.5	0.5	0.5		0.5
Ptilotus obovatus												0.5												0.5						0.5	0.5		0.5	0.5					
Ptilotus sp.																																							
Rhagodia eremaea																0.5																							
Rhodanthe margarethae																																							0.5
Rhynchosia bungarensis P4																																	0.5						0.5

Species	MH376	MH377	MH38	MH39	MH392	MH393	MH394	MH395	MH396	MH397	MH398	MH399r	MH40	MH400	MH401	MH402	MH403	MH404	MH405	MH406	MH407	MH408	MH409	MH41	MH42	MH43	MH44	MHJ301r	MHJ302	MHJ303	MHJ304	MHJ305	MHJ306	MHJ307	MHJ309r	MHJr02	MHJr04	MHJr06	MHr200	OPPS
Rhynchosia minima					0.5	0.5									0.5	0.5	0.5	0.5	0.5	0.5							0.5		0.5	0.5							0.5		0.5	0.5
Salsola australis								0.5								0.5																								0.5
Sarcostemma viminale																									0.5										0.5					0.5
Sauropus crassifolius																																								0.5
Scaevola ?parviflolia																																								
Scaevola spinescens																													0.5			0.5				0.5		0.5		
Schizachyrium fragile																																								0.5
Schoenoplectus subulatus																																								0.5
Sclerolaena costata								0.5								0.5	0.5				0.5	0.5	0.5																	
Sclerolaena sp.																0.5						0.5	0.5																	
Senna artemisioides subsp. *helmsii*																																								0.5
Senna artemisioides subsp. *oligophylla*								0.5								0.5	0.5	0.5			0.5		0.5										0.5	0.5						0.5
Senna ferraria						0.5																																		
Senna glutinosa subsp. *glutinosa*									0.5			0.5								0.5				0.5				0.5									0.5	0.5	0.5	
Senna glutinosa subsp. *pruinosa*		0.5																																	0.5		0.5			0.5
Senna glutinosa subsp. *x luerssenii*		0.5																							0.5										0.5					
Senna notabilis						0.5										0.5	0.5				0.5	0.5						0.5	0.5	1	1					0.5		0.5		
Senna sp. Meekatharra (E. Bailey 1-26)																					0.5																			0.5
Senna stricta																																								
Senna venusta																														1	1			0.5						0.5
Sesbania formosa	0.5																																							0.5
Sida arsiniata	0.5							0.5								0.5	0.5	0.5				0.5																			
Sida cardiophylla																																								
Sida echinocarpa																																								0.5
Sida fibulifera															0.5	0.5	0.5	0.5			0.5		0.5																	
Sida rohlenae subsp. *rohlenae*								0.5																0.5																	
Sida sp. Articulation below (A.A. Mitchell PRP 1605)									0.5									0.5						0.5																	0.5
Sida sp. Pilbara (A.A. Mitchell PRP 1543)		0.5			0.5																							0.5	0.5					0.5	0.5			0.5	0.5
Solanum ?cleistigamum																				0.5																				
Solanum cleistogamum																0.5						0.5	0.5				0.5	0.5	0.5											
Solanum diversiflorum					0.5	0.5										0.5	0.5	0.5	0.5							0.5	0.5	0.5	0.5										
Solanum elatius																																								
Solanum gabrielae																								0.5																	
Solanum horridum			0.5		0.5	0.5												0.5						0.5		0.5	0.5	0.5	0.5	0.5	0.5				0.5				
Solanum lasiophyllum																																								
Sporobolus australasicus																0.5	0.5					0.5	0.5									0.5	0.5	0.5					0.5
Stackhousia muricata																																								
Stackhousia muricata subsp. annual (W.R. Barker 2172)																																								
Stemodia grossa																0.5																								0.5
Streptoglossa adscendens																																	0.5							
Streptoglossa bubakii																															0.5			0.5						
Streptoglossa decurrens																0.5	0.5												0.5											0.5

Species	MH376	MH377	MH38	MH39	MH392	MH393	MH394	MH395	MH396	MH397	MH398	MH399r	MH40	MH400	MH401	MH402	MH403	MH404	MH405	MH406	MH407	MH408	MH409	MH41	MH42	MH43	MH44	MHJ301r	MHJ302	MHJ303	MHJ304	MHJ305	MHJ306	MHJ307	MHJ309r	MHJr02	MHJr04	MHJr06	MHr200	OPPS
Streptoglossa liatroides																																								
Streptoglossa sp.																					0.5																			
Striga curviflora																																0.5							
Stylobasium spathulatum	0.5		0.5						0.5									0.5	0.5	0.5						0.5	0.5		0.5			0.5	0.5	0.5		0.5				
Swainsona formosa																													0.5				0.5							0.5
Swainsona sp.																																								
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	0.5				0.5	0.5	0.5																			0.5	0.5				0.5	8	7	0.5					
Tephrosia sp. B Kimberley Flora (C.A. Gardner 7300)																																							
Tephrosia sp. Bungaroo Creek (M.E. Trudgen 11601)																																							0.5
Tephrosia sp. Fortescue (A.A. Mitchell 606)																																							
Tephrosia supina																																							0.5
Tephrosia uniovulata				0.5									0.5						0.5	0.5																			0.5
Tephrosia virens																																							
Themeda triandra			0.5																								0.5									0.5			
Tinospora smilacina																																							0.5
Trachymene oleracea subsp. *oleracea*																		0.5	0.5	0.5								0.5	0.5	0.5	0.5	1	0.5	0.5				0.5		
Trianthema cusackianum																																							
Trianthema pilosum																	0.5																						
Trianthema triquetrum					0.5											0.5	0.5				0.5	0.5	0.5																	0.5
Tribulus ?occidentalis																																							
Tribulus hirsutus																																							0.5
Tribulus macrocarpus								0.5									0.5	0.5											0.5			0.5							0.5
Tribulus platypterus	0.5																																						0.5
Tribulus sp.																																	0.5						
Tribulus suberosus																																							0.5
Trichodesma zeylanicum var. *zeylanicum*	0.5							0.5									0.5	0.5	0.5	0.5								0.5	0.5	0.5	0.5	0.5	0.5	0.5		0.5		0.5		
Triodia angusta																																							0.5
Triodia epactia	2							2								32	35	40	25	45	12	18	9			0.5	0.5		2			1	7	28		1				
Triodia longiceps																						0.5																		
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3			0.5		0.5				2															2	1					3					3				1	0.5
Triodia wiseana	15	20	25	15	3	7		20	23			5	17	12	14				0.5				0.5	20	6			25	50	25	26				16	17	20	55	25	
Triumfetta ?chaetocarpa																																							
Triumfetta appendiculata					0.5																					0.5	0.5					0.5	0.5						
Triumfetta chaetocarpa																		0.5	0.5	0.5											0.5								
Triumfetta clementii					0.5																							0.5	0.5										
Triumfetta johnstonii									0.5																															0.5
Triumfetta maconochieana																												0.5												
Triumfetta sp.																																								
Typha domingensis																																							0.5
Vigna lanceolata var. *lanceolata*																																							0.5
Wahlenbergia tumidifructa																																							
Waltheria indica					0.5	0.5												0.5	0.5							0.5	0.5	0.5				0.5	0.5	0.5					0.5

? denotes unconfirmed ID

Table M.3: Vascular flora species recorded during the current survey and previously in the vicinity of the survey area (Astron 2011, 2016a, 2016b; Biota 2003, Biota 2006, Biota 2007. 2011, 2012; Rio Tinto 2014).

Family	Species name	Conservation status	Weed	Current Astron Report	Astron 2011	Astron 2016a	Astron 2016b	Biota 2003	Biota 2006	Biota 2007	Biota 2011	Biota 2012	Rio Tinto 2014
Acanthaceae	*Dicladanthera forrestii*					x							
	Dicladanthera glabra	P2				x							
	Dipteracanthus australasicus subsp. *australasicus*					x							
	Rostellularia adscendens var. *clementii*				x	x	x					x	
Aizoaceae	*Trianthema cusackianum*			x			x						
	Trianthema glossostigmum								x	x		x	
	Trianthema oxycalyptrum						x						
	Trianthema oxycalyptrum var. *oxycalyptrum*								x	x			
	Trianthema pilosum			x		x	x		x	x		x	x
	Trianthema triquetrum			x		x	x		x	x		x	x
	Trianthema turgidifolium											x	
	Zaleya galericulata					x	x			x			x
Amaranthaceae	*Achyranthes aspera*				x	x	x		x	x		x	
	Aerva javanica		*	x	x	x	x		x	x	x	x	
	Alternanthera denticulata						x			x			
	Alternanthera nana			x	x	x	x	x	x	x	x	x	x
	Alternanthera nodiflora			x			x		x	x		x	
	Alternanthera sp.											x	
	Amaranthus aff. *interruptus*								x				
	Amaranthus cuspidifolius			x		x	x			x		x	
	Amaranthus interruptus				x					x			
	Amaranthus mitchellii			x		x	x	x					
	Amaranthus sp.					x	x		x				
	Amaranthus undulatus			x	x	x	x		x	x	x	x	
	Gomphrena affinis subsp. *pilbarensis*						x		x	x			
	Gomphrena cunninghamii			x	x	x	x	x	x	x		x	
	Ptilotus aervoides			x		x	x		x	x		x	
	Ptilotus appendiculatus			x	x	x	x	x	x	x	x	x	
	Ptilotus arthrolasius								x	x			
	Ptilotus astrolasius			x		x	x	x	x	x	x	x	x
	Ptilotus auriculifolius			x	x	x	x		x	x		x	
	Ptilotus axillaris			x		x	x		x	x		x	x
	Ptilotus calostachyus			x	x	x	x	x	x	x	x	x	x
	Ptilotus carinatus						x						
	Ptilotus clementii			x		x	x		x	x		x	
	Ptilotus fusiformis			x	x	x	x	x	x	x		x	
	Ptilotus gaudichaudii subsp. *gaudichaudii*								x	x			

Family	Species name	Conservation status	Weed	Current Astron Report	Astron 2011	Astron 2016a	Astron 2016b	Biota 2003	Biota 2006	Biota 2007	Biota 2011	Biota 2012	Rio Tinto 2014
Amaranthaceae	*Ptilotus gomphrenoides*						x						
	Ptilotus gomphrenoides var. *gomphrenoides*			x		x			x	x			
	Ptilotus incanus			x		x	x		x	x		x	
	Ptilotus macrocephalus								x	x			
	Ptilotus mollis										x		
	Ptilotus murrayi						x		x	x			
	Ptilotus nobilis				x		x						
	Ptilotus nobilis subsp. *nobilis*			x		x			x	x	x	x	x
	Ptilotus obovatus			x	x								
	Ptilotus obovatus var. *obovatus*					x	x		x	x			
	Ptilotus polystachyus								x	x			
	Ptilotus rotundifolius						x						
	Ptilotus sp.			x		x							
Apiaceae	*Daucus glochidiatus*						x			x			
Apocynaceae	*Carissa lanceolata*			x		x	x					x	
	Cynanchum floribundum			x	x	x	x			x	x		
	Cynanchum pedunculatum			x									
	Gymnanthera cunninghamii	P3					x						
	Rhyncharrhena linearis			x						x			
	Sarcostemma viminale			x			x						
	Sarcostemma viminale subsp. *australe*					x			x	x	x		
Araliaceae	*Astrotricha hamptonii*					x							
	Trachymene oleracea subsp. *oleracea*			x	x	x	x	x	x	x	x	x	
Arecaceae	*Phoenix dactylifera*		*	x	x		x		x	x			
Asteraceae	*Angianthus acrohyalinus*								x				
	Bidens bipinnata		*	x		x			x	x			
	Blumea tenella					x	x		x			x	
	Calocephalus beardii						x		x				
	Calocephalus knappii			x		x	x	x	x	x			
	Calotis hispidula			x		x			x	x			
	Calotis plumulifera			x					x	x			
	Calotis porphyroglossa					x							
	Calotis sp.						x						
	Centipeda minima subsp. *macrocephala*			x		x	x		x	x		x	
	Chrysocephalum sp.												x
	Flaveria trinervia		*	x		x	x		x	x			
	Gnephosis arachnoidea								x	x			
	Helichrysum luteoalbum			x			x			x		x	
	Ixiochlamys cuneifolia			x					x	x			

Family	Species name	Conservation status	Weed	Current Astron Report	Astron 2011	Astron 2016a	Astron 2016b	Biota 2003	Biota 2006	Biota 2007	Biota 2011	Biota 2012	Rio Tinto 2014
Asteraceae	*Lactuca saligna*									x		x	
	Lactuca serriola		*	x		x	x			x			
	Pentalepis trichodesmoides			x	x		x	x	x	x	x	x	
	Pentalepis trichodesmoides subsp. *hispida*	P2					x						
	Pentalepis trichodesmoides subsp. *trichodesmoides*					x							
	Peripleura arida						x						
	Pluchea dentex			x			x		x	x			
	Pluchea dunlopii							x	x	x	x	x	
	Pluchea ferdinandi-muelleri								x	x	x	x	
	Pluchea rubelliflora			x	x	x	x		x	x	x	x	x
	Pluchea sp.			x									
	Pluchea tetranthera						x		x	x			
	Pterocaulon serrulatum var. *serrulatum*					x							
	Pterocaulon serrulatum var. *velutinum*					x							
	Pterocaulon sp.			x	x		x						x
	Pterocaulon sphacelatum			x			x	x		x	x	x	x
	Pterocaulon sphaeranthoides			x	x	x	x		x	x		x	
	Pterocaulon sphaeranthoides x *sphacelatum*								x	x			
	Rhodanthe floribunda								x	x			
	Rhodanthe margarethae			x		x			x	x		x	
	Sonchus oleraceus		*	x		x	x		x	x	x	x	
	Streptoglossa adscendens			x									
	Streptoglossa bubakii			x	x	x	x		x	x		x	
	Streptoglossa decurrens			x		x	x		x	x	x	x	
	Streptoglossa liatroides			x		x			x	x			
	Streptoglossa odora								x	x		x	
	Streptoglossa sp.			x		x	x						
	Tridax procumbens						x						
	Vittadinia sp.								x	x			
Boraginaceae	*?Ehretia saligna*			x									
	Ehretia saligna			x		x	x						
	Ehretia saligna var. *saligna*						x		x	x			
	Heliotropium ?inexplicitum								x				
	Heliotropium chrysocarpum								x	x			
	Heliotropium crispatum								x	x		x	
	Heliotropium cunninghamii								x	x		x	
	Heliotropium heteranthum			x		x	x		x	x		x	
	Heliotropium ovalifolium			x		x	x				x		
	Heliotropium pachyphyllum			x						x		x	

Family	Species name	Conservation status	Weed	Current Astron Report	Astron 2011	Astron 2016a	Astron 2016b	Biota 2003	Biota 2006	Biota 2007	Biota 2011	Biota 2012	Rio Tinto 2014
Boraginaceae	*Heliotropium tanythrix*			x		x	x						
	Heliotropium tenuifolium								x	x		x	
	Heliotropium transforme								x	x			
	Trichodesma zeylanicum				x								x
	Trichodesma zeylanicum var. *zeylanicum*			x		x	x	x	x	x	x	x	
Brassicaceae	*Lepidium muelleri-ferdinandii*					x			x	x			
	Lepidium pedicellosum						x		x	x			
	Lepidium phlebopetalum								x	x		x	
	Lepidium pholidogynum			x		x			x	x		x	
	Lepidium platypetalum								x	x			
	Lepidium sp.						x						
Campanulaceae	*Lobelia arnhemiaca*			x			x		x		x	x	
	Lobelia heterophylla			x		x			x	x			
	Lobelia sp.			x									
	Wahlenbergia caryophylloides				x								
	Wahlenbergia tumidifructa			x		x	x		x	x			
Capparaceae	*Capparis spinosa*				x								
	Capparis spinosa var. *nummularia*			x		x	x	x	x	x	x	x	
	Capparis umbonata								x	x			
Caryophyllaceae	*Polycarpaea corymbosa*			x									
	Polycarpaea corymbosa var. *corymbosa*					x	x		x	x		x	
	Polycarpaea holtzei			x		x	x		x	x		x	
	Polycarpaea involucrata					x							
	Polycarpaea longiflora			x	x	x	x	x	x	x	x	x	
Celastraceae	*Stackhousia intermedia*					x	x		x	x		x	
	Stackhousia muricata			x									
	Stackhousia muricata subsp. annual (W.R. Barker 2172)			x			x			x			
Chenopodiaceae	?*Chenopodium gaudichaudianum*								x	x			
	Dysphania cristata					x							
	Dysphania glomulifera subsp. *eremaea*					x				x			
	Dysphania kalpari			x		x	x						
	Dysphania melanocarpa			x		x	x		x	x			
	Dysphania plantaginella				x		x		x	x		x	
	Dysphania rhadinostachya							x					x
	Dysphania rhadinostachya subsp. *inflata*											x	
	Dysphania rhadinostachya subsp. *rhadinostachya*			x	x	x	x		x	x			
	Dysphania sp.			x			x		x	x			
	Enchylaena tomentosa var. *tomentosa*			x		x	x		x	x	x	x	
	Maireana georgei									x		x	

Family	Species name	Conservation status	Weed	Current Astron Report	Astron 2011	Astron 2016a	Astron 2016b	Biota 2003	Biota 2006	Biota 2007	Biota 2011	Biota 2012	Rio Tinto 2014
Chenopodiaceae	*Maireana melanocoma*			x			x		x	x	x	x	
	Maireana planifolia			x			x		x	x	x		
	Maireana tomentosa						x						
	Maireana villosa				x								
	Rhagodia eremaea			x		x	x		x	x		x	
	Salsola australis			x	x	x	x		x	x		x	
	Sclerolaena cornishiana					x							
	Sclerolaena costata			x			x		x	x		x	x
	Sclerolaena cuneata									x			
	Sclerolaena densiflora								x	x	x	x	
	Sclerolaena eriacantha						x			x	x		
	Sclerolaena sp.			x			x				x		
Cleomaceae	*Cleome uncifera*								x				
	Cleome viscosa			x	x	x	x	x	x		x	x	x
Combretaceae	*Terminalia canescens*			x						x	x		
Convolvulaceae	*Bonamia alatisemina*										x		
	Bonamia erecta			x		x	x						x
	Bonamia linearis								x	x			
	Bonamia media				x	x	x	x	x	x			
	Bonamia pannosa					x			x	x		x	
	Bonamia pilbarensis			x		x	x				x	x	
	Bonamia rosea				x				x	x	x	x	
	Bonamia sp.					x	x						
	Convolvulus angustissimus subsp. *angustissimus*								x	x			
	Duperreya commixta			x		x	x		x		x	x	
	Dysphania glomulifera subsp. *eremaea*								x				
	Dysphania kalpari								x				
	Evolvulus alsinoides var. *decumbens*								x	x	x		
	Evolvulus alsinoides var. *villosicalyx*			x	x	x	x	x	x	x	x	x	x
	Ipomoea coptica								x	x			
	Ipomoea lonchophylla					x							
	Ipomoea muelleri			x	x	x	x	x	x	x	x	x	
	Ipomoea polymorpha			x			x			x			
	Ipomoea sp.					x							
	Operculina aequisepala					x							
	Polymeria ambigua			x		x	x			x		x	
	Polymeria ambigua/calycina							x	x	x			
	Polymeria sp.			x		x	x			x			

Family	Species name	Conservation status	Weed	Current Astron Report	Astron 2011	Astron 2016a	Astron 2016b	Biota 2003	Biota 2006	Biota 2007	Biota 2011	Biota 2012	Rio Tinto 2014
Cucurbitaceae	*Austrobryonia pilbarensis*					x			x				
	Citrullus colocynthis		*	x		x	x		x	x	x		
	Citrullus lanatus		*				x						
	Cucumis melo			x		x	x		x	x			
	Cucumis variabilis			x		x	x	x	x	x	x	x	x
	Trichosanthes cucumerina					x			x	x			
	Trichosanthes cucumerina var. *cucumerina*						x						
Cyperaceae	*Bulbostylis barbata*			x	x	x	x		x	x		x	x
	Bulbostylis turbinata								x	x			
	Cyperus bifax								x	x			
	Cyperus bulbosus						x						
	Cyperus cunninghamii subsp. *cunninghamii*			x	x	x	x		x	x	x	x	
	Cyperus difformis						x			x		x	
	Cyperus hesperius			x		x		x	x	x			
	Cyperus iria			x		x	x		x	x		x	
	Cyperus sp.						x						
	Cyperus squarrosus			x			x		x	x		x	
	Cyperus vaginatus			x	x	x	x	x	x	x	x	x	x
	Eleocharis atropurpurea						x			x			
	Eleocharis dulcis								x	x			
	Eleocharis geniculata			x					x	x	x	x	
	Fimbristylis depauperata					x							
	Fimbristylis dichotoma			x		x	x		x	x	x		
	Fimbristylis elegans						x						
	Fimbristylis microcarya									x		x	
	Fimbristylis sp.						x						
	Schoenoplectus subulatus			x					x	x		x	
Elatinaceae	*Bergia ammannioides*					x							
	Bergia pedicellaris								x	x			
	Bergia perennis subsp. *perennis*								x	x			
	Bergia trimera					x			x	x		x	
Euphorbiaceae	*Adriana tomentosa*			x									
	Adriana tomentosa var. *tomentosa*					x	x		x	x	x	x	
	Euphorbia aff. *australis*								x	x		x	
	Euphorbia aff. *drummondii*								x	x			
	Euphorbia schultzii							x					
	Euphorbia aff. *wheeleri*										x		
	Euphorbia alsiniflora (currently *E. coghlanii* or *E. trigonosperma*)										x	x	

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Euphorbiaceae	*Euphorbia australis*			x	x		x		x	x	x		x
	Euphorbia australis var. *australis*					x							
	Euphorbia australis var. *hispidula*			x		x							
	Euphorbia australis var. *subtomentosa*			x		x	x						
	Euphorbia biconvexa			x		x	x	x	x	x		x	
	Euphorbia boophthona			x		x	x	x	x	x		x	
	Euphorbia boophthona/tannensis			x									
	Euphorbia careyi			x					x	x		x	
	Euphorbia coghlanii								x	x			
	Euphorbia hirta		*	x	x		x		x	x	x	x	
	Euphorbia schultzii			x		x	x						
	Euphorbia sp.			x	x	x	x	x	x		x	x	
	Euphorbia tannensis			x									
	Euphorbia tannensis subsp. *eremophila*					x	x	x	x	x	x	x	x
	Euphorbia vaccaria var. *vaccaria*			x									
	Euphorbia wheeleri				x				x	x	x	x	
Fabaceae	?*Indigofera rugosa*										x		
	Acacia ?ampliceps										x		
	Acacia ?elachantha			x									
	Acacia ?orthocarpa			x									
	Acacia acradenia			x					x	x	x		
	Acacia ampliceps			x	x		x		x	x	x	x	
	Acacia ampliceps x sclerosperma					x						x	
	Acacia ancistrocarpa			x	x	x	x	x	x	x	x	x	x
	Acacia ancistrocarpa x ?										x		
	Acacia ancistrocarpa x arida									x			
	Acacia ancistrocarpa x ptychophylla			x								x	
	Acacia ancistrocarpa x trachycarpa											x	
	Acacia arida								x	x	x		
	Acacia atkinsiana			x		x	x		x	x	x		
	Acacia bivenosa			x	x	x	x	x	x	x	x	x	x
	Acacia citrinoviridis				x		x		x	x	x		
	Acacia colei										x		x
	Acacia colei var. *ileocarpa*			x	x	x	x	x	x	x		x	
	Acacia coriacea						x						
	Acacia coriacea subsp. *pendens*				x				x		x		
	Acacia cowleana									x			
	Acacia dictyophleba								x	x			
	Acacia elachantha			x		x		x		x	x	x	

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Fabaceae	*Acacia inaequilatera*			x	x	x	x	x	x	x	x	x	x
	Acacia maitlandii			x	x	x	x		x	x	x	x	
	Acacia monticola			x		x	x		x	x			
	Acacia orthocarpa			x	x	x	x	x		x	x		
	Acacia pruinocarpa			x	x	x	x	x	x	x	x	x	
	Acacia pteraneura										x		
	Acacia ptychophylla			x		x	x	x	x	x	x	x	x
	Acacia ptychophylla x ancistrocarpa											x	
	Acacia pyrifolia				x			x	x	x	x		x
	Acacia pyrifolia var. *morrisonii*								x			x	
	Acacia pyrifolia var. *pyrifolia*			x		x	x					x	
	Acacia sclerosperma subsp. *sclerosperma*			x		x	x		x	x	x	x	
	Acacia sericophylla								x	x	x		
	Acacia sp.			x							x		
	Acacia spondylophylla						x		x	x			
	Acacia synchronicia			x		x	x	x	x	x	x	x	x
	Acacia tenuissima						x	x	x	x	x		
	Acacia tetragonophylla								x	x			
	Acacia trachycarpa			x	x	x	x	x	x	x	x	x	
	Acacia trachycarpa x *tumida* var. *pilbarensis*			x		x	x				x		
	Acacia trudgeniana									x	x		
	Acacia tumida							x					
	Acacia tumida var. *pilbarensis*			x	x	x	x		x	x	x	x	
	Acacia wanyu				x		x		x	x	x		
	Acacia xiphophylla			x		x	x		x	x	x	x	
	Aeschynomene indica						x		x	x			
	Alysicarpus muelleri				x	x	x		x	x		x	
	Cajanus cinereus			x		x	x		x	x			
	Crotalaria cunninghamii						x				x		
	Crotalaria dissitiflora subsp. *benthamiana*								x	x			
	Crotalaria medicaginea				x			x	x				
	Crotalaria medicaginea var. *neglecta*			x		x	x			x		x	
	Crotalaria novae-hollandiae								x				
	Crotalaria novae-hollandiae subsp. *novae-hollandiae*					x	x			x			
	Cullen aff. *lachnostachys*								x				
	Cullen graveolens								x	x			
	Cullen lachnostachys						x		x	x		x	x
	Cullen leucanthum						x		x	x			
	Cullen leucochaites			x						x	x	x	x

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Fabaceae	*Cullen martinii*			x		x	x		x	x		x	x
	Cullen pogonocarpum			x		x			x	x		x	x
	Cullen pustulatum					x							
	Cullen sp.						x						
	Desmodium filiforme					x							
	Desmodium muelleri						x						
	Dichrostachys spicata								x				
	Erythrina vespertilio						x		x	x			
	Gastrolobium grandiflorum								x	x			
	Glycine canescens					x	x			x			
	Gompholobium oreophilum						x						
	Indigastrum parviflorum								x	x			
	Indigofera boviperda			x									
	Indigofera boviperda subsp. *boviperda*								x		x		
	Indigofera colutea			x	x	x	x		x	x		x	
	Indigofera linifolia					x	x		x	x		x	
	Indigofera linnaei			x		x	x		x	x		x	
	Indigofera monophylla			x		x	x	x	x	x	x	x	x
	Indigofera oblongifolia		*						x	x			
	Indigofera rugosa						x		x	x			
	Indigofera sp.						x						
	Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	P3		x		x	x					x	
	Indigofera sp. Fractiflexa (S. van Leeuwen 3773)					x							
	Indigofera trita			x		x			x	x		x	
	Isotropis atropurpurea			x		x	x		x	x	x	x	x
	Lotus australis											x	
	Lotus cruentus					x	x		x	x			
	Neptunia dimorphantha			x		x	x		x	x		x	
	Parkinsonia aculeata		*						x	x			
	Petalostylis cassioides								x	x			
	Petalostylis labicheoides			x	x	x	x	x	x	x	x	x	x
	Rhynchosia bungarensis	P4		x	x	x	x	x	x	x	x		
	Rhynchosia minima			x	x	x	x	x	x	x	x	x	x
	Senna ?*artemisioides* subsp. *oligophylla* hybrid with unknown species								x				
	Senna aff. *artemisioides* subsp. *oligophylla* (thinly sericeous MET 15,035)								x		x		
	Senna artemisioides subsp. *helmsii*			x		x	x		x		x	x	
	Senna artemisioides subsp. *oligophylla*			x		x	x	x	x			x	x

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Fabaceae	*Senna artemisioides* subsp. *oligophylla* x subsp. *helmsii*							x		x	x	x	
	Senna ferraria			x			x					x	
	Senna glutinosa subsp. *glutinosa*			x	x	x	x	x	x	x	x	x	x
	Senna glutinosa subsp. *glutinosa x luerssenii*							x					
	Senna glutinosa subsp. *glutinosa* hybrid with ?*artemisioides* subsp. *oligophylla*								x				
	Senna glutinosa subsp. *glutinosa* hybrid with ?*artemisioides* subsp. *oligophylla* (thinly sericeous MET 15,035)								x				
	Senna glutinosa subsp. *glutinosa* hyrbrid with subsp. x *luerssenii*										x	x	
	Senna glutinosa subsp. *glutinosa* hyrbrid with unknown species										x		
	Senna glutinosa subsp. *pruinosa*			x	x	x	x	x	x		x	x	x
	Senna glutinosa subsp. *pruinosa* hybrid with subsp. *glutinosa*										x		
	Senna glutinosa subsp. *pruinosa* hybrid with subsp. x *luerssenii*			x							x	x	
	Senna glutinosa subsp. x *luerssenii*					x	x	x	x	x	x	x	x
	Senna glutinosa subsp. x *luerssenii* hybrid with subsp. *stricta*								x				
	Senna notabilis			x	x	x	x	x	x		x	x	x
	Senna sp. Meekatharra (E. Bailey 1-26)			x								x	
	Senna stricta			x									
	Senna symonii					x	x						
	Senna venusta			x		x	x		x	x			x
	Sesbania cannabina				x	x	x		x	x	x	x	x
	Sesbania formosa			x	x		x		x	x	x		
	Swainsona complanata								x	x			
	Swainsona formosa			x		x	x	x	x	x		x	
	Swainsona forrestii						x						
	Swainsona kingii											x	
	Swainsona sp.			x			x						
	Tephrosia aff. *clementii*								x	x			
	Tephrosia aff. *rosea*									x			
	Tephrosia aff. sp. Fortescue (A.A. Mitchell 606)								x	x			
	Tephrosia aff. *supina*								x	x		x	
	Tephrosia rosea var. *clementii*				x								
	Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)			x	x	x	x		x	x	x	x	x
	Tephrosia rosea var. *rosea*				x								
	Tephrosia sp.						x			x			
	Tephrosia sp. B Kimberley Flora (C.A. Gardner 7300)			x		x	x	x	x	x	x		
	Tephrosia sp. Bungaroo Creek (M.E. Trudgen 11601)			x		x	x	x	x	x		x	x

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Fabaceae	*Tephrosia* sp. Fortescue (A.A. Mitchell 606)			x				x		x			
	Tephrosia sp. NW Eremaean (S. van Leeuwen et al. PBS 0356)						x			x			
	Tephrosia spechtii							x	x	x	x		
	Tephrosia stipuligera						x						
	Tephrosia supina			x	x	x	x			x			x
	Tephrosia uniovulata			x		x	x		x	x	x		
	Tephrosia virens			x		x							
	Vachellia farnesiana		*	x	x	x	x	x	x	x	x	x	x
	Vigna lanceolata					x						x	
	Vigna lanceolata var. lanceolata			x	x		x		x	x	x		
Gentianaceae	*Schenkia australis*						x					x	
	Schenkia clementii						x		x	x			
Goodeniaceae	*Dampiera candicans*			x		x	x		x	x	x	x	x
	Goodenia forrestii			x	x	x	x	x	x	x	x	x	
	Goodenia lamprosperma			x			x		x	x	x		
	Goodenia microptera			x	x	x	x		x	x		x	x
	Goodenia muelleriana											x	
	Goodenia stellata						x		x	x	x	x	
	Goodenia stobbsiana			x		x		x				x	x
	Goodenia tenuiloba						x		x	x		x	
	Goodenia triodiophila						x						
	Scaevola ?parvifolia			x									
	Scaevola parvifolia subsp. *pilbarae*								x	x			
	Scaevola spinescens			x		x	x	x	x	x	x		
	Velleia connata								x	x			
Gyrostemonaceae	*Codonocarpus cotinifolius*			x		x	x		x	x	x	x	x
Haloragaceae	*Haloragis gossei*								x	x			
	Haloragis gossei var. *gossei*					x							
	Haloragis maierae								x	x			
Juncaceae	*Juncus kraussii*						x						
Lamiaceae	*Basilicum polystachyon*					x	x		x	x		x	
	Clerodendrum floribundum var. *angustifolium*			x		x	x	x	x	x	x		
	Clerodendrum sp.			x									
	Clerodendrum tomentosum var. *lanceolatum*			x			x					x	
	Ocimum basilicum		*	x					x	x			
Lauraceae	*Cassytha capillaris*			x		x	x		x	x	x	x	x
	Cassytha filiformis						x	x					
	Cassytha sp.						x						

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Loranthaceae	*Amyema preissii*			x			x		x	x	x	x	
	Amyema sp.						x						
	Diplatia grandibractea					x				x			
	Lysiana casuarinae			x				x		x	x		
Lythraceae	*Ammannia baccifera*				x		x		x	x	x	x	
	Ammannia multiflora				x	x	x			x			
Malvaceae	*Abutilon* aff. *hannii*							x	x	x		x	
	Abutilon aff. *lepidum*				x					x		x	
	Abutilon aff. sp. Dioicum (A.A. Mitchell PRP 1618)							x					
	Abutilon amplum								x	x	x		
	Abutilon cryptopetalum					x							
	Abutilon cunninghamii									x			
	Abutilon fraseri					x		x	x	x		x	
	Abutilon lepidum			x	x	x	x		x	x		x	
	Abutilon leucopetalum			x									
	Abutilon macrum								x	x		x	
	Abutilon malvifolium					x			x	x			
	Abutilon otocarpum					x	x		x	x		x	
	Abutilon oxycarpum subsp. Prostrate (A.A. Mitchell PRP 1266)								x	x		x	
	Abutilon sp.			x			x		x				x
	Abutilon sp. Dioicum (A.A. Mitchell PRP 1618)			x	x	x	x		x	x	x	x	
	Abutilon sp. Pilbara (W.R. Barker 2025)			x		x	x		x	x		x	x
	Brachychiton acuminatus					x	x			x			
	Brachychiton gregorii					x							
	Corchorus ?crozophorifolius			x									
	Corchorus aff. *parviflorus*										x	x	x
	Corchorus crozophorifolius			x	x	x	x		x	x		x	
	Corchorus incanus									x			
	Corchorus lasiocarpus										x		
	Corchorus lasiocarpus subsp. *parvus*			x	x	x	x			x			
	Corchorus parviflorus			x	x		x						
	Corchorus sidoides			x		x							x
	Corchorus sidoides aff. subsp. *vermicularis*								x	x			
	Corchorus sidoides subsp. *sidoides*								x	x		x	
	Corchorus sp.			x		x	x				x		
	Corchorus tectus					x	x	x				x	
	Corchorus tridens			x		x	x		x	x		x	
	Gossypium australe			x	x	x	x					x	x
	Gossypium australe (Burrup Peninsula form)				x			x	x		x	x	

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Malvaceae	*Gossypium australe* (Whim Creek form)								x			x	
	Gossypium robinsonii			x	x	x	x	x	x		x	x	x
	Hibiscus aff. *coatesii*								x		x		
	Hibiscus aff. *sturtii*								x				
	Hibiscus austrinus						x						
	Hibiscus austrinus var. *austrinus*						x			x	x		
	Hibiscus brachychlaenus			x		x	x		x	x			
	Hibiscus brachysiphonius								x	x			
	Hibiscus burtonii					x				x			
	Hibiscus coatesii			x		x	x			x			
	Hibiscus goldsworthii			x	x	x	x		x	x			
	Hibiscus leptocladus			x		x	x		x	x			x
	Hibiscus panduriformis								x				
	Hibiscus sp.			x		x	x						
	Hibiscus sturtii			x			x						
	Hibiscus sturtii aff. var. *platychlamys*								x				
	Hibiscus sturtii aff. var. *grandiflorus*								x	x	x	x	
	Hibiscus sturtii var. *campylochlamys*			x		x	x		x	x	x	x	
	Hibiscus sturtii var. *grandiflorus*			x			x			x			
	Hibiscus sturtii var. *platychlamys*								x	x		x	
	Hibiscus sturtii var. *grandiflorus*			x			x			x			
	Hibiscus sturtii var. *platychlamys*								x	x		x	
	Hibiscus verdcourtii									x			
	Keraudrenia ?nephrosperma							x					
	Keraudrenia nephrosperma					x			x	x	x		
	Keraudrenia sp.			x									
	Keraudrenia velutina subsp. *elliptica*			x		x	x			x	x	x	x
	Malvastrum americanum		*	x	x	x	x	x	x	x	x	x	x
	Marsilea hirsuta						x		x	x			
	Melhania aff. *oblongifolia*							x					
	Melhania oblongifolia			x		x	x		x	x		x	
	Melhania sp.								x	x	x	x	
	Melochia pyramidata		*				x		x	x			
	Sida aff. *cardiophylla*								x	x			
	Sida aff. *clementii*									x			
	Sida aff. *echinocarpa*										x		
	Sida aff. *fibulifera*								x	x	x	x	
	Sida aff. sp. Pilbara (A.A. Mitchell PRP 1543)										x	x	
	Sida arenicola			x			x						
	Sida arsiniata			x	x	x	x		x	x	x	x	x
	Sida cardiophylla			x					x				

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Malvaceae	*Sida clementii*								x	x			x
	Sida echinocarpa			x		x	x	x	x	x		x	
	Sida fibulifera			x		x	x				x		
	Sida kingii								x	x			
	Sida platycalyx					x							
	Sida rohlenae					x							
	Sida rohlenae subsp. *rohlenae*			x			x		x	x	x		
	Sida sp.					x	x		x				x
	Sida sp. Articulation below (A.A. Mitchell PRP 1605)			x		x	x				x		
	Sida sp. Barlee Range (S. van Leeuwen 1642)	P3				x							
	Sida sp. dark green fruits (S. van Leeuwen 2260)					x	x						
	Sida sp. Excedentifolia (J.L. Egan 1925)					x							
	Sida sp. Pilbara (A.A. Mitchell PRP 1543)			x	x	x	x	x		x	x	x	x
	Sida sp. Roy Hill Station (M. Maier 17/3704)									x			
	Sida sp. 'rugose'								x	x			
	Sida sp. spiciform panicles (E. Leyland s.n. 14/8/90)								x	x	x	x	x
	Sida sp. verrucose glands (F.H. Mollemans 2423)				x	x	x				x	x	x
	Sida spinosa								x			x	
	Triumfetta ?chaetocarpa			x									
	Triumfetta appendiculata			x			x	x	x	x	x		
	Triumfetta chaetocarpa			x			x		x	x	x	x	
	Triumfetta clementii			x	x	x	x		x	x	x		
	Triumfetta johnstonii			x	x	x	x		x	x	x	x	x
	Triumfetta maconochieana			x	x	x	x		x	x	x		
	Triumfetta sp.			x									
	Waltheria indica			x		x	x	x	x	x	x	x	
	Waltheria virgata					x							
Marsileaceae	*Marsilea* sp.			x						x			
Menispermaceae	*Tinospora smilacina*			X		x	x		x	x			
Molluginaceae	*Glinus lotoides*								x	x	x		
	Glinus oppositifolius								x	x	x	x	
	Mollugo molluginea			x	x	x	x	x	x	x	x	x	x
Moraceae	*Ficus aculeata*						x						
	Ficus aculeata var. *indecora*			x	x	x			x	x	x		
	Ficus brachypoda			x		x	X		x	x	x		
	Ficus platypoda					x							
Myrtaceae	*Corymbia aspera*												x
	Corymbia candida			x	x	x	X				x	x	
	Corymbia candida subsp. *candida*							x	x	x			

Family	Species name	Conservation status	Weed	Current Astron Report	Astron 2011	Astron 2016a	Astron 2016b	Biota 2003	Biota 2006	Biota 2007	Biota 2011	Biota 2012	Rio Tinto 2014
Myrtaceae	*Corymbia deserticola* subsp. *deserticola*								x	x			
	Corymbia ferriticola			x		x				x			
	Corymbia hamersleyana			x	x	x	X	x	x	x	x	x	x
	Corymbia zygophylla								x	x	x		
	Eucalyptus camaldulensis				x				x				x
	Eucalyptus camaldulensis subsp. *refulgens*			x		x	X				x	x	
	Eucalyptus camaldulensis var. *obtusa*									x			
	Eucalyptus leucophloia							x					
	Eucalyptus leucophloia subsp. *leucophloia*			x	x	x	X		x	x	x	x	x
	Eucalyptus sp.			x		x	X						
	Eucalyptus victrix			x	x	x	X	x	x	x	x	x	x
	Eucalyptus xerothermica					x						x	
	Melaleuca argentea			x	x		X		x	x	x		
	Melaleuca bracteata											x	x
	Melaleuca glomerata			x	x	x	X		x	x	x	x	x
	Melaleuca linophylla			x	x		X		x	x			
Nyctaginaceae	*Boerhavia burbidgeana*					x	X		x	x			
	Boerhavia coccinea			x		x	X	x	x	x	x	x	x
	Boerhavia gardneri								x	x		x	
	Boerhavia paludosa			x	x								
	Boerhavia repleta			x		x	X		x	x		x	
	Boerhavia schomburgkiana					x	X		x	x			
	Boerhavia sp.			x	x	x	X				x	x	
Oleaceae	*Jasminum didymum* subsp. *lineare*			x		x	X	x	x	x	x	x	x
	Ludwigia perennis									x		x	
Orobanchaceae	*Argemone ochroleuca*		*		x					x			
	Striga curviflora			x			X						
	Striga squamigera								x	x			
Papaveraceae	*Argemone ochroleuca* subsp. *ochroleuca*		*	x		x	X	x	x		x	x	
Passifloraceae	*Josephinia* sp.									x			
	Passiflora foetida		*						x	x			
	Passiflora foetida var. *hispida*		*	x		x	X				x	x	x
Pedaliaceae	*Mimulus gracilis*				x		X		x	x			
Phrymaceae	*Peplidium aithocheilum*								x				
	Peplidium sp. E Evol. Fl. Fauna Arid Aust. (A.S. Weston 12768)									x		x	
Phyllanthaceae	*Flueggea virosa*			x									
	Flueggea virosa subsp. *melanthesoides*			x		x	X	x	x	x	x	x	
	Notoleptopus decaisnei							x			x	x	
	Notoleptopus decaisnei var. *decaisnei*								x	x			

Family	Species name	Conservation status	Weed	Current Astron Report	Astron 2011	Astron 2016a	Astron 2016b	Biota 2003	Biota 2006	Biota 2007	Biota 2011	Biota 2012	Rio Tinto 2014
Phyllanthaceae	*Notoleptopus decaisnei* var. Orbicularis (A.B. Craig 428)			x	x	x	X					x	
	Phyllanthus aridus								x				
	Phyllanthus erwinii			x		x	X		x	x		x	
	Phyllanthus maderaspatensis			x	x	x	X	x	x	x	x	x	x
	Phyllanthus reticulatus				x	x	X			x			
	Phyllanthus sp.			x									
	Sauropus crassifolius			x									
Plantaginaceae	*Amphipogon sericeus*						X			x			
	Plumbago zeylanica					x	X		x	x			
	Stemodia grossa			x	x	x	X	x	x	x	x		x
	Stemodia kingii								x	x			
Poaceae	*Amphipogon sericeus*			x		x							
	Amphipogon sp.										x		
	Aristida burbidgeae					x	X			x			
	Aristida contorta			x	x		X		x	x	x		
	Aristida holathera var. *holathera*			x		x	X		x	x	x	x	
	Aristida inaequiglumis					x	X			x			
	Aristida latifolia										x		x
	Bothriochloa bladhii											x	
	Bothriochloa ewartiana									x			
	Cenchrus ciliaris		*	x	x	x	X	x	x	x	x	x	x
	Cenchrus setiger		*	x		x	X	x	x	x	x	x	x
	Cenchrus sp.			x			X						
	Chloris barbata		*	x		x	X		x	x	x	x	x
	Chloris pectinata					x	X		x	x			
	Chloris virgata		*				x						x
	Chrysopogon fallax					x	x		x	x		x	x
	Cymbopogon ambiguus			x	x	x	x	x	x	x	x	x	
	Cymbopogon obtectus								x	x			
	Cymbopogon procerus										x		
	Cymbopogon sp.							x					
	Cynodon convergens					x	X		x	x		x	
	Cynodon dactylon		*	x	x	x	x		x	x	x	x	x
	Cynodon prostratus			x		x	X		x	x	x	x	
	Dactyloctenium radulans			x		x	x		x	x		x	
	Dichanthium fecundum								x	x			
	Dichanthium sericeum subsp. *humilius*					x	x		x	x		x	
	Digitaria brownii					x	x		x	x			
	Digitaria ctenantha					x	x		x	x			

Family	Species name	Conservation status	Weed	Current Astron Report	Astron 2011	Astron 2016a	Astron 2016b	Biota 2003	Biota 2006	Biota 2007	Biota 2011	Biota 2012	Rio Tinto 2014
Poaceae	*Echinochloa colona*		*	x		x	x		x	x			
	Enneapogon caerulescens			x	x		x		x	x			
	Enneapogon lindleyanus					x	x			x	x	x	
	Enneapogon polyphyllus						x		x	x			
	Enteropogon ramosus			x			x			x			
	Eragrostis cumingii					x	x		x	x		x	x
	Eragrostis dielsii			x		x	x		x	x		x	x
	Eragrostis eriopoda			x		x	x		x	x		x	x
	Eragrostis exigua					x			x	x			
	Eragrostis leptocarpa			x		x	x		x	x			
	Eragrostis pergracilis			x									
	Eragrostis setifolia					x	x		x	x			
	Eragrostis sureyana	P3										x	x
	Eragrostis tenellula				x	x	x		x	x		x	
	Eragrostis xerophila						x						
	Eriachne ?flaccida								x	x			
	Eriachne aristidea			x		x	x		x	x		x	
	Eriachne benthamii					x	x		x	x			
	Eriachne ciliata									x			
	Eriachne flaccida						x						
	Eriachne helmsii					x	x		x	x		x	
	Eriachne mucronata			x		x	x	x	x	x			
	Eriachne mucronata (arid form) (MET 12 736)				x								
	Eriachne mucronata (typical form)										x		
	Eriachne pulchella							x	x			x	
	Eriachne pulchella subsp. *dominii*			x		x	x			x	x		
	Eriachne pulchella subsp. *pulchella*			x	x	x	x						
	Eriachne sp.			x									
	Eriachne tenuiculmis			x		x	x	x	x	x	x		
	Eriochloa pseudoacrotricha									x			
	Eulalia aurea			x		x	x	x	x	x			
	Iseilema dolichotrichum								x	x			
	Iseilema eremaeum								x	x			
	Iseilema vaginiflorum						x						
	Leptochloa digitata								x	x			
	Leptochloa fusca						x						
	Mnesithea formosa					x							
	Panicum laevinode						x						
	Paraneurachne muelleri			x		x	x		x	x	x	x	x

Family	Species name	Conservation status	Weed	Current Astron Report	Astron 2011	Astron 2016a	Astron 2016b	Biota 2003	Biota 2006	Biota 2007	Biota 2011	Biota 2012	Rio Tinto 2014
Poaceae	*Paspalidium ?clementii*			x									
	Paspalidium basicladum					x		x					
	Paspalidium clementii			x	x	x	x	x	x	x		x	
	Paspalidium constrictum											x	
	Paspalidium rarum					x	x		x	x			
	Paspalidium sp.			x		x			x	x		x	
	Paspalidium tabulatum			x		x	x		x	x		x	
	Perotis rara			x		x	x		x	x		x	
	Schizachyrium fragile			x			x						
	Setaria dielsii									x		x	
	Setaria verticillata		*	x	x	x	x	x	x	x	x	x	
	Sporobolus australasicus			x	x	x	x		x	x		x	x
	Themeda triandra			x		x	x	x	x	x	x	x	
	Triodia ?epactia/pungens				x						x		
	Triodia angusta			x			x				x	x	
	Triodia epactia			x	x	x	x	x	x	x	x	x	x
	Triodia epactia (Form A)										x		
	Triodia epactia (Form B)										x		
	Triodia lanigera								x	x			
	Triodia longiceps			x		x	x		x	x	x	x	x
	Triodia pungens												x
	Triodia schinzii								x	x			
	Triodia sp.							x					
	Triodia sp. Robe River (M.E. Trudgen et al. MET 12367)	P3		x		x	x		x	x	x	x	x
	Triodia wiseana			x	x	x	x	x	x	x	x	x	x
	Tripogon loliiformis					x	x			x			
	Urochloa occidentalis					x	x		x	x			
	Urochloa piligera					x				x			
	Yakirra australiensis					x	x						
	Yakirra australiensis var. *australiensis*								x	x		x	
Polygalaceae	*Polygala* aff. *isingii*								x	x			
	Polygala glaucifolia			x		x	x						
	Polygala sp.					x	x						x
Polygonaceae	*Rumex vesicarius*		*		x	x	x		x	x	x		
Portulacaceae	*Calandrinia ptychosperma*						x		x	x		x	
	Calandrinia sp.			x			x			x			
	Portulaca cyclophylla			x			x						
	Portulaca oleracea			x	x	x	x	x	x	x		x	
	Portulaca pilosa						x						

Family	Species name	Conservation status	Weed	Current Astron Report	Astron 2011	Astron 2016a	Astron 2016b	Biota 2003	Biota 2006	Biota 2007	Biota 2011	Biota 2012	Rio Tinto 2014
Portulacaceae	*Portulaca* sp.								x				
Potamogetonaceae	*Potamogeton tricarinatus*								x	x			
Proteaceae	*Grevillea berryana*						x					x	
	Grevillea eriostachya								x	x			
	Grevillea pyramidalis				x			x	x	x			x
	Grevillea pyramidalis subsp. *leucadendron*			x		x	x				x	x	
	Grevillea wickhamii			x	x	x	x		x		x		x
	Grevillea wickhamii subsp. *aprica*							x		x		x	
	Grevillea wickhamii subsp. *hispidula*					x	x	x	x	x		x	x
	Grevillea wickhamii subsp. *macrodonta*								x	x			
	Hakea chordophylla			x	x	x	x	x	x	x	x	x	x
	Hakea lorea				x			x	x				x
	Hakea lorea subsp. *lorea*			x		x	x			x	x	x	
Pteridaceae	*Ceratopteris thalictroides*		x						x			x	
	Cheilanthes brownii		x	x		x							
	Cheilanthes contigua					x	x						
	Cheilanthes lasiophylla						x						
	Cheilanthes sieberi				x								
	Cheilanthes sieberi subsp. *sieberi*		x	x		x			x				
	Cheilanthes sp.					x	x						
Rubiaceae	*Oldenlandia crouchiana*			x	x	x	x		x	x		x	
	Oldenlandia galioides									x			
	Oldenlandia sp. 'gilgai'								x	x			
	Psydrax rigidula						x						
	Synaptantha tillaeacea			x			x						
	Synaptantha tillaeacea var. *tillaeacea*								x	x		x	
Santalaceae	*Santalum lanceolatum*								x	x			
Sapindaceae	*Dodonaea coriacea*			x		x	x	x	x	x	x	x	x
	Dodonaea lanceolata					x							
	Dodonaea pachyneura					x							
	Dodonaea viscosa subsp. *mucronata*								x	x			
Scrophulariaceae	*Eremophila forrestii*			x									
	Eremophila forrestii subsp. *forrestii*			x		x	x		x	x			
	Eremophila fraseri					x		x			x		
	Eremophila fraseri subsp. *fraseri*			x			x		x	x			
	Eremophila longifolia			x		x	x	x	x	x	x	x	x
Solanaceae	*Datura leichhardtii*		*				x		x	x	x		
	Nicotiana benthamiana			x		x	x		x	x			
	Nicotiana occidentalis			x	x						x		

Family	Species name	Conservation status	Weed	Current Astron Report	Astron 2011	Astron 2016a	Astron 2016b	Biota 2003	Biota 2006	Biota 2007	Biota 2011	Biota 2012	Rio Tinto 2014
Solanaceae	*Nicotiana occidentalis* subsp. *obliqua*								x	x		x	
	Nicotiana occidentalis subsp. *occidentalis*					x	x		x	x			
	Nicotiana sp.						x	x		x			
	Solanum ?cleistogamum			x									
	Solanum aff. *gabrielae*											x	
	Solanum ashbyae							x	x	x			
	Solanum cleistogamum			x	x	x		x	x				
	Solanum diversiflorum			x	x	x	x		x	x	x	x	x
	Solanum elatius			x									
	Solanum gabrielae			x					x	x	x		
	Solanum horridum			x		x	x		x	x	x		
	Solanum lasiophyllum			x	x	x	x		x	x			
	Solanum nigrum		*				x				x		
	Solanum phlomoides					x	x		x	x		x	x
	Solanum sp.					x	x				x	x	
	Solanum sturtianum								x	x	x		
Stylidiaceae	*Stylidium fluminense*						x			x			
	Stylidium weeliwolli									x			
Surianaceae	*Stylobasium spathulatum*			x		x	x	x	x	x	x	x	x
Thymelaeaceae	*Pimelea ammocharis*			x			x		x	x	x		
Typhaceae	*Typha domingensis*			x					x	x	x	x	
	Typha sp.						x						
Urticaceae	*Parietaria cardiostegia*									x			
Violaceae	*Hybanthus aurantiacus*			x	x	x	x	x	x	x	x	x	x
Zygophyllaceae	*Tribulopis angustifolia*						x					x	
	Tribulus ?occidentalis			x									
	Tribulus astrocarpus					x	x		x	x		x	
	Tribulus hirsutus			x	x	x	x		x	x		x	
	Tribulus macrocarpus			x		x	x		x	x	x	x	x
	Tribulus occidentalis						x		x	x			
	Tribulus platypterus			x			x		x	x		x	
	Tribulus sp.			x	x	x	x						
	Tribulus suberosus			x	x		x	x	x	x	x		
	Tribulus terrestris			x					x	x		x	

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Appendix N: Conservation Significant Flora and Introduced Flora Species Location and Descriptions

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Table N.1: Locations of Priority flora recorded in the survey area (GDA 94, Zone 50).

Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)	Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301) P3	20	0.5	424805	7592593	*Triodia* sp. Robe River (M.E. Trudgen et al. MET 12367) P3	500	10	418385	7593014
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	20	2	419387	7593676		500	30	418381	7593045
	100	10	419273	7593565		500	20	418387	7593073
	100	10	419247	7593542		100	5	418376	7593096
	100	10	419226	7593524		100	5	418386	7593131
	100	10	419202	7593505		500	40	418407	7593154
	80	8	419167	7593505		500	20	418430	7593171
	80	8	419140	7593516		500	20	418398	7593179
	100	10	419122	7593531		100	20	418367	7593193
	100	10	419107	7593550		100	20	418341	7593193
	2	0.5	419858	7597283		100	5	418318	7593203
	4	0.5	416050	7596605		100	5	418369	7593346
	80	5	417489	7594008		30	1	418463	7593297
	80	3	417984	7595230		30	1	418484	7593273
	100	5	417901	7593457		6	0.5	418514	7593248
	100	5	418021	7593458		30	2	418537	7593237
	20	0.5	418212	7592982		100	10	418607	7593125
	30	0.5	418216	7592945		4	0.5	418724	7592916
	100	10	418191	7592938		100	10	418771	7592828
	50	2	418192	7592903		500	30	418748	7592799
	100	5	418203	7592874		60	2	416228	7598918
	100	3	418227	7592835		60	2	416251	7598949
	100	3	418258	7592802		50	1	416271	7598977
	100	3	418297	7592777		60	2	416304	7599004
	100	3	418316	7592741		60	2	416337	7599020
	100	3	418333	7592710		40	1	416385	7599046
	20	0.5	418484	7592789		3	0.5	416397	7599092
	100	5	418456	7592855		20	0.5	416426	7599103
	100	5	418429	7592883		50	1	416455	7599110
	100	5	418410	7592906		50	1	416486	7599125
	100	5	418365	7592904		50	1	416522	7599137
	100	5	418356	7592871		50	1	416557	7599166
	100	5	418334	7592881		50	0.5	416579	7599204
	80	3	418315	7592914		70	1	416624	7599221
	80	3	418311	7592950		70	1	416656	7599215
	40	1	418291	7592973		40	0.5	416719	7599233
	80	2	418271	7592993		9	0.5	416760	7599266

Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)	Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	100	5	418368	7592987	*Triodia* sp. Robe River (M.E. Trudgen et al. MET 12367) P3	50	0.5	416798	7599296
	500	40	418395	7592980		50	0.5	416834	7599305
	30	0.5	416947	7599323		500	10	418797	7592688
	30	0.5	416989	7599330		70	5	418832	7592671
	2	0.5	417068	7599334		100	10	418828	7592620
	2	0.5	417113	7599329		500	10	418771	7592585
	3	0.5	417614	7599183		80	10	418706	7592575
	3	0.5	417584	7599142		100	10	418686	7592580
	1	0.5	417537	7599125		50	2	418485	7592787
	1	0.5	417485	7599120		1	0.5	418044	7595600
	1	0.5	417211	7598727		20	0.5	419120	7593498
	100	10	419843	7595544		20	0.5	419105	7593518
	100	10	419892	7595554		80	2	419083	7593529
	100	4	419958	7595506		40	0.5	419067	7593554
	100	5	419996	7595482		50	1	419057	7593589
	100	5	419973	7595454		20	0.5	419083	7593588
	100	3	419988	7595375		100	4	419094	7593582
	500	10	419933	7595393		30	0.5	418515	7598906
	30	1	419841	7595396		20	0.5	418516	7598881
	50	3	419834	7595440		10	0.5	418528	7598864
	20	0.5	419822	7595370		20	0.5	418538	7598851
	30	0.5	419841	7595343		40	1	418547	7598825
	40	1	419940	7595311		2	0.5	418262	7598305
	20	0.5	419953	7595254		20	0.5	415950	7596566
	100	3	419776	7595525		3	0.5	415923	7596597
	100	3	419750	7595698		10	0.5	418001	7592920
	50	1	419811	7595741		50	1	418023	7592901
	100	10	419844	7595727		30	0.5	419852	7598949
	500	10	419886	7595734		20	0.5	419870	7598940
	500	10	419906	7595756		30	0.5	419884	7599171
	100	10	419926	7595799		20	0.5	419911	7599313
	500	10	419898	7595840		10	0.5	419957	7599304
	50	5	419936	7595828		5	0.5	419913	7599295
	100	10	419971	7595848		50	2	419945	7599365
	100	10	419770	7595845		20	0.5	419947	7599388
	1	0.5	418165	7595132		40	2	419946	7599406
	500	10	418240	7595131		40	1	419929	7599415
	500	10	418236	7595185		30	0.5	419905	7599431
	500	10	418727	7592792		50	1	419887	7599427
	100	10	418724	7592745		30	0.5	419865	7599424
	100	10	418751	7592738		40	1	419843	7599439

Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)	Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	100	10	418800	7592745	*Triodia* sp. Robe River (M.E. Trudgen et al. MET 12367) P3	50	2	419862	7599456
	100	10	418828	7592715		40	1	419848	7599469
	10	0.5	419818	7599477		70	1	419811	7596767
	4	0.5	419786	7599480		40	0.5	419819	7596784
	6	0.5	419726	7599438		4	0.5	419808	7596820
	4	0.5	419782	7599421		10	0.5	419795	7596845
	10	0.5	419813	7599423		4	0.5	419767	7596877
	60	5	419795	7599372		20	0.5	419777	7596894
	40	1	419829	7599382		70	2	419817	7596962
	10	0.5	419799	7599323		20	0.5	419830	7596975
	50	1	419810	7599308		20	0.5	419847	7596994
	20	0.5	419808	7599285		40	0.5	419852	7597007
	30	0.5	419756	7599233		70	2	419878	7597017
	60	1	419741	7599251		40	0.5	419896	7597028
	10	0.5	419723	7599258		20	0.5	419909	7597054
	70	3	419692	7599302		30	0.5	419897	7597070
	10	0.5	419661	7599316		10	0.5	419898	7597091
	5	0.5	419640	7599300		10	0.5	419703	7596558
	5	0.5	419621	7599266		6	0.5	419641	7596527
	20	0.5	419599	7599241		40	0.5	419910	7596149
	50	1	419589	7599232		30	0.5	419977	7596090
	30	0.5	419561	7599205		60	1	419979	7596068
	50	1	419562	7599191		100	4	419960	7596023
	60	1	419586	7599181		40	0.5	419913	7596001
	60	1	419630	7599188		100	5	419897	7595983
	90	2	419636	7599168		60	1	419853	7595988
	9	0.5	419656	7599159		90	2	419834	7595974
	50	0.5	419646	7599144		5	0.5	419802	7595947
	40	0.5	419658	7599073		8	0.5	419840	7595930
	10	0.5	419632	7599023		60	1	419860	7595907
	10	0.5	419660	7596711		60	1	419878	7595910
	5	0.5	419692	7596729		40	0.5	419904	7595909
	5	0.5	419721	7596668		90	2	419928	7595925
	50	1	419751	7596647		20	0.5	419978	7595931
	50	1	419774	7596660		5	0.5	419961	7595905
	50	1	419793	7596636		20	0.5	419760	7595887
	20	0.5	419809	7596638		20	0.5	419734	7595873
	30	0.5	419828	7596651		5	0.5	418869	7595368
	20	0.5	419818	7596670		10	0.5	418873	7595377
	60	1	419799	7596679		3	0.5	418893	7595401
	30	0.5	419781	7596702		80	2	418409	7592738

Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)	Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	10	0.5	419790	7596726	*Triodia* sp. Robe River (M.E. Trudgen et al. MET 12367) P3	100	5	419403	7591938
	50	1	419801	7596746		500	20	419192	7592082
	10	0.5	417875	7599126		1	0.5	417739	7599097
	30	0.5	417920	7599131		40	0.5	417866	7599091
	20	0.5	417944	7599154		60	2	419183	7592144
	20	0.5	418108	7599156		50	1	419155	7592171
	1	0.5	418198	7599191		50	0.5	419082	7592117
	10	0.5	418225	7599194		50	1	419060	7592108
	10	0.5	418294	7599162		80	3	419085	7592077
	1	3	419923	7595542		80	5	419118	7592058
	1	0.5	416152	7596637		500	20	419146	7592046
	1	4	417955	7592828		100	5	419156	7592198
	1	0.5	418842	7595352		500	10	419155	7592240
	1	0.5	415894	7596615		70	1	419433	7592197
	1	1	415179	7597153		50	1	419250	7593405
	1	0.5	416340	7597314		20	0.5	419236	7593415
	1	3	419455	7592293		50	0.5	419226	7593427
	1	3	419307	7593552		60	1	419207	7593442
	40	1	419458	7592233		100	5	419186	7593453
	40	10	419272	7593410		100	5	419170	7593464
	100	10	419290	7593429		100	5	419154	7593470
	100	10	419303	7593453		80	2	419133	7593477
	100	10	419307	7593478		50	10	424750	7590409
	100	5	419329	7593521		60	20	424787	7590407
	100	8	419354	7593537		40	8	424805	7590523
	100	8	419368	7593561		30	6	424748	7590376
	50	5	419381	7593589		40	10	424452	7590225
	50	5	419393	7593617		40	10	424470	7590312
	50	3	419403	7593644		30	5	424420	7590157
	5	0.5	419405	7593676		30	5	424414	7590233
	100	8	419348	7593570		20	5	424280	7590257
	100	8	419322	7593559		40	10	424236	7590249
	500	10	419275	7592370		40	10	424188	7590225
	50	5	419240	7592343		40	10	424219	7590287
	50	5	419231	7592316		30	10	424181	7590287
	60	1	419383	7592095		50	20	424210	7590374
	80	3	419418	7592076		30	10	424168	7590403
	40	1	419448	7592071		20	5	424175	7590452
	80	2	419442	7592042		20	5	424181	7590508
	100	4	419427	7592019		20	5	424268	7590829
	60	2	419479	7592000		40	10	423782	7590017

Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)	Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	40	10	423879	7590189	*Triodia* sp. Robe River (M.E. Trudgen et al. MET 12367) P3	100	10	422217	7591122
	40	10	424210	7589764		1	0.5	417209	7598725
	10	2	424192	7589809		20	1	419955	7599265
	30	6	424266	7589954		20	1	420019	7599363
	20	5	424308	7589938		50	20	420012	7599428
	20	5	424294	7589979		30	5	420154	7599389
	30	10	424379	7590016		30	5	420181	7599408
	60	30	424440	7590072		50	20	420179	7599449
	50	20	424433	7589936		40	10	420213	7599498
	40	10	424410	7589864		30	7	420264	7599493
	40	10	423189	7591077		30	5	420291	7599429
	30	10	423193	7591036		20	5	420331	7599435
	30	10	425913	7591907		30	8	420362	7599410
	5	1	425829	7592126		40	10	420398	7599372
	30	10	425756	7592201		40	20	420439	7599318
	10	2	425652	7592207		40	20	420484	7599301
	80	20	425592	7592229		50	20	420518	7599266
	50	10	424191	7589632		50	20	420506	7599216
	40	2	424134	7589741		50	20	420465	7599200
	100	20	424029	7589836		20	1	420394	7599312
	70	10	423889	7590130		20	2	420436	7598788
	40	10	423566	7590449		20	2	420433	7598806
	40	10	423440	7590527		10	1	420480	7598861
	30	5	423881	7590419		30	5	420499	7598887
	100	30	424065	7590298		50	20	420514	7598999
	40	2	424200	7590225		20	7	420490	7598968
	100	30	424379	7590099		30	10	420560	7599015
	30	2	424421	7590008		50	20	420554	7599077
	100	30	423442	7590237		30	10	420610	7599125
	100	30	425537	7591982		10	5	420549	7599163
	5	0.5	419650	7597335		50	20	420529	7599192
	10	0.5	419713	7597290		20	5	420506	7599183
	10	0.5	419714	7597348		30	5	419322	7598817
	20	5	418619	7593647		30	5	419349	7598828
	20	5	418639	7595605		10	2	419396	7598824
	20	2	417877	7595418		20	4	419499	7598897
	30	5	417889	7595458		10	2	419458	7598882
	50	10	417934	7595434		20	4	419419	7598859
	7	0.5	422200	7591167		10	1	419533	7598801

Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)	Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	20	5	419572	7598867	*Triodia* sp. Robe River (M.E. Trudgen et al. MET 12367) P3	70	5	420316	7598941
	5	0.5	419617	7598754		70	5	420300	7598922
	20	2	419685	7598741		100	10	420279	7598903
	20	3	419671	7598688		100	10	420258	7598876
	30	5	419741	7598678		50	5	420238	7598841
	10	2	419776	7598675		10	0.5	420224	7599223
	20	3	419773	7598728		10	0.5	420218	7599285
	1	0.5	419795	7598790		70	5	420200	7599259
	10	2	419618	7598713		70	5	420153	7599191
	20	2	419530	7598681		50	1	420302	7597026
	20	5	419414	7598677		50	1	420324	7596970
	30	8	419372	7598717		50	1	420396	7596910
	10	1	419325	7598783		50	1	420454	7596860
	50	5	419963	7599242		50	1	420474	7596794
	30	3	419993	7599278		100	10	420415	7596721
	100	10	420016	7599282		100	10	420447	7596661
	100	10	420044	7599317		100	10	420537	7596666
	50	5	420072	7599333		100	10	420726	7596554
	100	5	420102	7599317		20	1	420755	7596539
	100	5	420132	7599324		100	10	420812	7596553
	100	10	420148	7599302		100	10	420865	7596597
	100	5	420173	7599342		20	10	418758	7595110
	100	5	420211	7599349		6	1	417848	7595293
	100	5	420244	7599366		10	2	420225	7598757
	30	2	420277	7599375		5	0.5	420245	7598793
	100	10	420302	7599333		5	0.5	420266	7598820
	100	10	420325	7599317		20	0.5	420301	7598839
	100	10	420373	7599300		20	0.5	420308	7598862
	100	10	420384	7599273		20	0.5	420365	7598895
	100	10	420435	7599252		100	8	420391	7598932
	70	5	420456	7599228		70	3	420404	7598960
	70	5	420485	7599198		100	10	420422	7598987
	70	5	420500	7599165		100	10	420439	7599032
	100	10	420473	7599134		100	10	420457	7599055
	100	10	420440	7599103		70	5	420486	7599088
	100	5	420416	7599084		70	5	420510	7599118
	100	5	420391	7599034		70	5	420527	7599145
	50	5	420351	7599002		70	5	420554	7599169
	70	5	420329	7598974		70	5	420597	7599176

Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)	Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	100	5	420617	7599156	*Triodia* sp. Robe River (M.E. Trudgen et al. MET 12367) P3	30	10	419493	7591405
	100	5	420616	7599122		60	20	419433	7591448
	100	5	420628	7599076		20	5	419398	7591414
	100	5	420594	7599048		30	10	419404	7591479
	100	5	420566	7599017		10	2	419334	7591454
	100	5	420539	7598996		10	2	419088	7591241
	70	5	420504	7598975		40	30	419147	7591227
	100	5	420511	7598951		30	20	419134	7591161
	100	10	419361	7598815		5	1	419190	7591540
	100	10	419391	7598807		5	1	419170	7591594
	100	10	419430	7598796		30	10	419169	7591629
	100	10	419448	7598774		100	10	419822	7591259
	5	0.5	419390	7598631		5	0.5	419962	7591217
	30	5	417088	7594188		5	0.5	419966	7591255
	10	1	417042	7594241		100	10	419767	7591381
	5	1	417057	7594291		100	10	419745	7591416
	5	1	417059	7594326		100	10	419714	7591441
	30	10	417049	7594395		100	10	419660	7591397
	50	20	417035	7594424		100	10	419642	7591410
	10	2	416992	7594583		100	10	419615	7591419
	20	2	416957	7594632		100	10	419582	7591417
	40	20	417280	7595683		100	10	419566	7591453
	8	1	416750	7596279		100	10	419532	7591470
	100	20	419405	7591940		500	10	419560	7591504
	50	5	419124	7591578		50	5	419563	7591539
	100	10	418392	7591836		100	10	419531	7591541
	20	5	418346	7591844		100	10	419503	7591568
	500	20	418298	7591853		100	10	419466	7591548
	50	5	418180	7591852		100	10	419434	7591527
	100	10	418239	7591922		100	10	419397	7591511
	100	10	418272	7592013		100	10	419410	7591481
	30	10	419787	7591284		100	10	419395	7591453
	50	30	419745	7591300		1	0.5	418583	7592103
	20	8	419719	7591300		5	0.5	416760	7593545
	20	8	419665	7591332		5	1	416362	7594200
	20	5	419660	7591358		10	3	416317	7594240
	20	5	419603	7591347		10	3	416287	7594274
	30	10	419554	7591331		5	1	416281	7594324
	40	10	419514	7591354		100	2	425635	7592473

Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)	Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	30	20	425577	7592493	*Rhynchosia bungarensis* P4	1	0.5	414563	7598015
	40	20	425597	7592443		4	0.5	415373	7598344
	30	10	425537	7592514		1	0.5	415398	7598328
	1	0.5	424876	7592488		4	0.5	418775	7598529
	10	2	425598	7592268		1	0.5	418301	7597624
	60	1	424047	7593080		2	0.5	418365	7598255
	2	0.5	414996	7596981		1	0.5	418446	7598353
	3	1	414984	7597120		1	0.5	418504	7598399
	50	1	416062	7598626		1	0.5	418557	7598433
	8	0.5	416901	7598802		5	0.5	418645	7598481
	1	0.5	418283	7598278		4	1	419035	7598644
Rhynchosia bungarensis P4	3	0.5	419796	7598175		1	0.5	419440	7598052
	3	0.5	419814	7598168		2	0.5	419530	7598041
	2	0.5	419952	7598090		4	0.5	419576	7598028
	3	0.5	419928	7598050		1	0.5	419591	7598024
	1	0.5	419917	7598059		1	0.5	419905	7597973
	2	0.5	414449	7597007		40	0.5	419989	7597784
	2	0.5	418992	7598426		40	0.5	419974	7597807
	1	0.5	419388	7598588		50	0.5	419968	7597818
	2	0.5	419691	7598566		50	0.5	419962	7597829
	1	0.5	419208	7598490		50	0.5	419942	7597858
	6	0.5	418981	7598515		50	0.5	419914	7597886
	3	0.5	418955	7598495		50	0.5	419894	7597899
	2	0.5	418907	7598476		20	0.5	419883	7597904
	3	0.5	418877	7598323		10	0.5	419869	7597911
	3	0.5	419221	7597963		50	0.5	419854	7597915
	1	0.5	419181	7592620		20	0.5	419830	7597928
	2	0.5	419199	7592598		20	0.5	419803	7597932
	1	0.5	419199	7592596		10	0.5	419657	7597960
	1	0.5	419300	7592829		20	0.5	419634	7597969
	20	0.5	419475	7597992		40	0.5	419609	7597991
	1	0.5	419227	7597968		30	0.5	419586	7598001
	5	0.5	419159	7597898		20	0.5	419572	7598002
	10	0.5	419168	7597899		1	0.5	419556	7598008
	4	1	414747	7597960		30	0.5	419547	7598006
	40	0.5	419511	7597997		10	0.5	419527	7598002
	20	0.5	419495	7597999		20	2	416194	7598381
	1	0.5	418381	7591986		30	2	416135	7598369
	1	0.5	418171	7591826		2	0.5	416081	7598367
	5	0.5	418178	7591845		30	3	416226	7598405

Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)	Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)
Rhynchosia bungarensis P4	20	1	416270	7598414	*Rhynchosia bungarensis* P4	3	0.5	420023	7597990
	1	0.5	417371	7598516		2	0.5	418277	7598205
	5	0.5	420205	7598435		2	0.5	418344	7598236
	5	0.5	420103	7598415		4	0.5	419188	7597913
	5	0.5	419631	7598591		4	0.5	419232	7597934
	1	0.5	419573	7598594		4	0.5	415473	7599316
	2	0.5	419490	7598605		1	0.5	419441	7598295
	1	0.5	420942	7596814		1	0.5	419457	7598286
	20	0.5	420571	7597607		3	0.5	419482	7598268
	10	0.5	420301	7597920		4	0.5	419494	7598267
	50	0.5	420016	7597737		1	0.5	419535	7598266
	30	0.5	420032	7597697		4	1	417986	7597984
	50	0.5	420041	7597662		1	0.5	418930	7598069
	30	0.5	420052	7597604		3	0.5	419002	7598341
	1	0.5	418516	7592058		1	0.5	419093	7597968
	15	0.5	420503	7597712		3	0.5	419129	7598357
	6	0.5	420440	7597773		1	0.5	419161	7597974
	6	0.5	420418	7597801		20	0.5	420133	7597620

Table N.2: Locations of Priority flora recorded in the survey area (Astron 2014) (GDA 94, Zone 50).

Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)	Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	20	2	415293	7596521	*Triodia* sp. Robe River (M.E. Trudgen et al. MET 12367) P3	10	2	416916	7597240
	20	2	415466	7596470		20	3	416951	7597239
	30	5	415949	7596559		50	20	416939	7597217
	20	3	415950	7596592		40	20	416927	7597196
	10	1	416390	7597178		60	30	416893	7597174
	20	5	416393	7597196		20	10	416916	7597162
	5	0.5	416379	7597235		6	1	416941	7597171
	10	0.5	416364	7597212		40	20	416965	7597177
	20	2	416310	7597243		50	20	416965	7597205
	20	2	416343	7597250		80	50	416981	7597227
	30	2	416274	7597277		50	30	417014	7597224
	20	2	416274	7597276		40	20	417041	7597214
	40	5	416261	7597330		80	40	417006	7597246
	10	1	416218	7597332		40	10	416982	7597290
	20	2	416199	7597340		50	20	416897	7597321
	10	1	416198	7597369		2	0.5	416871	7597355
	10	1	416203	7597399		30	10	416897	7597376
	10	1	416183	7597424		20	5	416926	7597390
	5	0.5	416143	7597440		10	2	416965	7597398
	20	1	416205	7597461		20	5	416741	7597379
	2	0.5	416217	7597430		20	5	416742	7597379
	1	0.5	416321	7597376		20	5	416742	7597379
	7	0.5	416330	7597356		10	2	416742	7597378
	30	5	416388	7597316		3	0.5	416630	7597447
	1	0.5	416388	7597316		10	1	416647	7597471
	8	1	416396	7597295		10	1	416613	7597494
	4	0.5	416425	7597310		10	1	416587	7597497
	10	0.5	416436	7597324		20	1	416608	7597534
	6	0.5	416463	7597311		50	20	416644	7597557
	2	0.5	416484	7597300		20	5	416615	7597573
	30	5	416548	7597270		30	10	416581	7597589
	3	0.5	416727	7597246		30	10	416526	7597563
	10	1	416784	7597239		50	30	416526	7597612
	6	0.5	416820	7597190		50	30	416507	7597640
	50	30	416819	7597216		40	20	416481	7597675
	40	20	416832	7597231		30	20	416458	7597699
	30	20	416838	7597250		40	20	416407	7597702
	10	1	416867	7597240		20	5	416395	7597723
	10	1	416878	7597221		10	1	415694	7597693
	20	5	416895	7597237		30	5	415708	7597621

Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)	Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	20	2	415652	7597493	*Triodia* sp. Robe River (M.E. Trudgen et al. MET 12367) P3	20	5	417874	7596731
	20	2	415651	7597460		60	10	418010	7595356
	30	5	415649	7597438		60	30	418228	7595348
	20	3	415676	7597393		10	1	418302	7595354
	10	1	415697	7597349		50	1	418702	7595364
	20	5	415710	7597328		70	40	418713	7595387
	5	0.5	415711	7597328		50	20	418726	7595406
	10	0.5	415734	7597307		10	20	418719	7595360
	20	2	415731	7597275		50	20	418736	7595266
	20	2	415758	7597247		40	10	418736	7595265
	30	2	415769	7597218		40	10	418792	7595242
	20	2	415787	7597188		30	10	418792	7595241
	40	5	415332	7596659		10	2	418792	7595241
	10	1	415341	7596632		100	30	418810	7595233
	20	2	415335	7596600		10	1	418843	7595237
	10	1	415320	7596581		50	10	418878	7595218
	10	1	415325	7596557		80	30	418901	7595211
	10	1	417001	7597201		20	2	418902	7595212
	5	0.5	416933	7597347		20	2	418902	7595212
	20	1	416791	7597667		60	20	418929	7595211
	2	0.5	416813	7597710		40	10	418952	7595228
	1	0.5	416832	7597752		40	10	419069	7595311
	7	0.5	416848	7597759		1	0.5	419069	7595310
	30	5	417147	7597726		50	20	419068	7595310
	1	0.5	417116	7597917		60	20	419090	7595302
	8	1	417231	7597895		40	10	419109	7595303
	4	0.5	417657	7597212		10	1	419127	7595320
	10	0.5	417669	7596900		80	40	419141	7595337
	6	0.5	417695	7596895		50	20	419154	7595353
	2	0.5	417738	7596899		20	5	419193	7595326
	30	5	417767	7596895		50	10	419220	7595303
	3	0.5	417786	7596903		70	30	419203	7595281
	10	1	417824	7596912		60	20	419184	7595255
	6	0.5	417848	7596930		80	30	419170	7595229
	50	30	417846	7596905		70	30	419164	7595207
	40	20	417846	7596876		50	20	419165	7595206
	30	20	417846	7596854		50	20	419176	7595181
	10	1	417855	7596827		50	20	419185	7595154
	10	1	417850	7596808		50	20	419189	7595128
	30	10	417853	7596781		40	10	419188	7595119
	30	8	417861	7596754		30	7	419188	7595118

Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)	Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	100	40	419183	7595091	*Triodia* sp. Robe River (M.E. Trudgen et al. MET 12367) P3	20	5	417851	7594776
	50	20	419212	7595074		20	5	417852	7594776
	80	30	419218	7595053		10	1	417867	7594807
	70	30	419218	7595051		10	1	417704	7594836
	50	20	419219	7595025		10	1	417785	7594723
	80	30	419005	7595204		10	1	418024	7594555
	10	2	418946	7595188		60	3	417702	7594906
	20	5	418917	7595182		20	1	417626	7594964
	60	30	418669	7595332		60	4	417630	7595011
	20	5	417966	7595352		20	2	417362	7593816
	20	5	417968	7595335		30	5	417353	7593777
	20	5	418002	7595318		50	5	417366	7593746
	30	5	418006	7595316		20	2	417339	7593759
	10	1	418008	7595316		20	2	417299	7593826
	50	20	418125	7594556		20	2	417335	7593855
	50	20	418125	7594555		40	5	417330	7593881
	60	30	418185	7594614		40	5	417297	7593905
	20	5	418207	7594629		10	0.5	417296	7593906
	10	1	418252	7594637		10	0.5	417300	7593930
	10	1	418271	7594574		20	1	417329	7593912
	10	1	418265	7594546		50	20	419245	7594984
	50	20	418293	7594523		40	10	419231	7594926
	80	30	418149	7594498		90	40	419202	7594915
	2	0.5	418149	7594497		40	10	419222	7594887
	10	1	418092	7594575		20	2	419221	7594885
	10	1	418072	7594569		50	20	419249	7594855
	5	0.5	418026	7594611		50	20	419244	7594845
	10	0.5	418037	7594642		50	20	419244	7594844
	20	1	418047	7594667		30	10	419197	7594880
	10	0.5	418061	7594690		50	30	419166	7594908
	1	0.5	418081	7594757		50	20	419159	7594907
	10	1	418008	7594788		40	20	419205	7594941
	30	10	417975	7594755		40	20	419229	7594919
	30	10	417982	7594725		20	2	415518	7596464
	70	30	417954	7594687		30	3	415288	7596541
	5	0.5	417939	7594643		20	3	415324	7596531
	40	10	417927	7594614		40	5	415339	7596520
	20	2	417904	7594620		20	2	415354	7596487
	40	5	417903	7594648		60	20	415361	7596473
	40	10	417877	7594665		20	2	415372	7596453
	60	30	417863	7594720		30	2	415403	7596435

Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)	Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	40	4	415397	7596427	*Triodia* sp. Robe River (M.E. Trudgen et al. MET 12367) P3	2	0.5	418349	7598518
	20	2	415381	7596434		4	0.5	418298	7598488
	20	2	415365	7596442		10	1	418294	7598460
	5	0.5	415353	7596464		10	1	418289	7598449
	5	0.5	415335	7596463		9	1	418269	7598378
	10	1	415330	7596481		4	0.5	418257	7598361
	20	2	415306	7596488		8	0.5	418218	7598272
	1	0.5	415286	7596483		20	1	417905	7598344
	5	1	415252	7596451		10	0.5	417892	7598357
	5	1	415229	7596452		20	1	417857	7598381
	5	1	415121	7596497		20	2	417841	7598389
	30	10	415107	7596506		30	2	417828	7598413
	10	1	415176	7596530		10	1	417805	7598415
	6	0.5	415190	7596576		2	0.5	417790	7598421
	10	1	415215	7596551		40	5	417805	7598430
	10	1	415232	7596550		10	1	417818	7598444
	10	1	415262	7596531		20	1	417837	7598467
	10	1	415178	7596632		9	0.5	417851	7598485
	10	1	415125	7596654		20	4	417871	7598513
	10	0.5	415171	7596613		6	0.5	417873	7598526
	10	1	415186	7596605		4	0.5	417658	7598600
	20	2	415330	7596527		4	0.5	417644	7598603
	20	2	415376	7596467		50	6	417631	7598605
	20	2	415370	7596400		40	4	417617	7598602
	40	4	415353	7596404		10	0.5	417596	7598600
	40	4	414898	7596310		10	0.5	417630	7598623
	5	0.5	414871	7596277		9	0.5	417645	7598631
	30	2	414809	7595987		5	0.5	417631	7598644
	10	1	414791	7595961		20	1	417616	7598660
	10	1	414870	7595904		20	1	417602	7598673
	10	0.5	414977	7595942		10	1	417591	7598681
	10	0.5	414988	7595948		20	2	417592	7598698
	60	10	415049	7595998		40	2	415289	7596550
	20	2	415427	7596290		50	3	415176	7596584
	10	1	415411	7596304		40	2	415113	7596653
	10	1	415418	7596364		20	1	414969	7596833
	10	1	415423	7596387		40	2	414980	7596878
	40	4	417147	7593998		60	3	415015	7596908
	2	0.5	418410	7598567		60	3	415048	7596900
	4	0.5	418385	7598536		500	10	415127	7596962
	10	0.5	418369	7598531		40	3	415160	7596926

Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)	Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	50	3	415330	7596593	*Triodia* sp. Robe River (M.E. Trudgen et al. MET 12367) P3	20	2	418434	7595988
	40	3	415224	7596958		40	4	418547	7595982
	30	2	415277	7597004		100	8	418532	7595919
	50	2	415192	7597007		500	20	418524	7595869
	60	4	415169	7597030		80	6	418539	7595820
	70	4	415064	7597029		500	10	418574	7595785
	20	1	415169	7597197		100	10	418605	7595745
	20	1	414931	7597145		100	7	418633	7595716
	40	2	414782	7597433		40	2	418671	7595775
	10	0.5	414790	7597665		60	4	418662	7595752
	20	1	415693	7597346		500	6	418650	7595704
	80	3	415727	7597294		60	5	418631	7595671
	40	3	415731	7597245		60	4	418720	7595613
	100	6	415772	7597231		50	3	418759	7595594
	20	2	415476	7597226		500	20	418785	7595561
	60	3	417096	7594004		70	5	418810	7595537
	50	4	417153	7593999		70	5	418832	7595504
	100	20	418996	7595035		40	2	418759	7595449
	60	7	418395	7596099		80	4	418732	7595416
	50	6	418415	7596080		70	6	418714	7595388
	500	10	418481	7596101		50	6	418697	7595343
	500	20	418503	7596105		20	2	418071	7595388
	500	10	418544	7596097		30	4	418008	7595417
	500	20	418542	7596131		70	7	417974	7595373
	500	10	418549	7596162		30	4	418026	7594492
	80	5	418554	7596198		90	10	418031	7594438
	20	1	418524	7596398		500	8	418007	7594389
	50	3	418189	7596627		500	20	418043	7594336
	100	5	418161	7596644		500	20	418048	7594298
	50	2	418146	7596666		500	20	418025	7594274
	100	7	418121	7596684		60	5	417925	7594398
	40	2	418099	7596711		500	1	417894	7594439
	90	6	418074	7596721		40	3	417895	7594439
	40	2	418025	7596701		40	3	417974	7594462
	50	3	417999	7596679		80	8	417977	7594423
	30	1	417959	7596636		500	10	418070	7594319
	40	3	417939	7596611		100	5	418088	7594288
	100	8	417877	7596649		10	1	418157	7594265
	80	5	417876	7596692		70	8	418194	7594270
	50	3	418377	7596047		100	8	418224	7594287
	100	10	418405	7596020		100	7	418263	7594317

Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)	Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	100	7	418229	7594358	*Triodia* sp. Robe River (M.E. Trudgen et al. MET 12367) P3	6	0.5	417259	7594309
	100	6	418220	7594396		10	1	417260	7594297
	60	6	418203	7594427		20	1	417273	7594257
	70	6	418176	7594452		10	1	417277	7594229
	50	3	418138	7594430		10	1	417298	7594184
	100	10	418125	7594385		20	1	417297	7594163
	80	5	418112	7594336		30	3	417296	7594143
	20	2	418103	7594434		10	1	417300	7594124
	100	10	419250	7594939		20	2	417298	7594202
	3	0.5	418120	7597425		8	0.5	417282	7594233
	100	10	419245	7594703		10	1	417225	7594407
	500	20	419207	7594709		10	1	417260	7594592
	500	20	419154	7594728		10	0.5	417293	7594652
	500	20	419099	7594721		10	0.5	417216	7594801
	500	20	419045	7594691		20	2	417425	7594830
	500	20	419213	7594787		20	1	417453	7594824
	40	4	419277	7594803		5	0.5	417512	7594932
	0	0.5	415159	7595674		10	1	417592	7594910
	6	0.5	415800	7598543		10	1	417588	7594883
	40	2	415886	7598446		10	0.5	417562	7594953
	10	1	415822	7598408		6	0.5	417525	7595108
	10	1	415777	7598410		20	0.5	417327	7595328
	50	3	415709	7598403		5	0.5	417298	7595283
	50	4	415676	7598433		5	0.5	417577	7595246
	50	3	415627	7598446		7	0.5	417569	7595236
	10	1	418294	7598442		6	0.5	417586	7595225
	30	4	416728	7593803		20	3	417588	7595265
	10	1	416479	7593578		10	2	417602	7595291
	10	0.5	416396	7594165		30	10	417617	7595296
	50	4	416419	7594171		10	0.5	417633	7595298
	20	2	416440	7594129		10	1	417649	7595301
	10	0.5	416510	7594071		10	3	417669	7595305
	10	0.5	416531	7594067		60	20	417678	7595304
	20	1	416623	7594032		50	10	417678	7595305
	30	2	416645	7594040		20	1	417693	7595306
	20	1	416704	7594031		20	2	417709	7595306
	10	0.5	416773	7593981		20	1	417720	7595308
	40	2	417273	7594553		8	1	417734	7595314
	20	2	417282	7594524		40	5	417738	7595320
	10	1	417277	7594482		10	0.5	417753	7595319
	5	0.5	417245	7594343		6	0.5	417747	7595340

Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)	Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	10	1	417260	7595909	*Triodia* sp. Robe River (M.E. Trudgen et al. MET 12367) P3	30	10	417736	7593197
	9	0.5	417265	7595867		20	8	417743	7593176
	6	0.5	417249	7595847		30	10	417743	7593158
	10	1	417248	7595826		40	10	417750	7593142
	20	2	417615	7595976		10	10	417718	7593059
	10	1	417623	7595991		20	10	417695	7593025
	40	10	417615	7596010		10	3	417691	7593019
	30	10	417617	7596022		10	1	417651	7592997
	9	4	417614	7596044		10	1	417637	7592880
	20	6	417627	7596056		40	10	417656	7592925
	40	10	417683	7595907		20	5	417668	7592946
	60	20	417693	7595888		10	2	417680	7592971
	50	10	417697	7595872		10	1	417722	7592986
	40	5	417704	7595858		20	3	417804	7592991
	40	10	417717	7595840		20	5	417795	7592947
	10	8	417766	7595799		10	2	417792	7592877
	10	3	417778	7595799		20	5	417791	7592856
	7	1	417800	7595804		6	0.5	417778	7592829
	20	5	417833	7595810		10	1	417816	7592827
	10	1	417867	7595798		20	6	417832	7592834
	10	3	417688	7596097		20	4	417841	7592864
	30	7	417673	7596096		20	2	417848	7592887
	30	9	417655	7596096		10	1	417852	7592923
	10	3	417648	7596107		10	1	417868	7592928
	30	9	417636	7596123		10	1	417927	7592900
	7	0.5	416871	7596167		20	5	418070	7592964
	5	0.5	416800	7596092		30	5	418210	7592858
	8	1	416796	7596079		30	5	418212	7592833
	30	5	416788	7596066		20	3	418218	7592802
	10	2	416788	7596047		10	2	418191	7592755
	20	5	416768	7596055		10	0.5	418159	7592715
	20	4	416832	7596108		10	0.5	418155	7592700
	10	1	416839	7596118		10	0.5	418138	7592675
	10	1	416847	7596129		10	0.5	418122	7592676
	10	3	416857	7596141		40	10	418105	7592675
	20	3	416787	7596247		20	4	418089	7592689
	30	10	416781	7596242		50	20	418016	7592671
	5	1	416234	7596789		20	2	418012	7592704
	20	3	417774	7593195		10	1	418007	7592721
	10	2	417761	7593195		10	1	417977	7592735
	40	10	417748	7593208		10	1	418018	7592943

Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)	Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	10	1	418038	7593046	*Triodia* sp. Robe River (M.E. Trudgen et al. MET 12367) P3	30	1	417477	7593362
	20	1	417700	7593106		50	8	417498	7593342
	40	5	417676	7593111		40	4	417516	7593333
	60	10	417670	7593123		60	6	417735	7593372
	60	20	417650	7593118		20	2	417763	7593382
	30	10	417607	7593144		5	0.5	417782	7593375
	60	10	417571	7593150		5	0.5	416787	7593649
	10	0.5	417448	7593043		20	1	416678	7593519
	20	1	417471	7593057		10	0.5	416676	7593609
	10	1	417456	7593085		40	2	416658	7593618
	20	1	417426	7593137		10	0.5	416684	7593625
	10	0.5	417412	7593160		20	2	416734	7593725
	10	0.5	417356	7593208		40	3	416754	7593751
	30	5	417338	7593212		1	0.5	414889	7595282
	10	1	417308	7593199		2	0.5	415512	7598423
	20	4	417235	7593183		40	5	417635	7598613
	10	0.5	417241	7593204		30	3	417609	7598598
	10	1	417235	7593216		10	2	417092	7594372
	10	1	417231	7593242		20	20	417101	7594403
	10	1	417256	7593289		40	60	417109	7594430
	50	5	417311	7593343		1	0.5	417181	7594559
	20	0.5	417345	7593346		3	0.5	417183	7594589
	10	0.5	417352	7593368		5	0.5	417185	7594622
	40	2	417338	7593377		5	0.5	417195	7594657
	40	3	417321	7593387		50	70	417166	7594711
	10	0.5	417302	7593390		30	40	417213	7594760
	30	1	417195	7593419		4	1	417253	7594755
	50	7	417141	7593347		9	1	417270	7594846
	60	10	417023	7593285		20	20	417280	7594869
	20	1	416950	7593510		20	20	417303	7594902
	20	1	416955	7593520		30	40	417309	7594930
	30	2	416974	7593532		40	40	417350	7594988
	40	2	416978	7593550		30	20	417397	7595383
	30	2	416973	7593581		20	5	417422	7595401
	60	8	417050	7593551		30	20	417587	7595514
	30	2	417196	7593466		40	20	417551	7595498
	10	0.5	417254	7593439		30	10	417525	7595508
	30	4	417393	7593409		50	30	417542	7595763
	20	1	417397	7593399		50	20	417516	7595784
	40	3	417430	7593377		10	5	417542	7595789
	30	2	417457	7593366		50	20	417566	7595772

Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)	Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	50	20	417572	7595786	*Triodia* sp. Robe River (M.E. Trudgen et al. MET 12367) P3	5	5	416813	7593905
	20	5	417584	7595805		40	20	416665	7593920
	10	3	417613	7595783		20	5	416509	7593637
	20	5	417808	7595687		4	1	416558	7593625
	30	8	417825	7595674		6	1	416575	7593627
	50	20	417853	7595668		30	10	416617	7593588
	40	10	417874	7595664		70	40	416670	7593601
	20	5	417874	7595651		40	20	416740	7593641
	70	40	417886	7595633		70	30	416871	7593613
	10	2	417902	7595610	*Rhynchosia bungarensis* P4	1	0.5	414379	7596678
	40	20	417636	7596062		10	5	414391	7596598
	30	10	417620	7596039		30	10	414378	7596612
	10	5	417607	7596013		20	10	414365	7596627
	40	20	417243	7595836		30	10	414401	7596578
	20	10	417245	7595882		30	10	414401	7596557
	10	5	417250	7595944		20	10	414392	7596536
	50	20	417223	7596003		5	10	414397	7596506
	70	30	417197	7596052		6	0.5	417536	7598076
	40	20	417167	7596049		8	0.5	417799	7598066
	30	10	417141	7596017		6	0.5	417816	7598095
	20	5	417102	7596000		3	0.5	417853	7598147
	30	10	417052	7596056		2	0.5	417716	7598329
	20	8	417024	7596092		5	0.5	414493	7597788
	30	20	416763	7596065		50	10	417818	7593183
	20	5	416788	7596152		50	10	417804	7593188
	2	0.5	416804	7596209		20	6	417791	7593182
	50	30	416769	7596233		20	6	417765	7593153
	40	20	416769	7596230		40	10	417755	7593135
	40	20	416761	7596254		50	20	417800	7593110
	20	5	416738	7596980		50	10	417794	7593128
	30	20	418006	7595354		50	10	417799	7593141
	10	2	417995	7595141		30	10	417819	7593166
	10	2	418092	7595136		20	3	417472	7593548
	40	20	418708	7595106		6	0.5	417368	7593550
	5	1	418881	7595084		30	3	417274	7593552
	40	20	419284	7594954		9	2	415835	7595740
	40	20	418622	7593672		20	5	415820	7595751
	60	30	418697	7593662		20	5	415804	7595749
	60	30	418697	7593662		10	0.5	415788	7595714
	40	20	418656	7593647		10	0.5	415769	7595709
	50	30	418535	7593750		2	0.5	415338	7598311

Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)	Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)
Rhynchosia bungarensis P4	4	0.5	415628	7598299	*Rhynchosia bungarensis* P4	6	0.5	418727	7598286
	3	0.5	415642	7598296		3	0.5	418916	7598293
	20	0.5	415660	7598289		3	0.5	418948	7598180
	5	0.5	415703	7598297		7	0.5	418849	7598163
	20	1	415726	7598294		3	0.5	414928	7595314
	10	0.5	415751	7598296		4	0.5	416158	7598103
	1	0.5	415933	7598303		2	0.5	416077	7598100
	8	0.5	415301	7598255		8	0.5	416085	7598109
	8	0.5	415113	7598228		4	0.5	416093	7598125
	2	0.5	414805	7598078		2	0.5	416141	7598064
	5	0.5	416059	7598100		2	0.5	416225	7598067
	4	0.5	416021	7598062		6	0.5	416254	7598073
	3	0.5	415974	7598022		4	0.5	416272	7598043
	7	0.5	418135	7598194		2	0.5	416298	7598017
	10	1	418121	7598192		3	0.5	415056	7595882
	3	0.5	418089	7598187		1	0.5	415382	7595709
	2	0.5	418053	7598195		1	0.5	414881	7595399
	7	0.5	418038	7598192		5	0.5	418773	7598077
	4	0.5	417356	7598199		4	0.5	418762	7598089
	20	1	417465	7598189		2	0.5	418736	7598075
	5	0.5	417611	7598153		2	2	418695	7598048
	10	0.5	417635	7598162		10	0.5	418606	7598044
	30	1	417654	7598145		2	0.5	418445	7598171
	10	0.5	417671	7598127		3	0.5	418420	7598164
	6	0.5	417842	7598132		10	0.5	418435	7598154
	3	0.5	417865	7598113		6	0.5	418469	7598137
	8	0.5	417903	7598110		4	0.5	418491	7598124
	5	0.5	417922	7598103		3	0.5	418502	7598138
	9	0.5	417941	7598095		10	0.5	418613	7598142
	5	0.5	417704	7598101		8	0.5	418629	7598148
	10	0.5	417611	7598095		5	0.5	418663	7598161
	4	0.5	417573	7598108		6	0.5	418693	7598166
	2	0.5	414451	7597792		4	0.5	418740	7598167
	1	0.5	414445	7597046		5	0.5	418795	7598185
	1	0.5	418737	7597974		2	0.5	418806	7598187
	2	1	418644	7597970		9	0.5	418817	7598192
	1	1	418578	7597972		1	0.5	418909	7598126
	2	0.5	418499	7597981		2	0.5	418954	7598163
	7	0.5	418351	7597980		2	0.5	418877	7597945
	2	0.5	418158	7598016		3	0.5	418906	7597946
	20	1	418627	7598270		6	0.5	418947	7597952

Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)	Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)
Rhynchosia bungarensis P4	3	0.5	418979	7597957	*Rhynchosia bungarensis* P4	2	0.5	417491	7598142
	5	0.5	418998	7597953		6	0.5	416488	7598127
	4	0.5	419056	7597950		4	0.5	416466	7598138
	1	0.5	418980	7597906		5	0.5	416454	7598142
	5	0.5	418859	7597858		3	0.5	416321	7598122
	7	0.5	418899	7597853		5	0.5	416301	7598136
	10	0.5	418908	7597862		3	0.5	416273	7598141
	9	0.5	418966	7597872		2	0.5	416251	7598141
	4	0.5	419000	7597887		7	0.5	416181	7598133
	20	2	419057	7597885		1	0.5	416135	7598132
	50	2	419116	7597893		1	0.5	416123	7598081
	20	1	419141	7597891		8	0.5	416282	7598050
	2	0.5	418807	7597802		2	0.5	416496	7598065
	3	0.5	418790	7597802		1	0.5	416848	7598067
	2	0.5	418759	7597794		10	1	417512	7598340

Table N.3: Locations of Priority flora recorded in the survey area (Astron 2016a) (GDA 94, Zone 50).

Species	Estimated Abundance	Density (%)	Easting (mE)	Northing (mN)	Species	Estimated Abundance	Density (%)	Easting (mE)	Northing (mN)
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301) P3	3	0.5	421377	7591601	*Triodia* sp. Robe River (M.E. Trudgen et al. MET 12367) P3	40	10	421920	7591012
						50	1	421384	7591393
	1	0.5	421679	7591028		100	10	421214	7591266
						20	1	421211	7591082
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	100	10	422856	7590408		40	5	421751	7591086
	10	1	421210	7591651		50	1	423244	7590188
	10	1	421899	7591310		10	1	423064	7590350
	30	10	421242	7591682		50	10	423263	7589924
	20	5	421198	7591708		20	5	423287	7589812
	30	5	421168	7591744		10	2	423425	7589587
	100	20	422441	7590880		5	0.5	423352	7589577
	100	0.5	421220	7591603		100	5	423042	7590369
	50	1	421130	7591567		50	1	423190	7590293
	20	1	421229	7591650		50	1	423888	7589485
	30	0.5	422863	7590397		20	5	423530	7590051
	100	1	422807	7590379		30	10	423215	7590010
	70	0.5	422534	7590457		5	1	423015	7589958
	70	0.5	422394	7590646		30	10	422940	7589875
	40	10	421258	7591655		30	10	422892	7589858
	50	20	421240	7591231		40	20	423131	7589972
	50	20	421194	7591099		100	2	423206	7590042
	50	20	421275	7591092		20	0.5	423100	7590008
	30	10	421496	7591657		20	0.5	423082	7589993
	40	20	421793	7591299		20	0.5	423050	7589969
	9	1	421857	7591296		10	0.5	423005	7589909
	30	10	421771	7591312		50	0.5	422967	7589865
	100	10	421202	7591203		20	0.5	423149	7589926
	50	1	421896	7590941					

Table N.4: Locations of Priority flora recorded in the survey area (Biota 2011) (GDA 94, Zone 50).

Species	Estimated Abundance	Density (%)	Easting (mE)	Northing (mN)	Species	Estimated Abundance	Density (%)	Easting (mE)	Northing (mN)
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	n/a	10	415182	7596883	*Triodia* sp. Robe River (M.E. Trudgen et al. MET 12367) P3	n/a	n/a	418170	7594389
	n/a	1	415297	7596586		n/a	1	418191	7592654
	n/a	3	415321	7597104		n/a	30	418199	7594437
	n/a	5	415497	7596499		n/a	30	418205	7594550
	n/a	1	415859	7597056		n/a	10	418213	7596209
	n/a	2	417593	7599240		n/a	15	418238	7592668
	n/a	10	417688	7596115		n/a	5	418273	7596258
	n/a	6	417712	7598838		n/a	1	418325	7592661
	1	n/a	417736	7599040		n/a	25	418461	7592945
	n/a	1	417739	7598923		n/a	1	418466	7593764
	>100	n/a	417751	7595340		n/a	5	418560	7593752
	n/a	30	417798	7592850		n/a	5	418627	7596376
	n/a	5	417861	7595827	*Rhynchosia bungarensis* P4	n/a	2	418711	7597773
	n/a	20	417951	7592989		n/a	1	418500	7597439
	n/a	5	417993	7593048		1	n/a	416877	7598515
	n/a	10	417994	7595357		n/a	n/a	415088	7595885
	n/a	10	418009	7595495		2	n/a	418720	7598250
	n/a	10	418012	7594283		5	n/a	418752	7598264
	n/a	25	418057	7594443		5	n/a	418772	7598273
	100		418065	7595200		2	n/a	418794	7598282
	n/a	n/a	418096	7593079		n/a	1	414409	7596028
	n/a	20	418101	7594363		n/a	n/a	417585	7598133
	n/a	15	418138	7594554	*Ptilotus mollis* P4	1	n/a	417798	7592850
	n/a	15	418168	7592661					

Table N.5: Locations of Priority flora recorded in the survey area (Biota 2006) (GDA 94, Zone 50). Cover estimates unavailable.

Species	Estimated Abundance	Easting (mE)	Northing (mN)	Species	Estimated Abundance	Easting (mE)	Northing (mN)
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	6-20	416156	7598761	*Rhynchosia bungarensis* P4	21-99	415735	7594422
	6-20	416158	7598729		10	415779	7594377
	6-20	416168	7598788		21-99	415833	7594321
	6-20	416195	7598808		1	418557	7598247
	6-20	416197	7598839		1	418571	7598133
	6-20	416209	7598881		2	418599	7597972
	6-20	416237	7594257		8	418624	7597897
	21-99	416457	7594055		4	418637	7597780
	6-20	417261	7599323		1	418674	7598271
	6-20	417279	7599327		1	418689	7598220
	6-20	417428	7599314		1	418700	7598450
	6-20	417478	7599271		2	418732	7598328
	6-20	418328	7599126		1	418733	7597951
	1-5	418362	7599016		3	418739	7597856
	6-20	418407	7598970		1	418745	7598302
	1-5	418496	7598579		6-20	418775	7597950
	6-20	419556	7599032		1	418805	7597937
	21-99	420302	7598832		3	418810	7599296
	6-20	421098	7591272		6-20	418837	7597917
	6-20	421433	7591110		2	418852	7597861
	6-20	421497	7591075		1	418879	7597912
	6-20	421609	7591022		1	418890	7598432
	6-20	421645	7590992		3	418896	7597942
	6-20	421997	7590812		1	418913	7598000
	6-20	422051	7590780		1	418917	7598370
	6-20	422244	7590807		1	418932	7598270
	6-20	422902	7591539		1	418949	7598227
	6-20	423067	7591012		7	418996	7597925
	6-20	423162	7590998		3	419006	7597885
	6-20	423276	7591112		6-20	419066	7598806
Rhynchosia bungarensis P4	2	415118	7594600		10	419221	7598732
	5	415251	7594701		1	419476	7595060
	10	415334	7594574		1	419492	7595081
	1	415368	7598627		1	419525	7594763
	1	415409	7598723		1	419543	7594641
	1	415468	7594523		2	419555	7594677
	2	415524	7594685		10	419738	7594584
	6-20	415626	7594556		1	419776	7594606
	3	415630	7594556		1	419813	7594598

Table N.6: Descriptions of Priority flora recorded in the survey area.

Species	Description	Habitat
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301) P3	Erect shrub or herb, 0.2 m to 2 m high. Pink flowers from May to July (WAHerb 1998-2016).	Drainage lines, creeks in hills or plains (WAHerb 1998-2016).
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	Hummock grass (WAHerb 1998-2016).	Rocky outcrops, breakaways, hillslopes and crests, and drainage lines (WAHerb 1998-2016).
Rhynchosia bungarensis P4	Compact, prostrate shrub to 0.5 m high. Flowers yellow (WAHerb 1998-2016).	Pebbly, shingle coarse sand amongst boulders. Banks of flow line in the mouth of a gully in a valley wall (WAHerb 1998-2016).

Table N.7: Locations of introduced flora recorded in the survey area (GDA 94, Zone 50).

Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)	Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)
**Aerva javanica*	500	20	419016	7598782	**Argemone ochroleuca* subsp. *ochroleuca*	1	0.5	415484	7599321
	500	20	418883	7598776		25	0.5	419333	7598320
	3	0.5	419872	7597913		20	0.5	419483	7595796
	10	0.5	419854	7597914		20	0.5	415500	7598159
	2	0.5	418352	7599401		10	0.5	415916	7598222
	250	3	416942	7599466		25	0.5	416415	7598321
	250	3	416797	7599482		20	0.5	419076	7598442
	8	0.5	419820	7598865		20	0.5	419119	7598478
	100	0.5	419940	7598798		25	0.5	419924	7598395
	4	0.5	416873	7599446		50	0.5	419822	7598415
	1	0.5	414512	7597629		25	0.5	419097	7598522
	1	0.5	419734	7598561		15	0.5	418993	7598520
	100	5	418905	7598764		50	0.5	418932	7598480
	10	3	420770	7598822		25	0.5	418878	7598452
	75	20	420692	7598775		10	0.5	419133	7597936
	20	8	420647	7598788		15	0.5	419243	7597954
	50	10	420487	7598715		100	1	419638	7592816
	10	5	418310	7598211		100	5	419181	7592620
	50	2	420169	7598726		100	0.5	419343	7592798
	100	10	420482	7598657		100	0.5	419257	7592776
	8	0.5	420083	7598409		100	1	419214	7592716
**Argemone ochroleuca* subsp. *ochroleuca*	50	0.5	419009	7598339		100	0.5	419201	7592598
	100	0.5	419187	7598362		500	1	419121	7592471
	20	0.5	419522	7595075		500	0.5	419147	7592494
	20	0.5	418991	7598074		100	1	419185	7592519
	10	0.5	419458	7598045		500	1	419185	7592562
	75	0.5	419587	7598051		75	0.5	419240	7592549
	20	0.5	419870	7597911		500	0.5	419213	7592654
	75	0.5	419692	7597959		10	0.5	419405	7592798
	5	0.5	419534	7598006		10	0.5	419479	7592784
	5	0.5	419488	7597998		10	0.5	419631	7592814
	20	0.5	419374	7597986		5	0.5	419385	7592771
	100	0.5	419371	7598007		25	0.5	419450	7592774
	50	0.5	419329	7597968		50	0.5	419527	7592760
	50	0.5	419295	7597951		25	0.5	419568	7592769
	7	0.5	419190	7597935		25	0.5	419647	7592806
	20	0.5	418823	7598115		10	0.5	419617	7592833
	50	0.5	414400	7595938		15	0.5	419637	7592878
	50	1	414411	7595777		25	0.5	419585	7592908
	100	2	414550	7595627		25	0.5	419595	7593000

Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)	Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)
Argemone. ochroleuca subsp. *ochroleuca*	10	0.5	419594	7593015	**Cenchrus ciliaris*	50	0.5	418381	7597453
	1	0.5	418373	7597453		75	1	418614	7598961
	1	0.5	415945	7598237		250	4	414843	7596468
	250	2	420450	7598624		250	5	414858	7596503
	25	0.5	420019	7598419		100	1	414897	7596613
	50	0.5	420517	7597654		25	0.5	418539	7599457
	3	0.5	420374	7597827		100	2	418585	7599434
	5	0.5	418576	7592091		75	1	419463	7595062
**Cenchrus ciliaris*	10	0.5	418877	7599037		1000	30	419503	7595060
	100	2	418981	7599094		20	0.5	419638	7592816
	500	5	415603	7599473		250	5	419181	7592620
	500	5	415624	7599505		250	1	419201	7592598
	500	5	415638	7599523		250	1	419290	7592597
	500	5	419640	7594577		5	0.5	419219	7592423
	50	0.5	419418	7598327		10	0.5	419253	7592442
	5000	20	419530	7595649		10	0.5	419171	7592494
	2500	20	419520	7595076		10	0.5	419199	7592502
	10	0.5	419055	7596970		2500	10	419139	7592521
	5	0.5	418952	7598082		5000	10	419073	7592523
	2	0.5	419101	7597972		15	0.5	419144	7592564
	5	0.5	419294	7598014		15	0.5	419179	7592569
	2	0.5	419453	7598049		3	0.5	419143	7592672
	10	0.5	419969	7597816		100	0.5	419259	7592660
	20	0.5	419871	7597911		2500	5	419298	7592667
	75	0.5	419685	7597962		500	2	419329	7592678
	100	5	419620	7597986		5	0.5	419617	7592823
	75	5	419565	7598002		15	1	419502	7592816
	100	5	419534	7598005		15	0.5	419352	7592761
	1000	20	419168	7597898		20	0.5	419402	7592770
	250	1	418738	7597720		20	0.5	419426	7592767
	2500	10	419269	7596509		25	0.5	419472	7592766
	2500	10	419287	7596113		20	0.5	419614	7592780
	2500	10	419277	7595825		75	1	419646	7592876
	1000	10	419327	7595375		50	0.5	419684	7593026
	5000	20	419532	7594945		50	0.5	419708	7593011
	1000	5	419609	7594800		250	3	419867	7592949
	1000	5	419702	7594614		8	0.5	420117	7597420
	20	0.5	418786	7598665		25	0.5	425139	7592492
	100	1	418615	7598961		25	0.5	424616	7592773
	100	1	418401	7599399		20	1	420734	7598904
	500	1	418218	7599433		250	30	418280	7597464

Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)	Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)
**Cenchrus ciliaris*	250	5	418983	7599094	**Cenchrus ciliaris*	250	10	424628	7590574
	50	2	417774	7597419		500	20	425706	7591423
	250	30	415850	7597562		2500	80	424628	7590574
	100	10	415954	7597484		10	0.5	425706	7591423
	10	1	425438	7592699		250	10	424628	7590574
	25	1	425265	7592676		500	40	425706	7591423
	25	1	425295	7592607		250	3	424628	7590574
	250	5	424870	7592464		100	1	425706	7591423
	100	5	424505	7592739		250	0.5	424628	7590574
	100	10	424915	7592330		500	5	425706	7591423
	100	20	416446	7597809		100	0.5	424628	7590574
	100	20	416983	7598570		100	1	425706	7591423
	250	20	417029	7598583		500	1	418612	7599347
	100	10	417234	7598543	**Cenchrus setiger*	5	0.5	418616	7598961
	50	0.5	419058	7598839		20	0.5	418850	7599091
	2500	10	420418	7598565		20	0.5	419337	7598630
	1000	10	420359	7598474		2500	10	415838	7599494
	2500	10	420053	7598410		1000	10	415602	7599473
	2500	20	424156	7592276		1000	10	415624	7599505
	2500	20	424062	7592356		1000	10	415638	7599523
	1000	10	424042	7592639		1000	10	415601	7599493
	1000	10	423925	7592625		500	5	415601	7599493
	1000	10	423888	7592708		500	5	419640	7594577
	1000	10	423853	7592795		5000	40	419530	7595649
	500	5	423822	7592926		5000	40	419521	7595076
	500	5	423800	7593009		2500	10	419272	7596501
	1000	10	423795	7593086		2500	10	419287	7596114
	5	0.5	420187	7597134		2500	10	419277	7595808
	20	1	420564	7596917		1000	10	419321	7595386
	20	0.5	420600	7596854		5000	20	419540	7594931
	5	0.5	420166	7597963		1000	5	419596	7594825
	50	0.5	418382	7592007		1000	5	419706	7594608
	2	0.5	418530	7592074		20	0.5	418606	7598974
	50	0.5	418990	7592357		250	2	418402	7599398
	2500	20	424166	7592224		250	3	418015	7599426
	100	1	424057	7592259		250	1	418699	7599289
	50	5	423930	7592607		250	3	414868	7596529
	500	1	414692	7595778		250	5	414892	7596572
	100	5	420357	7598195		250	5	415601	7599445
	5	0.5	424628	7590574		100	2	415574	7599425
	1000	30	425706	7591423		500	10	415544	7599388

Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)	Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)
**Cenchrus setiger*	500	5	415529	7599365	**Cenchrus setiger*	50	3	424515	7590207
	500	10	415510	7599338		75	1	424288	7590673
	1000	10	415424	7599279		2	0.5	425897	7591734
	250	2	415389	7599256		50	5	425872	7591688
	500	10	415357	7599247		500	20	425882	7591638
	100	1	415459	7599315		1000	30	425762	7591563
	75	0.5	415491	7599348		1000	30	425438	7592191
	1000	50	415520	7599378		25	2	423848	7591342
	50	0.5	419324	7595424		100	5	423972	7591421
	100	2	419340	7596283		250	10	424503	7591796
	100	1	419491	7595789		2500	80	424632	7591691
	250	5	418961	7596951		2500	80	424491	7591498
	500	10	418868	7596939		100	10	424391	7591444
	100	1	418408	7599258		100	10	424101	7591323
	250	4	418446	7599235		250	20	424466	7590916
	25	0.5	419676	7598570		250	10	424916	7591089
	100	1	419801	7598537		2500	20	425087	7591333
	100	1	419852	7598520		2500	70	425183	7591535
	100	1	419938	7598471		250	80	425374	7591384
	250	2	419982	7598441		2500	80	425089	7590901
	5	0.5	419290	7592596		500	10	424679	7590891
	3	0.5	419171	7592494		1000	20	425320	7591866
	500	5	419140	7592521		2500	80	425164	7591825
	15	1	419632	7594556		2500	80	424880	7591898
	50	2	420693	7598972		2500	2	425125	7592076
	50	2	420663	7598976		2500	80	425328	7591935
	100	10	420511	7598785		1000	50	423777	7591911
	25	0.5	418365	7597428		1000	2	423994	7591947
	50	2	417800	7597371		250	2	424394	7592003
	10	0.5	419087	7598819	**Chloris barbata*				
	2500	0.5	423972	7592427		50	20	423693	7592015
	2500	20	423947	7592519		1	0.5	424908	7591047
	2500	20	423928	7592576		5	0.5	425365	7591157
	1000	10	423924	7592626	**Citrullus colocynthis*	1	0.5	418612	7598964
	1000	10	423887	7592709		1	0.5	415556	7599414
	1000	10	423854	7592794		1	0.5	424715	7592542
	500	5	423822	7592926		4	1	414510	7597987
	500	5	423801	7593009		4	2	420045	7598742
	1000	10	423795	7593087		1	0.5	418398	7597429
	20	0.5	420600	7596854		1	1	417090	7598588
	50	3	424513	7590839		4	1	417314	7598554

Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)	Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)
**Citrullus colocynthis*	3	5	417374	7598480	**Flaveria trinervia*	1	0.5	419171	7592494
	1	0.5	419596	7595516		10	0.5	419200	7592486
	1	0.5	419050	7596320		1	0.5	419327	7592498
	1	0.5	420258	7597177		5	0.5	419202	7592502
	2	0.5	423373	7591523		5	0.5	419152	7592519
**Cynodon dactylon*	1	0.5	418928	7598067		25	0.5	419111	7592518
	100	0.5	419295	7597953		15	0.5	419122	7592567
	1	0.5	414405	7597083		2	0.5	419257	7592549
	1	0.5	414402	7597069		2	0.5	419199	7592596
	1	0.5	414397	7597027		3	0.5	419261	7592662
	1	0.5	419394	7598589		2	0.5	419328	7592678
	1	0.5	419409	7598604		4	0.5	418532	7592076
	1	1	419435	7598585		10	0.5	425111	7591962
	1	1	419482	7598571	**Lactuca serriola*	1	0.5	414411	7597087
	1	0.5	419547	7598580		1	0.5	419900	7591977
	10	0.5	418903	7597956		1	0.5	423863	7591333
	3	0.5	414837	7596656		6	0.5	424921	7591080
	3	0.5	415952	7598235		1	0.5	424865	7591891
**Echinochloa colona*	3	0.5	423936	7592562		1	0.5	423807	7591893
	1	0.5	424165	7592224	**Malvastrum americanum*	100	0.5	419530	7595650
	1	0.5	419534	7595539		1	5	419527	7598002
**Euphorbia hirta*	2	0.5	415953	7598268		2	0.5	415532	7599368
	5	0.5	419500	7595491		2	0.5	415459	7599297
	5	0.5	417532	7598132		1	0.5	415364	7599247
	50	0.5	423970	7592432		2	0.5	419446	7598575
	50	20	423946	7592520		2	0.5	419911	7598491
	50	20	423928	7592576		1	0.5	419181	7592620
	50	0.5	423924	7592626		10	0.5	419201	7592598
	100	0.5	423889	7592707		10	0.5	419077	7592665
	100	0.5	423851	7592796		2	0.5	419530	7591851
	100	0.5	423822	7592927		8	0.5	419624	7592782
	100	0.5	423799	7593010		15	0.5	419881	7592948
	100	0.5	423795	7593086		25	0.5	419860	7592884
	25	0.5	424167	7592221		1	0.5	419793	7592462
	20	0.5	423899	7592664		3	0.5	418864	7596735
	2	0.5	420367	7597873		50	0.5	424310	7592757
	25	5	425147	7591399		1	0.5	419623	7594538
	10	0.5	424189	7592093		3	0.5	420530	7598776
**Flaveria trinervia*	50	0.5	419638	7594575		1	0.5	418366	7597442
	1	0.5	419181	7592620		3	0.5	416087	7597323
	1	0.5	419218	7592470		10	1	425410	7592697

Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)	Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)
**Malvastrum americanum*	3	0.5	424867	7592496	**Passiflora foetida* subsp. *hispida*	1	0.5	419985	7598058
	1	0.5	424528	7592651		1	0.5	419821	7598126
	2	0.5	419578	7595527		1	0.5	414415	7597050
	3	0.5	424153	7592277		1	0.5	418984	7598424
	3	0.5	424062	7592356		1	0.5	418869	7598396
	15	0.5	423971	7592432		1	0.5	419188	7597970
	50	20	423947	7592520		4	0.5	418347	7597418
	50	20	423924	7592572		1	0.5	424839	7592491
	10	0.5	424043	7592639		1	0.5	423888	7592759
	50	0.5	423922	7592626		8	2	414405	7596632
	50	0.5	423889	7592707		3	0.5	423957	7592480
	50	0.5	423853	7592796		2	0.5	423929	7592593
	10	0.5	423822	7592927		1	0.5	424040	7592637
	25	0.5	424168	7592222		1	0.5	423923	7592625
	5	0.5	423817	7592882		2	0.5	423890	7592706
	20	2	424523	7590207		2	0.5	423850	7592796
	3	0.5	424556	7590208		1	0.5	423823	7592926
	15	2	423359	7591551		2	0.5	420695	7597393
	25	2	425845	7591633		2	0.5	420018	7597732
	10	1	425718	7591486		1	0.5	423938	7592560
	20	1	425449	7591709		1	0.5	423828	7592847
	15	1	425398	7591887		1	0.5	414964	7595806
	3	0.5	423854	7591350		2	0.5	415028	7595830
	10	1	424459	7591764		2	0.5	420586	7597598
	10	1	424553	7591676		1	0.5	419004	7598340
	10	1	424194	7591332		1	0.5	419169	7598362
	50	0.5	425060	7591269		1	0.5	419358	7598331
	15	0.5	425375	7591164		1	0.5	419413	7598324
	10	0.5	425415	7591929		1	0.5	419415	7598327
	15	0.5	425142	7592200		1	0.5	419616	7598277
	3	0.5	423776	7591890		1	0.5	419855	7598276
**Ocimum basilicum*	15	0.5	417910	7598016		1	0.5	418929	7598073
**Passiflora foetida* subsp. *hispida*	75	0.5	419329	7597968		2	0.5	419101	7597976
	50	0.5	419303	7597949		7	0.5	419213	7597986
	20	0.5	419265	7597974		10	0.5	419248	7598000
	20	0.5	419212	7597949		20	0.5	419292	7598014
	20	0.5	419190	7597935		10	0.5	419323	7598029
	1	0.5	414377	7595951		20	0.5	419357	7598043
	1	0.5	419055	7598271		20	0.5	419402	7598047
	1	0.5	419162	7598298		20	0.5	419440	7598052

Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)	Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)
**Passiflora foetida* subsp. *hispida*	20	0.5	419505	7598050	**Rumex vesicarius*	5	0.5	418392	7599245
	10	0.5	419552	7598031		1	0.5	418356	7599265
	5	0.5	419586	7598095		6	0.5	419728	7598444
	10	0.5	419542	7598104		8	0.5	419244	7592766
	10	0.5	419511	7598119		250	8	419213	7592718
	10	0.5	419561	7598139		1	0.5	419494	7592246
	10	0.5	419625	7598131		1	0.5	419330	7592646
	10	0.5	419647	7598115		1	0.5	419201	7592502
	5	0.5	419701	7598112		1	0.5	419261	7592661
	2	0.5	419875	7597993		10	0.5	419316	7592716
	3	0.5	419920	7597951		50	3	419261	7592716
	10	0.5	419944	7597933		75	1	419282	7592762
	20	0.5	419989	7597932		3	0.5	419628	7592801
	20	0.5	419982	7597906		1	0.5	419492	7593012
	2	0.5	419986	7597809		1	0.5	419536	7591885
	10	0.5	419970	7597814		1	0.5	419531	7591906
	20	0.5	419942	7597859		10	0.5	419504	7592762
	20	0.5	419895	7597898		4	0.5	419626	7592899
	10	0.5	419684	7597962		1	0.5	419774	7592785
	20	0.5	419564	7598002		1	0.5	419802	7592317
	20	0.5	419534	7598006		1	0.5	419465	7592025
	20	0.5	419490	7597999		1	0.5	424528	7590787
	10	0.5	419446	7597991		1	0.5	424307	7590708
	20	0.5	419390	7598007		2	0.5	423825	7591351
	75	0.5	419370	7598008		1	0.5	423911	7591419
**Phoenix dactylifera*	5	10	415568	7598295		50	1	424126	7591643
	3	10	415371	7598339		2	0.5	424711	7591065
**Rumex vesicarius*	1	0.5	418647	7593191		1	1	425435	7591151
	5	0.5	419194	7598359		3	0.5	423789	7591874
	5	0.5	419241	7598357	**Setaria verticillata*	100	1	419640	7594577
	1	0.5	419577	7598287		500	2	419521	7595076
	1	0.5	419912	7598280		2	0.5	419569	7594318
	5	0.5	418489	7599325		4	0.5	419443	7596439
	20	0.5	419783	7598882		10	0.5	419470	7592765
	1	0.5	414474	7595610		10	0.5	419620	7592779
	50	0.5	416904	7599430		10	0.5	419642	7592833
	1	0.5	419097	7598274		1	0.5	419181	7592620
	10	0.5	419220	7598312		50	0.5	419201	7592598
	15	0.5	419274	7598332		15	0.5	419297	7592616
	20	0.5	419597	7598972		100	0.5	419290	7592596
	10	0.5	414504	7597491		15	0.5	419119	7592490

Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)	Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)
**Setaria verticillata*	5	0.5	419153	7592519	**Vachellia farnesiana*	3	1	416231	7597078
	250	0.5	419110	7592520		1	0.5	424797	7592472
	75	0.5	419179	7592569		1	0.5	418999	7598649
	10	0.5	419305	7592768		2	2	416967	7598588
	10	0.5	419470	7592765		2	1	417065	7598586
	10	0.5	419620	7592779		10	0.5	419563	7595502
	10	0.5	419642	7592833		3	0.5	420418	7598567
	10	0.5	416125	7597302		2	0.5	420468	7598652
	5	0.5	423837	7592784		1	0.5	424062	7592356
	10	2	425847	7591604		3	0.5	423966	7592449
	10	0.5	425454	7591200		10	0.5	423931	7592579
	4	0.5	424298	7592069		6	0.5	424042	7592639
**Sonchus oleraceus*	5	0.5	419527	7595459		10	0.5	423921	7592626
	1	0.5	419540	7595516		10	0.5	423891	7592706
	1	0.5	419523	7594320		9	0.5	423822	7592925
	10	0.5	417954	7598071		1	0.5	420436	7596998
**Tribulus terrestris*	3	0.5	419557	7594343		4	0.5	424168	7592222
	50	0.5	418784	7592261		2	0.5	423879	7592697
**Vachellia farnesiana*	3	0.5	418985	7599094		1	0.5	414912	7595795
	1	0.5	419522	7595466		2	0.5	414636	7595813
	1	0.5	419549	7595438		5	0.5	423254	7591459
	1	0.5	419602	7598562		5	0.5	423779	7591149
	1	0.5	419881	7598512		5	20	423476	7591350
	1	0.5	419936	7598465		6	20	425877	7591613
	2	0.5	418868	7596739		10	20	425788	7591585
	2	0.5	424333	7592766		10	2	425454	7591685
	1	0.5	424987	7592353		4	0.5	423862	7591379
	7	3	420645	7598965		5	10	424082	7591662
	2	0.5	420694	7598934		5	2	424439	7591781
	2	5	420783	7598863		6	1	424557	7591640
	10	10	420536	7598797		2	0.5	425011	7591191
	2	2	418204	7597525		20	5	425207	7591403
	5	5	415857	7597601		2	0.5	423798	7591880
	7	10	416064	7597336		1	0.5	424313	7591861

Table N.8: Locations of introduced flora recorded in the survey area (Astron 2014) (GDA 94, Zone 50).

Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)	Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)
**Aerva javanica*	1	0.5	417776	7598306	**Cenchrus ciliaris*	500	30	418751	7598654
	4	0.5	417818	7598277		500	10	417522	7598452
	5	0.5	417845	7598268		6	0.5	417828	7598128
**Argemone ochroleuca* subsp. *ochroleuca*	20	0.5	415576	7598226		25	1	417738	7598321
	10	0.5	417547	7597929		250	1	417629	7598380
	100	1	418525	7598278		500	10	417610	7598412
	20	0.5	414729	7595452		1000	20	417558	7598472
	10	0.5	414529	7595497		50	10	418822	7597045
	25	0.5	416751	7598139		20	1	418434	7597978
	10	1	414695	7596117		75	0.5	414809	7595407
	250	20	414664	7596122		100	2	414767	7595427
	50	2	414446	7596068		100	2	414655	7595430
	250	40	414440	7596026		250	5	414547	7595466
	500	30	414454	7595887		10	1	415147	7595000
	50	0.5	418876	7598081		100	2	415380	7598375
	10	0.5	418210	7598162		10	0.5	418645	7598042
	50	10	418250	7598181		10	0.5	418965	7597968
	50	1	418362	7598193		10	5	418841	7597975
	10	0.5	418426	7598187		10	1	418820	7597894
	25	1	418814	7598215	**Cenchrus setiger*	50	10	418920	7597054
	50	0.5	418824	7598082		50	5	418928	7596673
	250	10	419044	7598151		50	5	419155	7596314
	50	5	419141	7598195		25	2	417379	7598592
	25	1	419081	7597897		8	0.5	414931	7595319
	100	10	418826	7598453	**Citrullus colocynthis*	15	30	416018	7597876
	100	5	418999	7592412		1	0.5	415008	7598234
	250	30	418974	7592398		2	1	417358	7598575
	3	0.5	418716	7592338		3	0.5	418476	7597984
	25	0.5	416663	7598135		1	1	418159	7598107
	100	10	416870	7598064		10	2	414449	7595898
	75	2	417228	7598024		3	0.5	418476	7597984
**Bidens bipinnata*	100	1	418229	7598181		2	0.5	417944	7598041
	500	50	414440	7595989		1	0.5	418086	7598077
**Cenchrus ciliaris*	500	2	416080	7597876		1	0.5	419060	7597915
	7	1	416050	7597874		1	0.5	418815	7597862
	500	10	415971	7597885	**Cynodon dactylon*	75	1	414396	7596748
	250	10	415772	7597797		50	2	418702	7598300
	10	2	414376	7597615		10	2	418991	7598191

Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)	Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)
**Euphorbia hirta*	4	0.5	416413	7598144	**Passiflora foetida* var. *hispida*	4	0.5	417968	7597991
**Flaveria trinervia*	6	0.5	418787	7597881		3	0.5	417964	7598084
						6	10	418938	7598153
**Lactuca serriola*	4	0.5	417739	7598059		10	0.5	419134	7598206
	15	0.5	417757	7598064		4	0.5	419023	7597958
	10	0.5	417911	7598016		1	0.5	419146	7597961
**Malvastrum americanum*	25	0.5	414897	7595371		3	0.5	417260	7598136
	10	1	418714	7592344		2	0.5	417194	7598153
	15	1	418600	7592392		2	0.5	417004	7598208
	10	0.5	418600	7592393		10	0.5	416794	7598164
	50	5	418582	7592403		6	0.5	416629	7598140
	1	0.5	416347	7598053		5	5	416329	7598047
**Passiflora foetida* var. *hispida*	2	1	414355	7597175		5	2	416479	7598061
	3	0.5	414437	7597080		5	2	416758	7598069
	4	0.5	414509	7596776	**Rumex vesicarius*	4	0.5	418550	7598288
	1	0.5	418705	7597957	**Setaria verticillata*	1	0.5	416440	7597065
	3	0.5	418613	7597961	**Sonchus oleraceus*	4	0.5	417926	7598079
	20	2	418510	7597972	**Vachellia farnesiana*	1	5	416002	7597896
	5	1	418371	7597974		6	5	414880	7595380
	20	4	417933	7598119		8	10	414586	7595503
	4	3	419102	7598317		1	0.5	416554	7596879
	10	2	419149	7598234		1	0.5	414928	7595313
	10	2	419084	7598204		1	0.5	414932	7595319
	1	1	416723	7598125		20	0.5	414885	7595396
	4	0.5	418879	7598063		10	2	414688	7595433
	2	0.5	418778	7598079		15	2	414627	7595452
	5	5	418748	7598081		1	0.5	415389	7598560
	3	1	418698	7598058		2	2	419037	7597967
	3	0.5	418440	7597973		6	0.5	416554	7596883
	3	0.5	418218	7597978		1	0.5	416293	7598059
	5	0.5	418111	7597998		1	0.5	417482	7598129

Table N.9: Locations of introduced flora recorded in the survey area (Astron 2016a) (GDA 94, Zone 50).

Species	Estimated abundance	Cover (%)	Easting (mE)	Northing (mN)
**Cenchrus ciliaris*	10	0.5	422774	7591327
	7	0.5	422641	7591250
**Cenchrus setiger*	100	40	422774	7591326
**Citrullus colocynthis*	1	0.5	421410	7591675
**Echinochloa colona*	1	0.5	422757	7591364
**Flaveria trinervia*	1	0.5	422665	7591243
**Malvastrum americanum*	1	0.5	422544	7591408
	50	0.5	422654	7591370
	20	0.5	422775	7591327
	5	0.5	422529	7591459
	100	1	422696	7591378
**Rumex vesicaria*	3	0.5	422347	7591481
**Vachellia farnesiana*	4	0.5	422507	7591460
	3	0.5	422774	7591328
	1	1	422564	7591456
	5	1	422696	7591378
	20	10	422654	7591369

Table N.10: Locations of introduced flora previously recorded in the survey area (Biota 2011) (GDA 94, Zone 50).

Species	Estimated abundance/ density (%)	Easting (mE)	Northing (mN)	Species	Estimated abundance/ density (%)	Easting (mE)	Northing (mN)
**Aerva javanica*	10 individuals	415433	7599382	**Cenchrus ciliaris*	10-30% cover	415401	7599482
	10 individuals	415476	7599361		20% cover	415407	7598601
	5 individuals	415490	7599438		30% cover	415410	7598644
	1 individual	418150	7599492		n/a	415414	7598890
	<1% cover	419066	7598806		30-50% cover	415417	7599383
**Argemone ochroleuca* subsp. *ochroleuca*	100 individuals	414409	7596028		n/a	415425	7598587
	n/a	418447	7597444		n/a	415426	7598840
	n/a	415511	7599368		30-50% cover	415433	7599382
	n/a	415555	7599421		n/a	415452	7598595
	50+ individuals	418557	7598247		30% cover	415462	7598684
	20+ individuals	418611	7598065		n/a	415473	7599174
	15 individuals	418674	7598271		30-50% cover	415476	7599361
	1 individual	418713	7597363		30% cover	415480	7598788
	n/a	418748	7598282		n/a	415494	7598639
	n/a	418852	7597861		1 individual	415508	7599271
	50+ individuals	418902	7598393		n/a	415511	7599368
	50+ individuals	418956	7598116		30-50% cover	415520	7598631
	20+ individuals	418983	7597976			415555	7599421
	<1% cover	419066	7598806		30-50% cover	415568	7599362
	n/a	419098	7598758		30% cover	415582	7599071
**Cenchrus ciliaris*	n/a	416637	7598464		n/a	415610	7599171
	n/a	416755	7598536		n/a	415622	7599405
	n/a	416877	7598515		30-50% cover	415639	7599281
	n/a	417226	7598568		n/a	415665	7598713
	n/a	417340	7598620		n/a	415701	7599093
	<1% cover	417585	7598133		n/a	415709	7599330
	n/a	418415	7597452		n/a	415724	7599351
	n/a	418447	7597444		n/a	415781	7599403
	n/a	418464	7597574		n/a	415877	7599457
	n/a	418500	7597439		n/a	418110	7599500
	n/a	418603	7597647		n/a	418303	7599399
	n/a	418711	7597773		n/a	418340	7599434
	n/a	418821	7597775		n/a	418453	7599212
	n/a	419011	7597073		2 individuals	418512	7599373
	n/a	419028	7596312		1 individual	418570	7599150
	n/a	419034	7597225		20 individuals	418647	7598598
	n/a	419065	7596392		n/a	418743	7598618
	10% cover	415347	7598695		1 individual	418752	7598744
	n/a	415369	7598901		1 individual	418787	7598666

Species	Estimated abundance/ density (%)	Easting (mE)	Northing (mN)	Species	Estimated abundance/ density (%)	Easting (mE)	Northing (mN)
**Cenchrus ciliaris*	<1% cover	418837	7597917	**Cenchrus setiger*	50+ individuals	419137	7595870
	1 individual	418844	7598902		n/a	419138	7596314
	1 individual	418848	7598874		1 individual	419142	7595859
	n/a	418905	7597980		30% cover	419143	7595876
	1 individual	418932	7598270		1 individual	418742	7598247
	<1% cover	419066	7598806		n/a	415511	7599368
	n/a	419074	7596083		n/a	419074	7596083
	n/a	419120	7596114		n/a	419078	7596193
	5 individuals	419137	7595870	**Citrullus colocynthis*	n/a	415555	7599421
**Cenchrus setiger*	n/a	415366	7598572		1 individual	418294	7599421
	10-30% cover	415401	7599482		1 individual	418619	7598530
	20% cover	415407	7598601		2 individuals	418733	7597951
	n/a	415414	7598890	**Cynodon dactylon*	<1% cover	417585	7598133
	30-50% cover	415417	7599383	**Datura leichhardtii*	n/a	415607	7599463
	n/a	415426	7598840	**Euphorbia hirta*	1 individual	414394	7596056
	30-50% cover	415433	7599382		n/a	419066	7598806
	30-50% cover	415476	7599361	**Malvastrum americanum*	<1% cover	414409	7596028
	20% cover	415480	7598788		20 individuals	415328	7594578
	30-50% cover	415511	7599368		1 individual	415410	7598644
	30-50% cover	415555	7599421		n/a	415511	7599368
	30% cover	415568	7599362		n/a	415555	7599421
	n/a	415610	7599171		n/a	415781	7599403
	30-50% cover	415622	7599405		n/a	418434	7599274
	n/a	415639	7599281		n/a	418453	7599212
	n/a	415709	7599330		n/a	418626	7598981
	n/a	415724	7599351		1 individual	418867	7596641
	n/a	415781	7599403		n/a	418968	7596926
	n/a	418110	7599500		2 individuals	419043	7596078
	n/a	418453	7599212		n/a	419078	7596193
	n/a	418626	7598981		n/a	419120	7598769
	n/a	418639	7598895		<1% cover	419121	7593033
	n/a	418743	7598618		n/a	419138	7596314
	n/a	418825	7598997		1 individual	419143	7595876
	n/a	418828	7598963	**Passiflora foetida* var. *hispida*	1 individual	414394	7596056
	<1% cover	418837	7597917		<1% cover	417585	7598133
	10 m diameter	418867	7596641		1 individual	418500	7597439
	30% cover	418968	7596926		n/a	418905	7597980
	n/a	418975	7596532	**Rumex vesicarius*	1 individual	414394	7596056
	1 individual	419066	7598806				

Species	Estimated abundance/ density (%)	Easting (mE)	Northing (mN)	Species	Estimated abundance/ density (%)	Easting (mE)	Northing (mN)
**Solanum nigrum*	3 individuals	417585	7598133	**Sonchus oleraceus*	<1% cover	418611	7598065
					<1% cover	418691	7597883

Table N.11: Locations of introduced flora previously recorded in the survey area (Biota 2006) (GDA 94, Zone 50).

Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)	Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)
**Aerva javanica*	10	0.5	415433	7599382	**Cenchrus ciliaris*	n/a	1	415494	7598639
	10	0.5	415476	7599361		n/a	1	415508	7599271
	5	0.5	415490	7599438		n/a	30-50	415511	7599368
	1	0.5	418150	7599492		n/a	1	415520	7598631
	1	0.5	419066	7598806		n/a	30-50	415555	7599421
	1	0.5	419172	7598711		n/a	30	415568	7599362
	1	0.5	419252	7595971		n/a	1	415582	7599071
	1	0.5	419294	7595929		n/a	1	415610	7599171
	n/a	0.5	420741	7598792		n/a	30-50	415622	7599405
**Argemone ochroleuca* subsp. *ochroleuca*	n/a	0.5	415511	7599368		n/a	1	415639	7599281
	n/a	0.5	415555	7599421		n/a	1	415665	7598713
	50	n/a	418557	7598247		n/a	1	415701	7599093
	20	0.5	418611	7598065		n/a	1	415709	7599330
	15	0.5	418674	7598271		n/a	1	415724	7599351
	1	0.5	418713	7597363		n/a	1	415781	7599403
	n/a	0.5	418748	7598282		n/a	0.5	415877	7599457
	n/a	0.5	418852	7597861		n/a	0.5	418110	7599500
	50	n/a	418902	7598393		n/a	0.5	418303	7599399
	50	n/a	418956	7598116		n/a	0.5	418340	7599434
	20	0.5	418983	7597976		n/a	0.5	418453	7599212
	n/a	0.5	419066	7598806		2	0.5	418512	7599373
	n/a	0.5	419098	7598758		1	0.5	418570	7599150
	1	0.5	419366	7596012		20	0.5	418647	7598598
	n/a	0.5	419551	7594537		n/a	0.5	418743	7598618
	n/a	0.5	420483	7598698		1	0.5	418752	7598744
**Cenchrus ciliaris*	n/a	10	415347	7598695		1	0.5	418787	7598666
	n/a	1	415369	7598901		n/a	0.5	418837	7597917
	n/a	10-30	415401	7599482		1	0.5	418844	7598902
	n/a	0.2	415407	7598601		1	0.5	418848	7598874
	n/a	30	415410	7598644		n/a	0.5	418905	7597980
	n/a	1	415414	7598890		1	0.5	418932	7598270
	n/a	30-50	415417	7599383		n/a	0.5	419066	7598806
	n/a	1	415425	7598587		n/a	0.5	419074	7596083
	n/a	1	415426	7598840		n/a	0.5	419120	7596114
	n/a	30-50	415433	7599382		n/a	0.5	419137	7595870
	n/a	1	415452	7598595		n/a	0.5	419172	7598711
	n/a	30	415462	7598684		n/a	0.5	419235	7598732
	n/a	1	415473	7599174		n/a	0.5	419252	7595971
	n/a	30-50	415476	7599361		n/a	0.5	419266	7596537
	n/a	30	415480	7598788		n/a	1	419297	7595353

Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)	Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)
**Cenchrus ciliaris*	n/a	0.5	419349	7595752	**Cenchrus setiger*	n/a	30	418968	7596926
	n/a	10	419359	7595341		n/a	0.5	418975	7596532
	n/a	0.5	419364	7595713		1	0.5	419066	7598806
	20	0.5	419417	7595235		n/a	0.5	419074	7596083
	n/a	30	419476	7595060		n/a	0.5	419078	7596193
	n/a	0.5	419487	7595013		n/a	0.5	419120	7596114
	n/a	0.5	419512	7594859		50	n/a	419137	7595870
	n/a	50	419548	7595441		n/a	0.5	419138	7596314
	n/a	0.5	419575	7594780		1	0.5	419142	7595859
	n/a	0.5	419705	7594753		n/a	30	419143	7595876
	n/a	0.5	419727	7594571		n/a	3-4	419252	7595971
	n/a	30	419798	7594579		30	0.5	419324	7596078
	n/a	30	419983	7594428		5	n/a	419326	7595471
**Cenchrus setiger*	n/a	0.5	415366	7598572		1	n/a	419347	7596429
	n/a	10-30	415401	7599482		10	n/a	419359	7595341
	n/a	20	415407	7598601		100	n/a	419361	7595175
	n/a	0.5	415414	7598890		20	n/a	419417	7595235
	n/a	30-50	415417	7599383		n/a	0.5	419521	7595075
	n/a	0.5	415426	7598840		n/a	30	419548	7595441
	n/a	30-50	415433	7599382		n/a	30	419634	7595406
	n/a	30-50	415476	7599361		n/a	30	419654	7595302
	n/a	30	415480	7598788		2	0.5	419664	7595278
	n/a	0.5	415511	7599368		n/a	0.5	419705	7594753
	n/a	30-50	415555	7599421		n/a	30	419748	7594917
	n/a	0.5	415568	7599362		n/a	2-10	419798	7594579
	n/a	0.5	415610	7599171		n/a	2-10	419983	7594428
	n/a	0.5	415622	7599405	**Chloris barbata*	n/a	0.5	420496	7598702
	n/a	0.5	415639	7599281	**Citrullus colocynthis*	n/a	0.5	415511	7599368
	n/a	0.5	415709	7599330		n/a	0.5	415555	7599421
	n/a	0.5	415724	7599351		n/a	0.5	418294	7599421
	n/a	0.5	415781	7599403		n/a	0.5	418619	7598530
	n/a	0.5	418110	7599500		n/a	0.5	418733	7597951
	n/a	0.5	418453	7599212		n/a	0.5	419402	7595864
	n/a	0.5	418626	7598981	**Datura leichhardtii*	n/a	0.5	415607	7599463
	n/a	0.5	418639	7598895		n/a	0.5	420483	7598698
	n/a	0.5	418743	7598618	**Euphorbia hirta*	n/a	0.5	419066	7598806
	n/a	0.5	418825	7598997					
	n/a	0.5	418828	7598963	**Malvastrum americanum*	20	0.5	415328	7594578
	n/a	0.5	418837	7597917		1	0.5	415410	7598644
	n/a	n/a	418867	7596641		n/a	0.5	415511	7599368

Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)	Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)
**Malvastrum americanum*	n/a	0.5	415555	7599421	**Malvastrum americanum*	1	0.5	419543	7594641
	n/a	0.5	415781	7599403		3	0.5	419561	7595627
	n/a	0.5	418434	7599274		n/a	0.5	419597	7594411
	n/a	0.5	418453	7599212		1	0.5	419610	7595456
	n/a	0.5	418626	7598981		n/a	0.5	419613	7594502
	1	0.5	418867	7596641		n/a	0.5	419726	7594917
	n/a	0.5	418968	7596926		n/a	0.5	419813	7594710
	2	0.5	419043	7596078		n/a	0.5	420483	7598698
	2	0.5	419078	7596193		n/a	n/a	423013	7591421
	n/a	0.5	419120	7598769		1	n/a	423113	7591468
	+	0.5	419121	7593033		n/a	n/a	423320	7591446
	n/a	0.5	419138	7596314		n/a	n/a	423338	7591443
	1	0.5	419143	7595876	*Ocimum basilicum	n/a	0.5	420496	7598702
	2	0.5	419366	7596012	*Passiflora foetida	n/a	0.5	418905	7597980
	2	0.5	419507	7594663	*Sonchus oleraceus	1	0.5	418611	7598065
	n/a	0.5	419521	7595075		n/a	0.5	418691	7597883

Table N.12: Locations of introduced flora previously recorded in the survey area (Biota 2003)(Zone 50).

Species	Estimated abundance	Density (%)	Easting (mE) (GDA94^)	Northing (mN) (GDA94^)
**Cenchrus ciliaris*	n/a	n/a	419908	7592671
**Cenchrus setiger*	n/a	n/a	419908	7592671

Note: Additional introduced flora species were recorded in proximity to, but outside, the Mesa H survey area boundary.
^Converted to GDA94 from the redundant "AGD84" originally published.

Table N.13: Description of introduced flora recorded in the survey area.

Species	Description	Habitat
**Aerva javanica* (Kapok Bush) 	An erect, much-branched perennial, herb between 0.4 m and 1.6 m high. It has white woolly flowers arranged in spikes between January and October (WAHerb 1998-2016).	Often on sandy soils, along drainage lines (WAHerb 1998-2016).
**Argemone ochroleuca* subsp. *ochroleuca* (Mexican Poppy) 	An erect, prickly, glaucous annual herb between 0.2 m and 1 m in height with white, cream and yellow flowers between February/March and July/November (WAHerb 1998-2016).	Generally along creek edges, riverbanks and roadsides. Occurs in red/white/grey sand and red-brown clay loam (WAHerb 1998-2016).
**Bidens bipinnata* 	An erect annual herb growing to 1 m high. Produces yellow flowers from March to September (WAHerb 1998-2016).	Occurs in a variety of soils including alluvium, clay, loam over sandstone and limestone. Habitat preferences include rivers, creeks, coastal areas and rocky hillsides (WAHerb 1998-2016).
**Cenchrus ciliaris* (Buffel Grass) 	A tufted or sometimes stoloniferous perennial grass between 0.2 m and 1.5 m in height with purple, ciliate flowers between February and October. Seedheads form a dense hairy cylindrical spike to 10 cm long (WAHerb 1998-2016).	**C. ciliaris* favours sand but may also establish in loamy and clayey soils. It is a widespread weed of roadsides, creek lines and river edges (WAHerb 1998-2016).

Species	Description	Habitat
**Cenchrus setiger* (Birdwood Grass) 	An erect, tussock, stoloniferous perennial grass that grows to 0.5 m high. It has cream to purple flowers that occur from April to May (WAHerb 1998-2016).	**C. setiger* favours brown sands, red loam and pindan soils. It is often found on sand dunes, plains, rangelands, stony hillsides and floodplains (WAHerb 1998-2016).
* *Chloris barbata* (Purpletop Chloris) 	Annual or perennial (short-lived), grass, between 0.4 m and 1.1 m high. It has purple flowers in February or between April and October (WAHerb 1998-2016).	Occurs on white or red sand, loam, and black clay, often on sand dunes and river levees (WAHerb 1998-2016).
**Citrullus colocynthis* (Colocynth) 	A trailing perennial, herb or climber with deeply lobed, scabrous leaves. It has greenish yellow flowers between January and October. Fruits are a spherical melon, mottled green and yellow or all yellow with dull yellow-brown seeds (WAHerb 1998-2016).	Commonly occurs on sandy, rocky, stony loam, clay and wet soils; often in floodplains and disturbed areas (WAHerb 1998-2016).
**Cynodon dactylon* (Couch Grass) 	A rhizomatous (or stoloniferous), prostrate perennial grass from 0.05 m to 0.3 m high. Flowers are green or purple June to November (WAHerb 1998-2016).	**C. dactylon* occurs in sand, loam or clay habitats (WAHerb 1998-2016).

Species	Description	Habitat
**Echinochloa colona* (Awnless Barnyard Grass) 	A tufted annual grass between 0.2 m and 0.9 m high. It has a green/purple inflorescence between February and July (WAHerb 1998-2016).	Occurs on black sand and black clay, near watercourses and swamps (WAHerb 1998-2016).
**Euphorbia hirta* (Asthma Plant) 	An erect or prostrate much branched hairy annual herb, growing between 0.1 m and 0.8 m high. Leaves are opposite, narrowly ovate with dark red blotches. Yellow-green-white axillary flowers are produced between January and October (WAHerb 1998-2016).	Occurs on alluvial soils, often along watercourses (WAHerb 1998-2016).
**Flaveria trinervia* (Speedy Weed) 	An erect annual herb, with ovate leaves. It has yellow flowers clustered to form a dense inflorescence (WAHerb 1998-2016).	Occurs in a variety of soils, particularly sandy and clayey sites. Typically occurs in drainage lines (WAHerb 1998-2016).
**Lactuca serriola* (Prickly Lettuce) 	Erect annual or biennial herb 0.4 m to 2 m high. Flowers yellow, October to February (WAHerb 1998-2016).	Roadsides, gardens, cultivated fields, disturbed sites (WAHerb 1998-2016).

Species	Description	Habitat
**Malvastrum americanum* (Spiked Malvastrum) 	An erect, hairy perennial herb or shrub between 0.5 m and 1.3 m in height. Flowers are yellow and orange, between April and July (WAHerb 1998-2016).	**M. americanum* occurs in a variety of sandy and clayey soils, as well as in limestone and calcrete. It typically occurs along stony ridges and hillsides, floodplains and along drainage lines (WAHerb 1998-2016).
**Ocimum basilicum* (Basil) 	Aromatic annual or perennial herb to 0.6 m high. Blue-purple, pink and/or white flowers from February to August (WAHerb 1998-2016).	Sandy soils and disturbed areas (WAHerb 1998-2016).
**Passiflora foetida* var. *hispida* (Stinking Passion Flower) 	A woody climber to 9 m high with an unpleasant smell. It produces cream-white or blue flowers from February to November (WAHerb 1998-2016).	**P. foetida* var. *hispida* is commonly found in coastal areas, rivers and creek banks (WAHerb 1998-2016).
**Phoenix dactylifera* (Date Palm) 	A perennial tree-like monocot (palm) between 0.4 m to 8 m high. It produces flowers from July to September (WAHerb 1998-2016).	It is found on the edges of permanent pools and watercourses (WAHerb 1998-2016).

Species	Description	Habitat
**Rumex vesicarius* (Ruby Dock) 	An erect, fleshy annual herb to 1 m high. Produces red-pink flowers from July to September (WAHerb 1998-2016).	Occurs in a variety of habitats and soils, including sandy alluvial and gravelly ironstone soils. Often occurs along roadsides and other disturbed areas (WAHerb 1998-2016).
**Setaria verticillata* (Whorled Pigeon Grass) 	A loosely tufted annual grass, 0.1 m to 1.3 m high. It flowers from December to June (WAHerb 1998-2016).	**S. verticillata* is found on sand, clay and loam. It is a common weed of disturbed areas and riverine edges (WAHerb 1998-2016).
**Sonchus oleraceus* (Common Sowthistle) 	An erect, fleshy annual herb to 1 m high. Produces red-pink flowers from July to September (WAHerb 1998-2016).	Occurs in a variety of habitats and soils, including sandy alluvial and gravelly ironstone soils. Often occurs along roadsides and other disturbed areas (WAHerb 1998-2016).

Species	Description	Habitat
**Tribulus terrestris* (Caltrop) 	Prostrate, annual herb with yellow flowers less than 1 mm wide from January to December. It has greyish pinnate leaves and produces spiny roughly spherical fruit (Hussey et al. 2007, WAHerb 1998-2016).	Often found in sandy soils and in waste areas (WAHerb 1998-2016).
**Vachellia farnesiana* (Mimosa Bush) 	An erect, sprawling, thicket-forming shrub or tree up to 4 m in height. It has dark grey, rough bark, pinnate leaves and long stiff thorns at right angles to the stems. Branchlets are also covered in rough, light coloured "wart"-like markings. It produces globular yellow flowers from June to August (WAHerb 1998-2016).	**V. farnesiana* favors low lying areas, disturbed areas and river and creeks banks (WAHerb 1998-2016).

Appendix O: Survey Effort (Tracklogs)

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412000 414000 416000 418000 420000 422000 424000 426000 428000

7600000 7598000 7596000 7594000 7592000 7590000 7588000

Robe River

Jimmawurrada Creek

Millstream - Yarraloola Rd

Legend

- Main Road
- Railway
- River/Creek
- Mesa H Survey Area
- GPS Tracklogs

Robe River Mining Co. Pty Ltd

Mesa H – Level 2 Vegetation and Flora Assessment, May 2016

Figure O.1: Survey Effort

Datum: GDA 1994 - Projection: MGA Zone 50

0 500 1,000 1,500 2,000 metres

N

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Mesa H
Riparian Community Assessment

June 2016

Prepared for
Robe River Mining Co. Pty Ltd

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Report Reference: 14269-16-BISR-5Rev0_170804

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Mesa H
Riparian Community Assessment

Prepared for
Robe River Mining Co. Pty Ltd

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Approval

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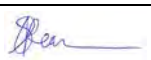
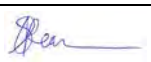
			Name	**Signature**
A	30/09/2016	P. Royce	S. Pearse	
B	21/04/2017	M. Brand	S. Pearse	
0	04/08/2017	M. Brand	S. Pearse	

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Abbreviations

Abbreviation	Definition
ANZECC/ARMCANZ	Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand
Astron	Astron Environmental Services
BAM Act	*Biosecurity and Agriculture Management Act 2007 (*State)
Biota	Biota Environmental Sciences
BOM	Bureau of Meteorology
DAFWA	Department of Agriculture and Food Western Australia (State)
DRF	Declared Rare Flora
EC	Electrical Conductivity
ecologia	ecologia Environment
EPA	Environmental Protection Authority (State)
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999* (Commonwealth)
ESA	Environmentally Sensitive Areas
GDA94	Geocentric Datum of Australia 1994
GDE	Groundwater Dependent Ecosystem
GPS	Global Positioning System
IBRA	Interim Biogeographic Regionalisation for Australia
IUCN	International Union for Conservation of Nature
MGA	Map Grid of Australia
MNES	Matters of National Environmental Significance (under the EPBC Act)
MGA94	Map Grid of Australia 1994
Parks and Wildlife	Department of Parks and Wildlife (State)
P	Priority
PEC	Priority Ecological Community
RNE	Register of the National Estate
sp.	Species (singular)
SRE	Short Range Endemic
The 'survey area'	Riparian Community project area
TDS	Total Dissolved Solids
TEC	Threatened Ecological Community
TPFL	Threatened and Priority Flora Database (administered by Parks and Wildlife)
TP List	Threatened and Priority Flora List (administered by Parks and Wildlife)
TV	Trigger Value
UWA	University of Western Australia
WAHerb	Western Australian Herbarium
WC Act	*Wildlife Conservation Act 1950* (State)
WoNS	Weeds of National Significance
WRM	Wetland Research & Management

Executive Summary

Rio Tinto on behalf of Robe River Mining Co. Pty Ltd is evaluating the potential development of the Mesa H deposit located adjacent to the Mesa J Operation. One aspect of the environmental assessment process for the Mesa H development under consideration is water management, as off-site discharge is likely to result in additional water being directed into the Robe River. In anticipation of potential impacts due to increased stream flow, Astron Environmental Services was commissioned to undertake a Level 2 flora and vegetation assessment and Level 1 vertebrate fauna and aquatic fauna assessment in the riparian community survey area which is 2,128 hectares in size.

Five vegetation associations were described within the survey area, none of which represent a Threatened Ecological Community or Priority Ecological Community. The dominant trees in the upper stratum of three vegetation associations represent potentially Groundwater Dependent Ecosystems. Vegetation condition broadly ranged from 'poor' to 'excellent'. Approximately 17 hectares (less than 1%) of the survey area was 'disturbed', the majority of which represented established tracks and rail infrastructure within the survey area. Other disturbances included small pockets of riparian vegetation being burnt within the past 10 years and grazing on alluvial plains and in drainage lines.

There were 124 plant species from 37 families and 82 genera recorded from sampling sites and opportunistically throughout the survey area. The families and genera recorded are typical of what would be expected in riparian vegetation of major drainage lines in the Pilbara. No Threatened taxa were recorded, however three Priority flora species, *Triodia* sp. Robe River (M.E. Trudgen et al. MET 12367) P3, *Livistona alfredii* P4 and *Rhynchosia bungarensis* P4, were recorded within the Robe River and its tributaries. There were 23 weed species recorded within the sampling sites and opportunistically. None of the weed species recorded is listed as a declared pest for the Shire of Ashburton or a Weed of National Significance.

Two broad fauna habitat types were recorded in the survey area: Riverine and Drainage Line. The Riverine habitat is considered to be of high importance to fauna species providing a range of ecological values to a wide suite of species. Thirteen permanent pools (approximately 16.4 hectares) were recorded within the survey area in the Riverine habitat. These pools are considered a significant fauna habitat due to the refuge they provide to fish, amphibians and water fowl during dry times and the dense vegetation they support. The Drainage Line habitat is a commonly recorded habitat for the wider Pilbara region and considered to be of low to moderate value to a wide spectrum of fauna species. The survey area contains some of the most significant permanent pools in the area (such as Yeera Bluff) that are significant ecological features to the local fauna both up and downstream. The springs and pools of the Robe River that occur in the survey area are considered wetlands of sub-regional significance (Kendrick 2001).

The database searches and literature review results indicate that 318 vertebrate fauna have been previously recorded within 40 kilometres of the survey area, including six amphibian species, 102 reptile species, 160 bird species and 50 mammal species. Thirty-one terrestrial vertebrate fauna species, comprising two reptiles and 29 bird species were recorded within the survey area. This includes one conservation significant species, the Rainbow Bee-eater, which is listed as Migratory under the *Environment Protection and Biodiversity Conservation Act 1999* and Schedule 5 under the *Wildlife Conservation Act 1950*.

A total of 28 species of conservation significance, have been previously recorded in the vicinity of the survey area. Of these, six species were considered to have a 'high' likelihood of occurrence: the Pilbara Olive Python (Vu; S3), Rainbow Bee-eater (Mi; S5), Eastern Great Egret (Mi; S5), Northern Quoll (En; S2), Ghost Bat (Vu; S3) and Pilbara Leaf-nosed Bat (Vu; S3).

Based on the number of previous records of the Matter of National Environmental Significance species (Northern Quoll, Pilbara Olive Python, Ghost Bat and Pilbara Leaf-nosed Bat), the survey area and its surrounds potentially support locally significant populations. These species may be locally common, but their presence is restricted to areas of preferred habitat. Although the fauna habitats of the survey area do not support the caves and den sites these species shelter in, they do provide quality foraging habitat in close proximity to an abundance of suitable shelter. This feature is an important component to supporting the populations and presence of the Matter of National Environmental Significance species in the survey area and its surrounds.

As part of the aquatic ecosystems survey, 12 pools were sampled along the main channel of the Robe River. Sites included six potentially exposed sites adjacent to the predicted groundwater drawdown cone of depression and within the predicted surface extent of dewatering discharge; and six reference sites upstream of the Jimmawurrada Creek confluence. Water quality was highly variable amongst sites, with salinity levels ranging from fresh (592 µS/cm) to brackish (1,700 µS/cm), pH from circum-neutral (6.9) to slightly alkaline (7.9) and dissolved oxygen from hypoxic (14.5%) to supersaturated (134.9%).

Exceedances of the Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand default trigger values for the protection of 95% of species in slightly-moderately disturbed tropical northern Australian systems were recorded for nitrogen nutrients (N-total, N-NO_x & N-NH_3) at most sites upstream (reference sites) and downstream (impact sites) of the Jimmawurrada-Robe confluence. Elevated background levels of N-NO_3 and N-NH_3 within the survey area are unsurprising, given that the Robe River catchment is already affected by current and historic pastoral practices, with groundwaters also appearing to be enriched.

A total of 81 microinvertebrate taxa were recorded from the survey area, of which 46 were present at potentially exposed sites downstream of the Jimmawurrada-Robe confluence, and 69 were recorded at upstream reference sites. The microinvertebrate fauna was generally typical of that commonly recorded from tropical/sub-tropical freshwater systems, comprising Protista, Rotifera, Copepoda, Cladocera (water fleas) and Ostracoda (seed shrimp), with species from the family Lecanidae dominating within the Rotifera. One microinvertebrate species listed for conservation significance, the copepod *Eodiaptomus lumholtzi* (International Union for Conservation of Nature Vulnerable) was recorded. The conservation listing of this species is considered in need of revision, because it now occurs at numerous locations across the Pilbara region.

A total of 59 taxa were recorded from hyporheic samples, the majority of which were species not specially adapted to groundwater environments (stygoxene). Of these 59 taxa, 8% were considered stygobitic (obligate groundwater inhabitants), 31% occasional hyporheic stygophiles (species that use the hyporheic zone seasonally or during early life history stages), and 2% possible hyporheic taxa. Stygobitic taxa collected included the amphipod *Nedsia* sp., the thermosbaenacean *Halosbaena tulki*, and the ostracods *Candonopsis* cf. *tenuis* and *Vestalenula marmonieri*. Of these, *Nedsia* sp. is considered to be a short range endemic species.

A total of 148 macroinvertebrate taxa were recorded from surface waters (117 from upstream reference sites, and 116 from downstream potentially exposed sites), with composition typical of freshwater systems throughout the world, being dominated by Insecta, in particular Diptera (true flies) and Coleoptera (aquatic beetles). One macroinvertebrate species listed for conservation significance, the Pilbara Pin Damselfly *Eurysticta coolawanyah* (International Union for Conservation of Nature: Near Threatened), was recorded at potentially exposed downstream sites.

A total of 3,515 individual fish, representing 11 species, were recorded in the survey area. True freshwater species included Western Rainbowfish, Spangled Perch, Pilbara Tandan (Eel-tailed Catfish), Fortescue Grunter, Barred Grunter, Terapontidae (Grunter) hybrids and Bony Bream. Estuarine/marine vagrant fish species included Milkfish, Tarpon/Ox-eye Herring, Mullet and Banded Scat/Striped Butterfish. The conservation listed Fortescue Grunter (*Leipotherapon aheneus*; International Union for Conservation of Nature Lower Risk/Near Threatened; P4) was the second most abundant fish species of the survey area.

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1 Introduction

1.1 Project Background

Rio Tinto, on behalf of Robe River Mining Co. Pty Ltd (the Proponent), is evaluating the potential development of the Mesa H deposit located adjacent to the Mesa J Operation and approximately 13 km to the south-west of the town of Pannawonica, Western Australia (Figure 1). A key component of the pre-feasibility and feasibility studies being undertaken is the environmental surveys which are required to inform the environmental assessment process for the potential development of the Mesa H deposit.

One aspect of the Mesa H development under consideration is water management involving mine dewatering, off-site discharge and processing/dust suppression water use. Groundwater abstraction has the potential to impact the groundwater levels in the vicinity of the Robe River and off-site discharge is likely to result in additional surplus water being directed into the Robe River. For this reason, biological surveys of the riparian vegetation along the relevant section of the Robe River (and tributaries such as portions of the Jimmawurrada Creek) are required.

Astron Environmental Services (Astron) was commissioned to undertake some of these environmental surveys. This report presents the outcome of a Level 2 vegetation and flora assessment of the Robe River riparian community, and also a Level 1 fauna assessment (Table 1). The survey area is 2,128 ha.

Astron commissioned Wetland Research & Management (WRM) to design and conduct a baseline sampling program encompassing aquatic ecosystems of the Robe River both upstream and downstream of the Mesa H development.

A vegetation and flora survey of previously unsurveyed sections of the Robe River was completed in June 2016. In addition to this, information pertaining to the riparian zone of three separate surveys which overlap the current survey area helped inform the vegetation and flora aspects of this assessment:

- Astron Environmental Services (2016a), '*Middle Robe and East Deepdale Level 2 Vegetation and Flora Assessment'*, unpublished report to Rio Tinto
- Astron Environmental Services (2016b), '*Mesa H Level 2 Vegetation and Flora Assessment'*, report in preparation for Robe River Mining Co. Pty Ltd
- Astron Environmental Services (2016c),'*Mesa H Riparian Vegetation Baseline Monitoring'*, report in preparation for Robe River Mining Co. Pty Ltd.

Table 1: Summary of Astron's Riparian Community Assessment.

Level of survey	Survey area size	Relevant regulatory guidance documents
Level 2 flora and vegetation assessment	2,128 ha	• Environmental Protection Authority (EPA) Position Statement No. 3 (Environmental Protection Authority 2002) • EPA Guidance Statement No. 51 (Environmental Protection Authority 2004a) • EPA & Parks and Wildlife Technical Guide (Environmental Protection Authority and Department of Parks and Wildlife 2015)

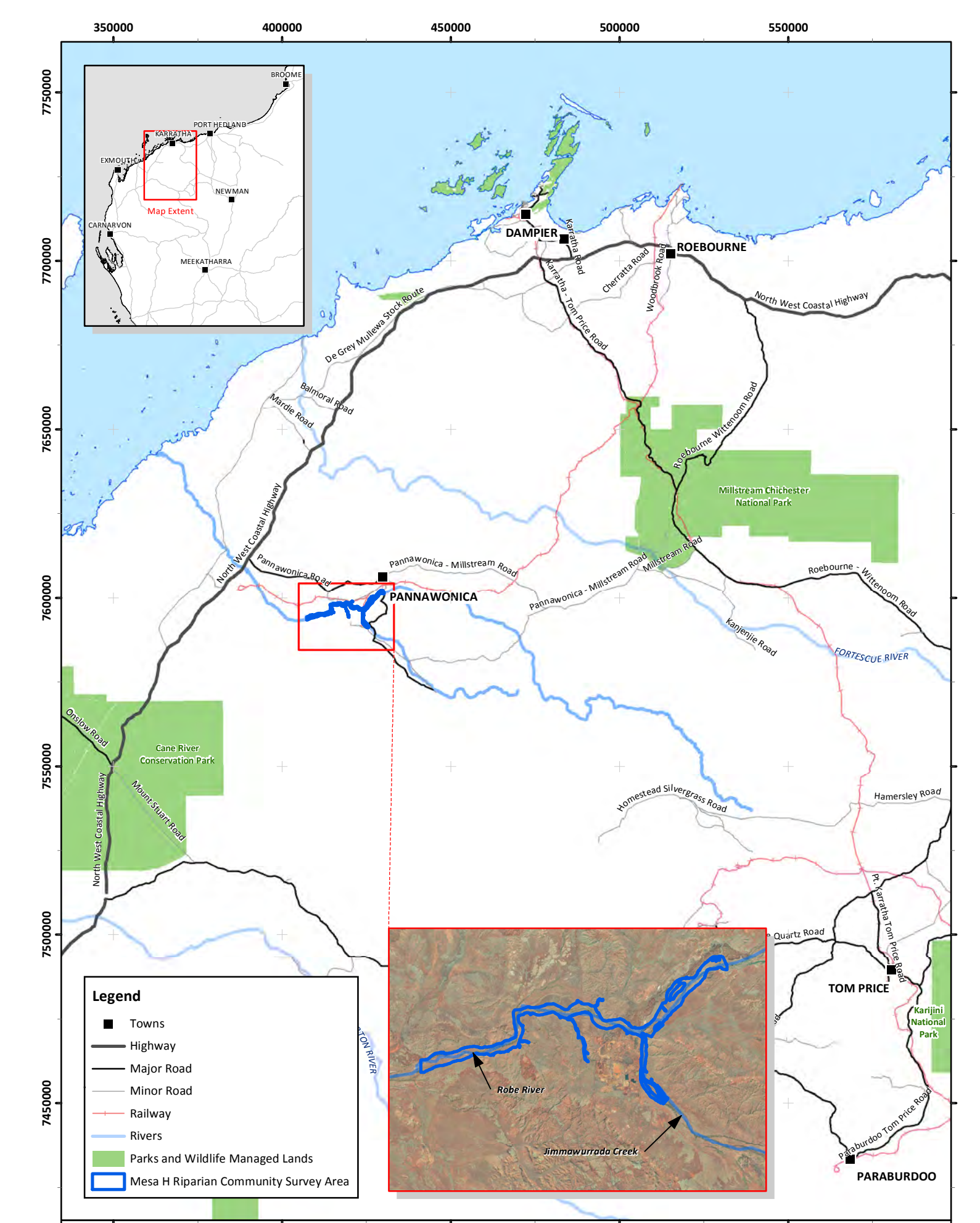
Level of survey	Survey area size	Relevant regulatory guidance documents
Level 1 fauna assessment	2,128 ha	• EPA Guidance Statement No. 56 (Environmental Protection Authority 2004b) • EPA and DEC Technical Guide (Environmental Protection Authority and Department of Environment and Conservation 2010)
Baseline Aquatic Survey	12 sites (6 upstream and 6 downstream of the proposed discharge point)	• Australian and New Zealand Guidelines for Fresh and Marine Water Quality (Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand 2000) • EPA Guidance No. 20, Sampling of Short Range Endemic Invertebrate Fauna for Environmental Impact Assessment in Western Australia (Environmental Protection Authority 2009) • EPA Position Statement No. 3 (Environmental Protection Authority 2002) • EPA Guidance Statement No. 56 (Environmental Protection Authority 2004b)

1.2 Scope and Objectives

The scope of the assessment includes determining the floristic composition and condition of the riparian vegetation, mapping vegetation communities and detailing fauna values along an approximate 28 km section of the Robe River and two of its tributaries. The objectives were to undertake a:

- desktop assessment, including database searches and literature review of available resources.
- vegetation and flora assessment, to include:
  - description of dominant vegetation types (with supporting photographs of each type with location data) including the dominant species and structure
  - the presence or likely presence of Threatened (Declared Rare) and Priority flora, and weeds
  - a list of the vascular plant species recorded within the survey area
- fauna and fauna habitat assessment, to include:
  - habitat assessment and photographs for any significant areas or sites observed that may be suitable for Matters of National Environmental Significance (MNES) species
  - the presence or likely presence of Threatened and Priority fauna
  - opportunistic sightings, species present and their significance
- baseline aquatic assessment, to include:
  - identification of baseline and future riverine monitoring sites, and where possible, inclusion of long-term monitoring sites established previously by Streamtec/the University of Western Australia (UWA)
  - semi-qualitative sampling for aquatic fauna and water quality to allow statistical comparison of any changes overtime
  - qualitative visual assessment of general habitat conditions at all sites

  - identification of all specimens to the lowest taxonomic level practicable
  - assessment of the conservation status of aquatic fauna recorded
  - report water quality data against the Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand (ANZECC/ARMCANZ) (2000) guidelines for freshwater ecosystems
  - discussion on the potential impacts of the development on aquatic ecosystems
  - preparation of a detailed technical report of all findings
- preparation of a final report which addresses the tasks outlined above, relevant contextual information, methodology, timing and limitations (WRM report displayed in full in Appendix A).



Robe River Mining Co. Pty Ltd

Mesa H Riparian Community Assessment - June 2016

Figure 1: Survey Area Location

astron
delivering environmental intelligence™

Author: D. Roocke	Date: 05-04-2017
Drawn: W. An	Figure Ref: 14269-16-BIDR-1RevB_170406_Fig01

Datum: GDA 1994 - Projection: MGA Zone 50

0 10 20 30 40 50 Km

N

2 Environmental Context

2.1 Physical Environment

2.1.1 Climate

The climate of the Pilbara region of Western Australia is classified as arid tropical with two distinct seasons: a hot, wet summer (October – April) and a mild, dry winter (May – September) (Bureau of Meteorology 2016).

Based on long-term climatic data from the nearest Bureau of Meteorology (BOM) weather station at Pannawonica (Station 5069) (approximately 13 km north-east of the survey area), the mean annual rainfall since 1971 is 404 mm (Bureau of Meteorology 2016). The mean maximum daily temperatures range between 26.7°C and 41°C, and range above 30°C for much of the year (Figure 2) (Bureau of Meteorology 2016).

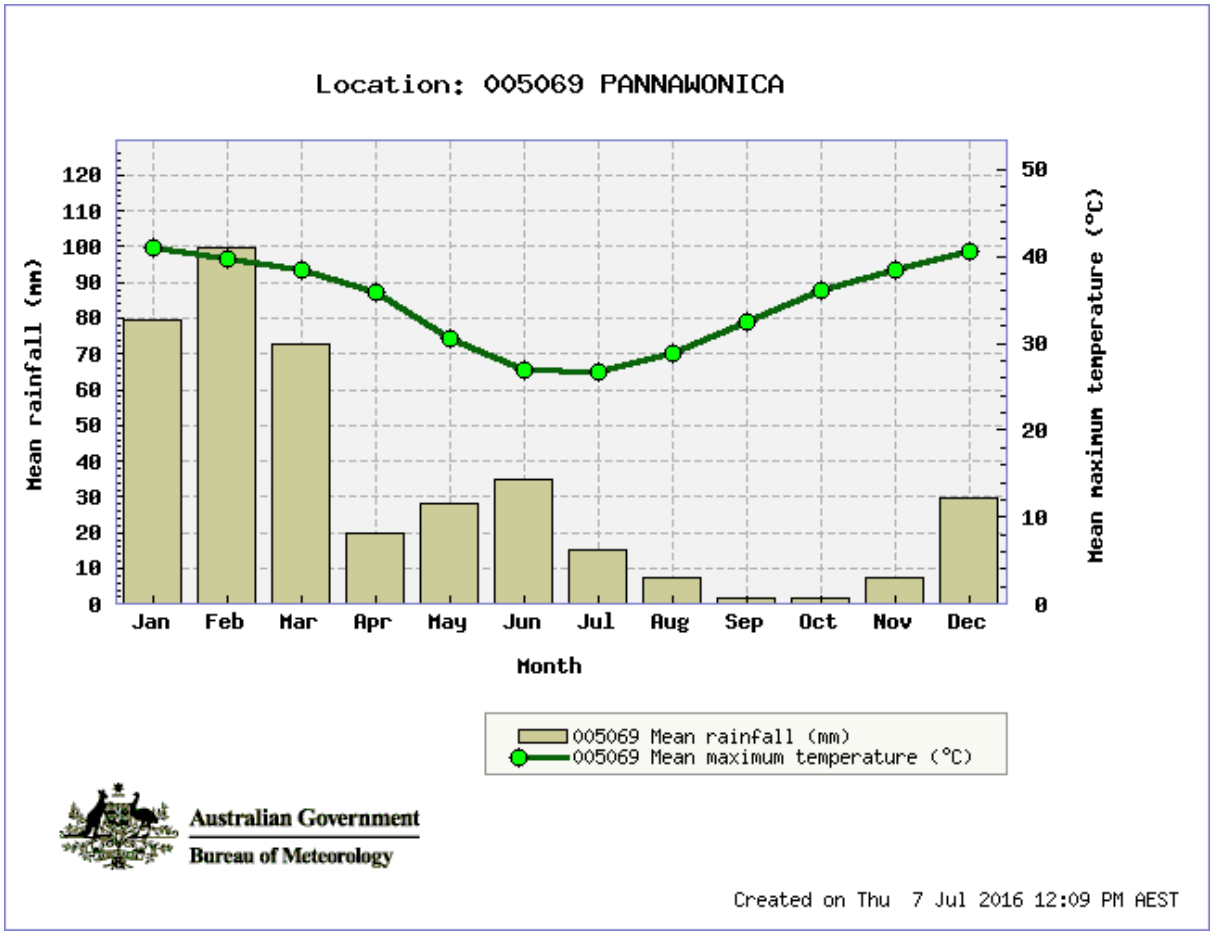


Figure 2: Climate data for Pannawonica (Station 5069). Mean annual rainfall data calculated from 1971-2016 and mean maximum temperature (calculated from 1971-2005) (Bureau of Meteorology 2016).

2.1.2 Geology and Soils

The survey area occurs on the Hamersley Basin which overlies the Archaean Pilbara Craton and comprises of mafic and felsic volcanics, shale, siltstone, sandstone and conglomerate, as well as dolomite and banded iron formation. The basin is extensively deformed from numerous tectonic events, resulting in extensive folding and faulting through the geological formations (van Vreeswyk

et al. 2004). The surface geology of the survey area is comprised of seven units (Stewart et al. 2008) as presented in Table 2. Geological mapping of the survey area and surrounds is presented in Figure B.1 (Appendix B).

Table 2: Geological units of the survey area.

Geological name	Label	Area within survey area (ha)
Marra Mamba Iron Formation: chert, ferruginous chert, jaspilite, banded iron formation, minor shale, siltstone, mudstone	Achm	184.9
Mount McRae Shale and Mount Sylvia Formation: interbedded shale, chert, banded iron-formation	Ashm	1.4
Jeerinah Iron Formation: shale, sandstone, siltstone, mudstone, dolomite, local microbanded chert, jaspilite, conglomerate; fine-grained massive rhyolite; mafic tuff with local accretionary lapilli and agglomerate; thin basalt/dolerite and andesitic basalt flows	Awfj	51.2
Robe Pisolite: pisolitic, oolitic and massive limonite, goethite and hematite deposits containing fossil wood fragments; iron ore	Czlr	107.2
Boolgeeda Iron Formation: fine-grained, finely laminated, dark-grey-brown to black flaggy iron-formation, minor chert, jaspilite, shale	Lchb	3.1
Woongarra Rhyolite: rhyolite, rhyodacite, rhyolitic volcaniclastic breccia and banded iron formation	Lfhw	40.5
Alluvium 38485: channel and flood plain alluvium; gravel, sand, silt, clay, locally calcreted	Qa	1730.3
Colluvium 38491: colluvium, sheetwash, talus; gravel piedmonts and aprons over and around bedrock; clay-silt-sand with sheet and nodular kankar; alluvial and aeolian sand-silt-gravel in depressions and broad valleys in Canning Basin; local calcrete, reworked laterite	Qrc	9.3

The survey area is mapped as soil landscape zone 285 – Hamersley Plateaux in the Fortescue Province (Tille 2006). This soil unit is described as hills and dissected plateaux with some stony plains and hardpan wash plains on volcanic and sedimentary rocks. It is comprised predominately of stony soils with red shallow loams and some red-brown non-cracking clays and red loamy earths (Tille 2006). Some drainage habitats occur and these are characterised by sand, gravel, pebbles and stones (van Vreeswyk et al. 2004).

2.1.3 Surface Water and Hydrology

The Robe River is considered a seasonal watercourse and flows in an east-west orientation. A number of permanent pools in the river were observed within the survey area and have been previously reported in Kendrick (2001) as wetlands of subregional significance. Numerous creeks and smaller drainage lines stem from the main flow line. There are no regionally significant wetlands in proximity. A section of the survey area, represented as the northern extent of Jimmawurrada Creek, is within a Public Drinking Water Source Area, the Bungaroo Water Reserve (Department of Water 2008).

2.2 Biological Environment

2.2.1 Interim Biogeographic Regionalisation of Australia

The Interim Biogeographic Regionalisation for Australia (IBRA version 7) divides the Australian continent into 89 bioregions and 419 subregions (Department of the Environment and Energy 2016a). The IBRA regions represent a landscape-based approach to classifying the land surface, including attributes of climate, geomorphology, landform, lithology, and characteristic flora and fauna. The survey area occurs in the Pilbara Bioregion, of which 5% to 10% is represented in the national reserve system (Department of the Environment and Energy 2016b).

The biodiversity of the 53 subregions recognised in Western Australia was documented as part of a national audit to provide priorities for conservation action (Department of Conservation and Land Management 2002). The survey area occurs in two subregions, the Chichester and Hamersley subregions of the Pilbara region. The subregions are described in the audit as:

- Chichester PIL1 – undulating Archean granite and basalt plains include significant areas of basaltic ranges and plains support shrub steppe characterised by *Acacia inaequilatera* over *Triodia wiseana* hummock grasslands, and ranges comprise of *Eucalyptus leucophloia* tree steppes (Kendrick and McKenzie 2001). This subregion represents approximately 1% of the survey area.
- Hamersley PIL3 – dissected bold plateaux and ranges of flat lying of moderately folded sandstone and quartzite with vegetation described as Mulga low woodland over tussock grasses occurring on fine textured soils in valley floors, with scattered Snappy gum (*Eucalyptus leucophloia*) over *Triodia brizoides* on skeletal soils of the ranges (Kendrick 2001). This subregion represents 99% of the survey area.

2.2.2 Land Systems

Land systems of the Western Australian rangelands have been mapped and described by the Department of Agriculture and Food (DAFWA) outlining the distributions and providing comprehensive descriptions of biophysical resources, including soil and vegetation condition. A total of 102 land systems occur in the Pilbara bioregion covering 181,723 km^2, of which six occur in the survey area (Table 3). The layout of these land systems within the survey area is shown in Figure B.2 (Appendix B).

Table 3: Distribution of land systems within the survey area and Pilbara bioregion (van Vreeswyk et al. 2004).

Land system	Total area within Pilbara bioregion (ha)	Total area within survey area (ha)	Proportion within survey area (%)
Boolgeeda - stony lower slopes and plains below hill systems supporting hard and soft spinifex grasslands and mulga shrublands	961,847	0.04	<0.1
McKay - hills, ridges, plateaux remnants and breakaways of meta sedimentary and sedimentary rocks supporting hard spinifex grasslands	425,967	1.79	<0.1
Newman - rugged jaspilite plateaux, ridges and mountains with hard spinifex	1,994,339	38.30	<0.1
River - active flood plains, major rivers and banks supporting grassy eucalypt woodlands, tussock grasslands and soft spinifex grasslands	481,994	1859.92	<0.1
Robe - low limonite mesas and buttes supporting soft spinifex (and occasionally hard spinifex) grasslands	128,680	169.02	<0.1
Urandy - stony plains, alluvial plains and drainage lines supporting shrubby soft spinifex grasslands	132,039	58.82	<0.1
TOTAL	**4,124,866**	**2,127.89**	<0.1

2.2.3 Pre-European Vegetation

Pre-European vegetation was mapped across the Pilbara region at a scale of 1: 1,000,000 (Beard 1975). The survey area is located in the Stuart Hills, Chichester Plateau and Hamersley Plateau physiographic units of the Fortescue Botanical District (Figure B.3, Appendix B). These physiographic units are described as:

Hamersley: a compact unit defined by the outcropping of jaspilite and dolomite, with some shale, siltstone and volcanics. Vegetation is described as:

- ranges – tree steppe of *Eucalyptus brevifolia* (likely to represent *E. leucophloia*) over *Triodia wiseana* hummock grasslands
- valley plains – mulga (*Acacia aneura* complex) low woodlands, or tussock grasslands on cracking clay soils
- basalt hills – mosaic of mulga low woodland and *Acacia pyrifolia* and *Triodia* species shrub steppe.

Chichester Plateau: this very long narrow unit forms a watershed between numerous rivers flowing north to the coast and the Fortescue drainage on the southern side. It is bounded for most of its northern length and at its western end by abrupt escarpments rising from the coastal plains, but the decent to the Fortescue is much less abrupt and more gradual. Vegetation is described as:

- high plains – *Acacia pyrifolia* - *Triodia* shrub steppe on hard alkaline red soils, changing to grass savannah on clay soils in the lower portions.

Stuart Hills: this unit consists mostly of plains, gently undulating pediplains extending out from Breakaways and residuals capped by Robe pisolites, and stony hills and steeply dissected pediments on fine-grained sandstone, shale and dolomite. Vegetation is described as:

- hills and plains – *Triodia wiseana* and *T. basedowii* hummock grasslands with sparse shrubs, particularly *Acacia bivenosa*
- drainage lines – *Corymbia hamersleyana* and *C. candida* occur occasionally, with *Senna* species and ephemerals
- major rivers – *Eucalyptus camaldulensis* and *Acacia citrinoviridis* along river and mulga low woodland on river flats and tributaries.

Six pre-European vegetation units, 82, 173, 603, 605, 609, 620 (Shepherd, Beeston, and Hopkins 2002), are associated with the survey area:

82: 'Hummock grasslands, low tree steppe; snappy gum over *Triodia wiseana*',

173: 'Hummock grasslands, shrub steppe; kanji over soft spinifex and *Triodia wiseana* on basalt',

603: 'Hummock grasslands, sparse shrub steppe; *Acacia bivenosa* over hard spinifex',

605: 'Hummock grasslands, shrub steppe; *Acacia pachycarpa* and waterwood over soft spinifex'

609: 'Mosaic: Hummock grasslands, open low tree steppe; bloodwood with sparse kanji shrubs over soft spinifex/Hummock grasslands, open low tree steppe; snappy gum over *Triodia wiseana* on a lateritic crust'

620: 'Hummock grasslands, shrub steppe; snakewood over soft spinifex'.

Table 4 summarises the current and pre-European extent of these six vegetation units in the Pilbara and the survey area.

Table 4: Extent of pre-European vegetation in the survey area (Government of Western Australia 2014).

Vegetation association	Mapping unit (Beard 1975)	Extent in survey area (ha)	Current extent in Pilbara bioregion (ha)	Pre-European extent (ha)	Proportion of pre-European extent remaining (%)
82	e16Lr t3Hi	402.6	2,550,899.0	2,563,583.2	99.5
173	a2Sr t1, 3Hi	81.4	1,747,677.6	1,752,420.9	99.7
603	a6Sb t3Hi	282.2	55,764.0	56,726.9	98.3
605	a5,11Sr t1Hi	259.3	114,115.9	114,115.9	100.0
609	e24Lr a2Sp t1Hi /e16Lr t3Hi	765.4	72,765.2	74,186.1	98.1
620	a11Sr t1Hi	337.0	15,539.4	15,539.4	100.0

2.3 State and Commonwealth Conservation Categories and Management

Commonwealth and State regulatory authorities maintain databases of the locations and conservation status of significant flora, fauna and ecological communities in Western Australia. The *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) provides a legal framework to protect and manage MNES including listed flora, fauna and ecological communities.

These listed flora, fauna and ecological communities are allocated conservation categories, which are outlined in Tables C.1 and C.2 (Appendix C).

Ecological communities may be subject to processes that threaten to destroy or significantly modify it across much of its range. These communities are identified as Threatened Ecological Communities (TECs) and are listed at both Commonwealth level under the EPBC Act and State level by the Western Australian Minister for Environment (Table C.3, Appendix C). The Department of Parks and Wildlife (Parks and Wildlife) maintains a list of Priority Ecological Communities (PECs), which may also be under threat and are assigned one of four Priority rankings according to the criteria outlined in Table C.4 (Appendix C).

Under Western Australian legislation, all native flora is protected and it is an offence to 'take' protected flora. The *Wildlife Conservation Act 1950* (WC Act) also provides for native plant species to be specially protected when they are under identifiable threat of extinction, are rare, or otherwise in need of special protection (Department of Parks and Wildlife 2015a). Such specially protected flora is considered under the WC Act to be 'declared rare' (Threatened) (Table C.5, Appendix C). In addition, due to the diversity of Western Australia's flora, many species are known from only a few collections or locations, but have not been adequately surveyed. Such flora may be rare or threatened, but cannot be considered for declaration as Threatened flora until adequate surveys have been undertaken. These flora species are included on a supplementary conservation list managed by Parks and Wildlife called the *Priority Flora List*. Priority flora are categorised according to level of threat and other information and the conservation categories are described in Table C.6 (Appendix C).

Groundwater Dependent Ecosystems (GDEs) are often a focus of conditions applied through a Ministerial Statement. GDEs in the Pilbara play an important ecological role by providing essential habitat for species and a haven for biological diversity and productivity in an otherwise harsh, dry climate. Therefore, the vegetation comprised within GDEs may be considered locally significant.

2.4 Introduced Flora (Weeds)

Significant weed species are identified at both the state and national level. The Australian Weeds Strategy (Australian Weeds Committee 2012) identifies Weeds of National Significance (WoNS) which have the potential to impact primary industry and/or environmental and social values. The management of weeds in Western Australia is primarily regulated through the *Biosecurity and Agriculture Management Act 2007* (BAM Act). Species listed under this act are allocated one of three declared pest categories which define the required level of management (Department of Agriculture and Food Western Australia 2016). Declared pest categories and listed weed species' priority ratings are presented in Table C.7 (Appendix C).

2.5 Land Use and Tenure

The survey area is located within the Shire of Ashburton, and is on two pastoral leases; Yalleen Station and Yarraloola Station. The local area is used for pastoralism, mineral exploration and mining activity.

The Millstream-Chichester National Park is the nearest conservation reserve to the survey area, located approximately 79 km to the north-east. The Cane River Conservation Park is located approximately 48 km to the south-west, Murujuga National Park is approximately 120 km north and Karijini National Park is approximately 180 km south-east of the survey area (refer to Figure 1).

3 Methodology

3.1 Desktop Assessment

3.1.1 Database Searches

A search for Environmentally Sensitive Areas (ESAs) in the vicinity of the survey area was conducted using the WA Atlas (Landgate 2016) and Register of the National Estate (RNE) spatial database (Department of the Environment and Energy 2008). Despite all references to the RNE being removed from Commonwealth legislation in 2012, current State regulations (*Environmental Protection (Clearing of Native Vegetation) Regulations 2004*) declare any area registered on the RNE as an ESA (Department of the Environment and Energy 2016c).

In addition, database searches were conducted to identify listed conservation significant ecological communities, and flora and fauna species within, or in close proximity to, the survey area. Search results are presented in Appendix D and details are summarised in Table 5. Conservation categories for ecological communities and flora are presented in Appendix C. Introduced flora species were compared to the DAFWA list to determine if any have been listed as declared pests (Department of Agriculture and Food Western Australia 2016) and the WoNS list (Australian Weeds Committee 2012). Introduced flora categories are also presented in Appendix C.

Table 5: Database searches requested.

Database name	Date search results received	Search focus	Search area
Vegetation & Flora			
Protected Matters Search Tool (Department of the Environment and Energy 2016d)	25/07/2016	Matters of National Environmental Significance flora	50 km radius from the approximate Mesa H Level 2 Vegetation and Flora (Astron Environmental Services 2016b) survey area centre point, defined by the coordinates: 21°44’11 S, 116°11’50 E
Threatened and Priority Ecological Communities database (Department of Parks and Wildlife 2015b)	05/10/2015	Listed Threatened and Priority Ecological Communities	20 km radius surrounding the Mesa H Level 2 Vegetation and Flora (Astron Environmental Services 2016b) survey area boundary (shapefiles provided)
Threatened and Priority Flora Database (TPFL) (Department of Parks and Wildlife 2015c)	29/09/2015	Threatened and Priority flora	20 km radius surrounding the Mesa H Level 2 Vegetation and Flora (Astron Environmental Services 2016b) survey area boundary (shapefiles provided)
Threatened and Priority Flora Species List (TP list) (Department of Parks and Wildlife 2015d)			
Western Australian Herbarium flora (Department of Parks and Wildlife 2015e)			

Database name	Date search results received	Search focus	Search area
NatureMap (Department of Parks and Wildlife 2016a)	25/07/2016	Terrestrial flora of conservation significance	40 km radius from the approximate Mesa H Level 2 Vegetation and Flora (Astron Environmental Services 2016b) survey area centre point, defined by the coordinates: 21°44'11 S, 116°11'50 E
Terrestrial Fauna			
NatureMap (Department of Parks and Wildlife 2015f)	22/09/2015	Terrestrial fauna and fauna of conservation significance	40 km radius from the approximate Mesa H Level 2 Fauna (Astron Environmental Services 2016d) survey area centre point, defined by the coordinates: 21°44'47 S, 116°12'02 E
Threatened and Priority Fauna Database (Department of Parks and Wildlife 2015g)	30/09/2015	Threatened and Priority fauna species	20 km radius from the approximate Mesa H Level 2 Fauna (Astron Environmental Services 2016d) survey area centre point defined by the coordinates: -21.738899, 116.205782 (MGA50, GDA94)
Protected Matters Search Tool (Department of the Environment 2015)	21/09/2015	Threatened and Priority fauna species	40 km buffer from the approximate Mesa H Level 2 Fauna (Astron Environmental Services 2016d) survey area centre point defined by the coordinates: -21.738899, 116.205782 (MGA50, GDA94)
BirdLife Australia (Birdlife Australia 2015)	30/09/2015	Bird species	1 degree from the approximate Mesa H Level 2 Fauna (Astron Environmental Services 2016d) survey area centre point defined by the coordinates: -21.74617, 116.20118 (MGA50, GDA94)

3.1.2 Vegetation and Flora

The 30 PECs listed by Parks and Wildlife for the Pilbara region (Department of Parks and Wildlife 2016b) were reviewed to determine if any were analogous with ecological communities recorded in the survey area.

Prior to conducting the field surveys, aerial imagery was interpreted to identify potential habitat types. The conservation significant flora species returned from the database searches were then categorised according to the criteria in Table 6 for potential occurrence within the survey area.

Table 6: Pre-survey criteria used to assess the likely presence of conservation significant flora in the survey area.

Likelihood of occurrence	Pre-survey
Likely	Species previously recorded within the survey area or within 10 km of the survey area and suitable habitat appears to be present in the survey area
Potential	Species previously recorded within 10 km to 20 km of the survey area and/or suitable habitat appears to be present in the survey area
Unlikely	No suitable habitat appears to be present in the survey area

Following the field surveys, the conservation significant flora species identified during the desktop assessment as having the highest potential to occur within the survey area, yet were not recorded during the current survey, were again assessed to determine their likelihood of occurrence within the survey area. Post-field survey likelihood of occurrence was primarily based on validating the presence (and thorough inspection) of suitable habitats within the survey area, combined with life form, habitat and flowering information for each flora species.

3.1.3 Literature Review

3.1.3.1 Vegetation and Flora

Vegetation and flora surveys which have recently been commissioned by Rio Tinto and that are within the vicinity of the survey area are presented in Figure E.1 (Appendix E). The data and results from three reports have also been incorporated into this assessment:

- Middle Robe and East Deepdale Level 2 Vegetation and Flora Assessment (ecologia Environment 2013)
- Mesa H Level 2 Vegetation and Flora Assessment (Astron Environmental Services 2016b)
- Mesa H Riparian Vegetation Baseline Monitoring (Astron Environmental Services 2016c).

A further five surveys previously commissioned by Rio Tinto between 2003 and 2012 provided contextual information appropriate for this riparian survey area, and were supplied to Astron and reviewed as part of the desktop assessment:

- Mesa J Tail Track Extension Vegetation, Flora and Fauna Survey (Astron Environmental Services 2011)
- Mesa J Extension Vegetation, Flora and Fauna Assessment (Biota Environmental Sciences 2003)
- A Vegetation and Flora Survey of the Proposed Mesa A Transport Corridor, Warramboo Deposit and Yarraloola Borefield (Biota Environmental Sciences 2006a)
- Baseline Flora and Vegetation Assessment of Robe Valley Mesas (Mesas B, C, D, E, F, H and I) (Biota Environmental Sciences 2011a)
- Greater Bungaroo Flora and Vegetation Survey (Biota Environmental Sciences 2012).

Ecologia (2013) presents Phase 1 vegetation and flora data for Astron (2016a) and does not contain the final results for that survey, therefore was not considered in this assessment to avoid duplication of information. Additional vegetation and flora surveys have previously been commissioned by Rio

Tinto within the vicinity of the survey area, however did not contain landforms and vegetation analogous to riparian communities, therefore were not used for contextual information.

3.1.3.2 Terrestrial Fauna

Terrestrial fauna surveys have previously been commissioned by Rio Tinto within the vicinity of the survey area and supplied to Astron for the desktop assessment. The reports reviewed as part of the fauna aspects of this assessment include:

- Mesa J Tail Track Extension Vegetation, Flora and Fauna Survey (Astron Environmental Services 2011)
- Mesa H Level 1 Flora, Vegetation and Fauna Assessment (Astron Environmental Services 2014)
- Mesa H Level 2 Fauna Assessment (Astron Environmental Services 2016d)
- Bungaroo Iron Ore Mine and Infrastructure Project, Level 2 Fauna Survey (Astron Environmental Services 2016e)
- Middle Robe and East Deepdale Level 2 Fauna Assessment (Astron Environmental Services 2016f)
- Yarraloola Targeted Fauna Survey (Biologic Environmental Survey 2014)
- Fauna Habitats and Fauna Assemblage of Mesa A and Mesa G (Biota Environmental Sciences 2005)
- Fauna Habitats and Fauna Assemblage of the Mesa A Transport Corridor and Warramboo (Biota Environmental Sciences 2006b)
- Bungaroo Trial Pit and Transport Corridor to Mesa J, near Pannawonica (Biota Environmental Sciences 2007)
- Mesa G Baseline Fauna Survey (Biota Environmental Sciences 2009)
- Greater Bungaroo Seasonal Fauna Survey (Biota Environmental Sciences 2010a)
- Robe Valley Mesas Fauna Survey (Biota Environmental Sciences 2011b)
- Middle Robe and East Deepdale Flora, Vegetation, Vertebrate and Invertebrate Fauna Survey (ecologia Environment 2013).

3.1.3.3 Aquatic Ecosystems

Numerous aquatic ecological surveys have been undertaken within the vicinity of the survey area and were used for the desktop assessment. A more comprehensive description of the aquatic surveys and studies are provided in Appendix A. The reports reviewed as part of the aquatic aspects of this assessment include:

- Streamtec/UWA, annual sampling of Robe River pools (Dobbs and Davies 2009; Streamtec 1996-2014)
- Pilbara Biological Survey: An arid zone awash with diversity: patterns in the distribution of aquatic invertebrates in the Pilbara region of Western Australia (Pinder et al. 2010)
- Fish fauna of the inland waters of the Pilbara (Morgan and Gill 2004)
- API Aquila: Baseline Aquatic Ecosystem Surveys (Wetland Research & Management 2009)

- HD1: Pilbara Regional Aquatic Surveys Wet & Dry 2011 Sampling (Wetland Research & Management 2013)
- HD1: Pilbara Regional Aquatic Surveys Wet & Dry 2015 Sampling (Wetland Research & Management 2016)
- Mesa A/Warramboo Yarraloola Borefield Development: Baseline Stygofauna Assessment (Biota Environmental Sciences 2006c)
- West Pilbara Iron Ore Project Stygofauna Assessment (Biota Environmental Sciences 2010b)
- Bungaroo South: Subterranean Fauna Assessment (Bennelongia Environmental Consultants 2013)
- Exploring the relationship between sampling efficiency and short-range endemism for groundwater fauna in the Pilbara region, Western Australia (Eberhard et al. 2009)
- Pilbara stygofauna: deep groundwater of an arid landscape contains globally significant radiation of biodiversity (Halse et al. 2014).

3.2 Field Survey

The flora field survey was undertaken concurrently with the riparian monitoring survey from 26 May to 7 June 2016 (Astron Environmental Services 2016c). Six other field surveys have also assessed parts of the survey area (Table 7). Applicable data from all seven field surveys has been included to inform the riparian community vegetation and flora assessment. The Level 1 fauna survey was undertaken on 8 May 2016. Habitat assessment data and mapping from the Mesa H fauna survey and Middle Robe and East Deepdale fauna survey (Astron Environmental Services 2016d, 2016f) were used for areas that overlapped with the current survey area. The baseline aquatic ecosystem survey was completed between 28 April and 7 May 2016. The scientists and the dates of the surveys are listed in Table 7.

Table 7: Field survey timing and personnel.

Component	Survey dates	Field personnel
Middle Robe and East Deepdale Level 2 Vegetation and Flora Assessment – Phase 1	15 to 27 June 2015	Janelle Atkinson (Flora permit SL011215; Declared Rare Flora (DRF) 141-1415) Daniel Roocke (Flora permit SL011212; DRF 142-1415) Dr Kellie McMaster (Flora permit SL011404) Linda Vaughan (Flora permit SL011214)
Middle Robe and East Deepdale Level 2 Vegetation and Flora Assessment – Phase 2	21 September to 3 October 2015	Janelle Atkinson (Flora permit SL011215; DRF 141-1415 Daniel Roocke (Flora permit SL011212; DRF 142-1415)
Mesa H Level 2 Vegetation and Flora Assessment – Phase 1	23 to 30 October 2014	Janelle Atkinson (Flora permit SL010911; DRF 107-1516) Daniel Roocke (Flora permit SL010827; DRF 139-1314) Alice Bott (Flora permit SL011640); DRF 140-1314)
	24 September to 4 October 2015	Natalie Cadd (Flora permit SL011621; DRF 170-1415) Dr Kellie McMaster (Flora permit SL011404)
Mesa H Level 2 Vegetation and Flora Assessment – Phase 2	27 April to 14 May 2016	Janelle Atkinson (Flora permit SL011617, DRF 141-1415) Daniel Roocke (Flora permit SL011627, DRF 131-1516) Linda Vaughan (Flora permit SL011631) Dr Kellie McMaster (Flora permit SL011810)

Component	Survey dates	Field personnel
	19 to 22 July 2016	Janelle Atkinson (Flora permit SL011617), DRF 141-1415 Daniel Roocke (Flora permit SL011627), DRF 131-1516
Level 2 Riparian Community Vegetation and Flora Survey	26 May to 7 June 2016	Janelle Atkinson (Flora permit SL011617; DRF107-1415) Daniel Roocke (Flora permit SL011627; DRF 131-1516)
Middle Robe and East Deepdale – Level 2 Fauna Assessment	15 to 28 June 2015	Matthew Love Matthew Johnston Ray Lloyd Frances Leng
	17 to 27 August 2015	Matthew Love Matthew Johnston Ray Lloyd John Trainer
Mesa H Level 2 Fauna Assessment	24 September to 3 October 2015	Matthew Johnston John Trainer
	27 April to 9 May 2016	Matthew Love John Trainer
Level 1 Riparian Community Fauna Survey	8 May 2016	Matthew Love John Trainer
Mesa H Baseline Aquatic Ecosystem Survey	28 April to 7 May 2016	Adam Harman Emma Thillainath Fintan Angel

3.2.1 Weather

Daily weather observations recorded from Mesa J were used to describe local rainfall and temperatures preceding the surveys (Figure 3). Rainfall in the second half of 2015 was 28% below average with 45 mm recorded for the 6 month period. Above average rain was recorded in January 2016, although only 30 mm was recorded from February to March compared to the mean of 192 mm for the corresponding period. The months of May, June and July 2016 recorded above average rainfall with a total of 137 mm, which is 60 mm more than the long term mean. The mean maximum temperatures between May 2015 and July 2016 were generally slightly higher than the long-term averages, ranging between 27.0°C and 43.1°C (Figure 3).

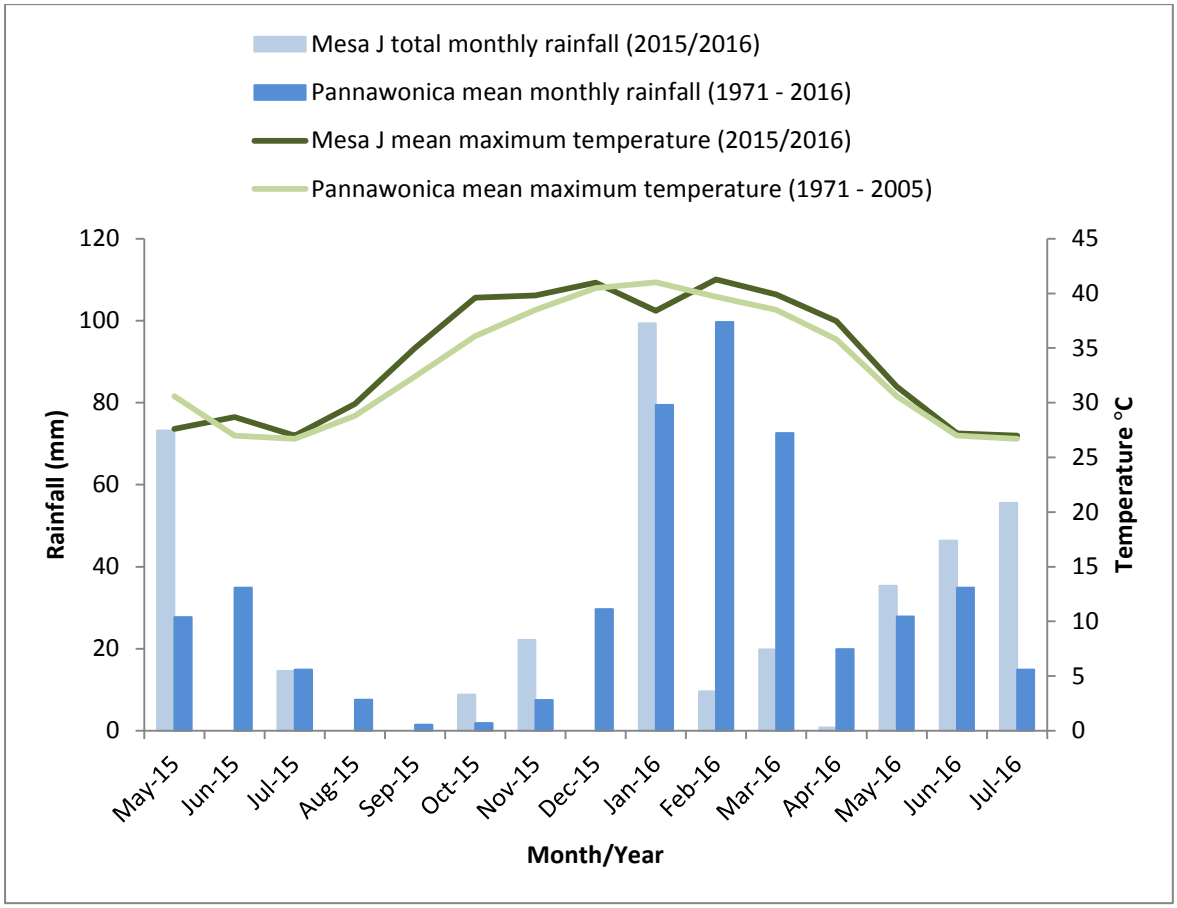


Figure 3: Pannawonica mean monthly rainfall (1971 – 2016) and Mesa J total recorded rainfall (2015 - 2016), and Pannawonica mean monthly maximum temperatures (1971 – 2005) and Mesa J mean monthly maximum temperatures from May 2015 to July 2016. Mesa J data provided by Rio Tinto (2016a). Pannawonica data from Bureau of Meteorology (2016).

3.2.2 Vegetation and Flora Assessment

The vegetation and flora field surveys were undertaken in accordance with the requirements outlined in the Environmental Protection Authority (EPA) (Environmental Protection Authority 2002, 2004a; Environmental Protection Authority and Department of Parks and Wildlife 2015) and Rio Tinto policy and guidance documents.

Information acquired during the desktop assessment assisted in the design of the field surveys. Pre-survey planning involved the examination of 1:10,000 scale aerial photography to identify potential landforms, habitat and vegetation types. It also involved a review of the flora and vegetation assessments previously completed within the Robe River and adjacent to Mesa H for context and to identify data gaps. Proposed quadrat locations were identified prior to the field surveys according to the replicates supporting previous vegetation mapping (Astron Environmental Services 2016a, 2016c).

Data from 28 current and previous sampling sites, representing 27 quadrats and one relevé, was collected (Table 8). Four quadrats were previously sampled as part of the Middle Robe and East Deepdale study (Astron Environmental Services 2016a). Sixteen sampling sites had a single season of survey only. Vegetation associations were aligned with those described in the Mesa H Level 2 Vegetation and Flora Assessment (Astron Environmental Services 2016b).

Table 8: Survey effort for existing and newly installed quadrats and relevés occurring within the survey area.

Author; project; phase of survey	Number of sites	Name of sites
Astron Riparian Community Assessment (current survey) 1 phase	7 quadrats	MH379, MH381, MH384, MH385, MH387, MH388, MH389
Astron Mesa H Level 2 Flora and Vegetation Survey (Astron Environmental Services 2016b) 2 phase	7 quadrats 1 relevé	MH43, MH44, MH203, MH204, MH303, MH321, MH332, MH337r
Astron Mesa H Level 2 Flora and Vegetation Survey (Astron Environmental Services 2016b) 1 phase	9 quadrats	MH354, MH363, MH373, MH392, MH393, MH394, MH397, MH398, MH401
ecologia (2013)and Astron Middle Robe and East Deepdale (2016a) 2 phase	3 quadrats	E07, E09, E20
Astron Middle Robe and East Deepdale (2016a) 1 phase	1 quadrat	AM215

Quadrats were positioned by measuring a square of 50 m by 50 m in suitable terrain, or dimensions measuring 2,500 m^2 where necessary. The four corners of the quadrats were permanently marked with fence droppers and the following information was collected at each quadrat:

- Location – coordinates measured using a handheld GPS (MGA50, GDA94).
- Recorder and date – personnel involved in sampling that location and the survey date.
- Species – representative vascular plant species present. The inventory of associated species was more comprehensive for a quadrat location, with each flora species present recorded; at relevés the species most typical of the vegetation unit and represented at that location were recorded. Species that could not be identified in the field were collected for later identification at the Astron herbarium or Western Australian Herbarium (WAHerb).
- Weeds – the coordinates and density of any introduced flora.
- Foliar cover – the percentage cover was estimated for each flora species.
- Vegetation description – vegetation was described according to the Aplin (1979) modification of the vegetation classification system of Specht (1970) (Table F.1, Appendix F) and the National Vegetation Information System, level 5 (Department of the Environment and Energy 2016e). At this level, vegetation is described to 'association' where up to three dominant genera for each of the upper, middle and ground strata are categorised based on dominant growth form, cover and height.
- Vegetation condition – assessed according to the vegetation condition classification adapted from Trudgen (1988) (Table F.2, Appendix F).
- Habitat – a broad description of the surrounding landscape based on landform, topography and soil.
- Photographs – a representative photograph was taken of each quadrat.
- Disturbances – records of any obvious disturbances such as fire, tracks or grazing.
- Geology – rock type and abundance.
- Soil – including colour and texture.

Quadrat and relevé locations are presented in Figure G.1 (Appendix G).

3.2.3 Vegetation Description and Mapping

Vegetation was described and mapped to be consistent with the descriptions and mapping previously conducted in and adjacent to the survey area (Astron Environmental Services 2016c). Results from the sections of riparian landform within the survey area that had already undergone assessment were incorporated into the data. Vegetation units were described and mapped using the data collected from quadrats, and followed the same convention as that previously used; the vegetation association code is described according to the initials of the dominant flora species defining the community.

3.2.3.1 Vegetation Condition Mapping

Vegetation condition was mapped according to vegetation association boundaries throughout the survey area, using a combination of quadrat data, opportunistic observations and the mean condition rating for each vegetation association. Vegetation condition was rated at each survey site using the five point Trudgen (1988) scale, and then applied to the whole vegetation association polygon in which it was mapped. A mean condition rating was calculated for each vegetation association using the data collected from survey sites and this was applied to any polygons not already attributed with a rating.

3.2.4 Targeted Flora Survey

Previously recorded conservation significant flora records (Astron Environmental Services 2016a, 2016b; Biota Environmental Sciences 2003, 2006a, 2011a; Department of Parks and Wildlife 2015c, 2015d, 2015e) and associated habitat preference information were used to identify vegetation associations and habitat within the survey area that have the potential to support conservation significant flora. The habitats and vegetation associations considered to have the potential to support conservation significant flora were located within the survey area from 1:10,000 colour aerial imagery and on-ground observations.

Population information for conservation significant flora was captured electronically using ArcPad (Esri) on a handheld device. The information recorded included population size, density, landform, soil and reproductive characteristics.

3.2.5 Terrestrial Fauna

3.2.5.1 Habitat Assessment

Data from 10 current and previous fauna habitat assessments located in the survey area were collected. Seven habitat assessments were previously sampled as part of the Mesa H fauna study (Astron Environmental Services 2016d) and one habitat assessment was previously sampled as part of the Middle Robe and East Deepdale fauna study (Astron Environmental Services 2016f) (Table H.1, Appendix H). The locations are shown in Figure H.1 (Appendix H) and the following information was collected at each site:

- Location – coordinates measured using a handheld GPS (GDA94).
- Recorder and date – personnel involved in undertaking the fauna habitat assessment and the survey date.
- Habitat/landform – position in the landscape - major fauna habitat types were described based on the landform and vegetation.
- Vegetation type – a broad description of vegetation type and structure.

- Soils – a brief description of soil type.
- Microhabitat – presence of specific microhabitat features, e.g. leaf litter, logs, burrows, rocky outcrops, rock crevices, hollows, permanent or semi-permanent water.
- Condition – habitat condition was assessed based on the presence of anthropogenic (human-induced) disturbances, and using the condition ratings suggested by Thompson and Thompson (2010) (Table F.3, Appendix F).
- Disturbance – any disturbance such as clearing, fire, weeds, flooding, vehicular, machinery, tracks or grazing.
- Photographs – a representative photograph was taken of each habitat assessment site.

The information derived from the fauna habitat assessments was used to delineate fauna habitats throughout the survey area, which were then mapped accordingly. In sections of the survey area that overlap with other recent fauna surveys the data from fauna habitat assessments and the fauna habitat mapping was used to ensure consistency between projects.

3.2.5.2 Active Foraging

Active searches were undertaken throughout the survey area in microhabitats suitable for ground-dwelling reptiles and mammals. Active searches included the following:

- searching and recording scats, tracks and other traces
- turning over rocks and logs and peeling off bark
- raking soil and leaf litter
- searching around water bodies.

3.2.6 Aquatic Ecosystem

A total of 12 pools were sampled along the main channel of the Robe River. Sites included six potentially exposed sites adjacent to the predicted groundwater drawdown cone of depression and within the predicted surface extent of dewatering discharge; and six reference sites upstream of the Jimmawurrada Creek confluence. Reference sites upstream of Mesa H were selected to serve as the "control" for potentially impacted sites. Surveys conducted in April/May 2016 are part of the benchmark or "before" phase against which to assess any future changes following mine development. A more comprehensive description of aquatic survey methodology is provided in Appendix A.

3.2.6.1 Water Quality

At each site, pH, dissolved oxygen and temperature were measured in situ using hand-held Wissenschaftlich-Technische-Werkstätten field meters. Water depth was measured using a graduated pole. Undisturbed water samples were collected for laboratory analyses of major ions, alkalinity, dissolved metals, nutrients and total suspended solids. Water samples for nitrogen and phosphorus nutrient and dissolved metal analyses were filtered in the field through 0.45 µm nitrocellulose filters. Samples were stored refrigerated or frozen for a maximum of 10 days prior to transport on ice to analytical laboratories at ChemCentre, Bentley, together with chain-of-custody forms.

Water quality data were compared against default ANZECC/ARMCANZ (2000) guidelines (trigger values) for the protection of freshwater ecosystems. Default trigger values (TVs) for 95% aquatic

species protection were considered more appropriate than default TVs for 99% protection, given that the Robe River catchment in the vicinity of current mining developments is already slightly to moderately disturbed by historic mining and pastoral practices (Strategen Environmental Consultants 2006). In accordance with ANZECC/ARMCANZ (2000), the default 99% TVs were applied to bioaccumulating metals such as selenium. For metals and nutrients, dissolved concentrations (0.45 µm filtered samples) were compared to the default TVs. Filtered concentrations were considered a better reflection of the fraction that may be bioavailable. By contrast, comparison of the default TVs to the total metal or total nutrient concentration may overestimate the risk to the environment (Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand 2000).

3.2.6.2 Microinvertebrates

Microinvertebrate samples were collected from each site by gentle sweeping over an approximate 15 m distance with a 53 µm mesh plankton net. Care was taken not to disturb the benthos (bottom sediments) during sampling. Samples were preserved in 70% ethanol and sent to Dr Russell Shiel at the University of Adelaide, South Australia, for processing. Dr Shiel is a world authority on microfauna, with extensive experience in fauna survey and impact assessment across Australasia, including the Pilbara.

Microinvertebrate samples were processed by identifying the first 200 to 300 individuals encountered in an agitated sample decanted into a 125 mm^2 gridded plastic tray, with the tray then scanned for additional missed taxa also taken to species, and recorded as 'present'. Specimens were identified to the lowest taxon possible, i.e. species or morphotypes. Abundance data were reported as log_{10} scale abundance classes (i.e. 1 = individual, 2 = 2 to 10 individuals, 3 = 11 to 100 individuals, 4 = 101 to 1000 individuals, 5 = >1000 individuals). Where specific names could not be assigned, vouchers were established. These vouchers are held by Dr Shiel at the University of Adelaide, South Australia.

3.2.6.3 Hyporheos

At each site, hyporheic sampling was conducted using the Karaman-Chappuis method (Delamare Deboutteville 1960). This involved digging a hole approximately 20 cm deep and 40 cm diameter in alluvial gravels in dry streambed adjacent to the water's edge, allowing the hole to infiltrate with water, and sweeping the water column with a modified 110 µm mesh plankton net. The water column was swept immediately after the hole had filled, and again after approximately 30 minutes, once other sampling had been conducted.

Samples were preserved in 70% ethanol and returned to the laboratory for processing. Any aquatic fauna present was removed from samples by sorting under a low power dissecting microscope. In-house expertise was used to identify the majority of hyporheic taxa using available published keys and through reference to the established voucher collections held by WRM. External specialist taxonomic expertise was sub-contracted to assist with Chironomidae (Dr Don Edward, UWA) and micro-crustacea (Dr Russell Shiel, University of Adelaide).

3.2.6.4 Macroinvertebrates

Macroinvertebrate sampling was conducted with a 250 µm mesh pond net. All meso-habitats were sampled, including trailing riparian vegetation, woody debris, open water column and benthic sediments with the aim of maximising the number of species recorded. Each sample was washed through a 250 µm sieve to remove fine sediment, while leaf litter and other debris were carefully washed in the sieve and removed by hand. Samples were then preserved in 70% ethanol. In the

laboratory, macroinvertebrates were removed from samples by sorting under a low power dissecting microscope.

Collected specimens were identified to the lowest practicable level (typically genus or species) and enumerated to $\log_{10}$ scale abundance classes (i.e. 1 = individual, 2 = 2 to 10 individuals, 3 = 11 to 100 individuals, 4 = 101 to 1000 individuals, 5 = >1000 individuals). In-house expertise was used to identify invertebrate taxa using available published keys and through reference to the established voucher collections held by WRM. External specialist taxonomic expertise was sub-contracted to assist with Chironomidae (Dr Don Edward, UWA).

3.2.6.5 Fish

A number of fish sampling methods were used at each site in order to collect as many species and individuals as possible. Methods included electrofishing, seine nets and gill nets. Electrofishing is an extremely useful and efficient sampling tool in rivers with clear, low salinity, slow flow water. All meso-habitats within a maximum 40 m reach were shocked with the intention of recovering as many species/individuals as possible. Shocking was not continuous, but targeted areas of optimum habitat, whereby the operator would shock, move to a new habitat before shocking again, and so prevent fish being driven along in front of the electrical field.

Duplicate 30 m multi-panel gill nets were set at each site where there was sufficient depth of water. Each net consisted of six 5 m panels, with panels increasing in size from 1 inch to 6 inch stretched mesh size. At each sampling location, two nets were set for approximately 2.5 hours. Nets were checked frequently to avoid fish deaths. Catch from the duplicate nets were combined to form one replicate sample from each sampling location.

Smaller species and juveniles were sampled by beach seine (10 m net, with a 2 m drop and 6 mm mesh) deployed in shallow areas where there was little vegetation or large woody debris. Typically, two seine hauls were made at each location to maximise the number of individuals caught.

All fish were identified in the field, measured for standard length, and then released alive. Fish nomenclature followed that of Allen *et al.* (2002). Fish measurements provided information on the size structure, breeding and recruitment of fish populations.

3.3 Taxonomy and Nomenclature

Plant specimens that were not identified in the field were later identified in Perth by Astron Botanists Janelle Atkinson, Natalie Cadd and Daniel Roocke. Each of these botanists has worked extensively in the Pilbara and is very familiar with the flora of the region. The assigned nomenclature is consistent with the current listing of scientific names recognised by the WAHerb and was used for the species list and associated species information collected. Where specimens had inadequate descriptive material to allow confident identification, they were assigned a 'sp.' (species) epithet, indicating that identification could not be confirmed beyond genus level. Data from each quadrat was entered into a customised database.

3.4 Limitations

Following completion of the desktop assessment and field survey, a review of any limitations that may affect a complete assessment of the data collected was conducted. The limitations listed in Table 9 are based on those suggested as considerations in Guidance Statement No. 51 (Environmental Protection Authority 2004a) and Guidance Statement No. 56 (Environmental Protection Authority 2004b).

Table 9: Statement of limitations.

Potential limitation	Degree of limitation	Statement regarding potential limitations
(i) Sources of information and availability of contextual information. Is the region well documented?	No limitation	Broad-scale contextual information is available from Van Vreeswyk et al. (2004), IBRA (Kendrick 2001; Kendrick and McKenzie 2001) and Beard (1975) mapping. Numerous consultants' reports have been completed within a 50 km radius of the survey area.
(ii) Scope. The level of survey and detail required to undertake the survey. Was there adequate time to complete the survey to the desired standard?	No limitation	The assessment incorporates data from current and previous vegetation, flora, fauna and aquatic systematic surveys from the survey area. As such, the level of detail and scope of this study is deemed adequate.
(iii) Proportion of biota collected and identified. Was the survey sampling, timing and intensity considered adequate? Was the survey conducted at what was considered an appropriate time of the year for plant identification? Were any taxonomic groups considered to be under-represented?	Minor limitation	The seasonal conditions for field surveys conducted in October 2014 (Astron Environmental Services 2014), September-October 2015 and April-May 2015 (Astron Environmental Services 2016b) were considered dry, with below average rainfall in the months preceding. The seasonal conditions for the July 2015 survey, trip 2 of Phase 2 (Astron Environmental Services 2016b), were considered excellent, following substantial rainfall in the three months preceding. Despite unfavourable seasonal conditions for many surveys, the specimens collected were generally of reasonable quality with flowering and fruiting material available; few specimens were unable to be confidently identified to species level. Most taxonomic groups expected within the survey area were well represented, and floristic richness was considered reasonable given the seasonal conditions. Only opportunistic fauna records were undertaken during the Level 1 fauna assessment; as such many of the reptiles and mammals inhabiting the survey area were not recorded. Due to the recent biological surveys that have been conducted in and around the survey area the faunal assemblage is well known. The aquatic sampling was timed to correspond with recessional flow conditions at the end of the wet (April-May) season. It was considered that the end of the wet season would be a more ecologically important time of year to sample, as biological diversity would be expected to be at its highest. Inherent physical sampling deficiencies are acknowledged as a barrier to sampling aquatic fauna,

Potential limitation	Degree of limitation	Statement regarding potential limitations
		and in particular fish. For example, fish catch rates may have been hindered by the abundance of aquatic vegetation (macrophytes and algae) which physically obstructed seine and gill nets at some sites. This was somewhat compensated for by the use of a back-pack electrofisher, which generates a pulsed direct electrical current to draw fish out from under such habitat.
(iv) Completeness. Is there further work which may be required i.e. was the relevant area fully surveyed?	No limitation	The survey area was considered adequately surveyed to compile a representative list of species, (including conservation significant and introduced species), as well as describe and map vegetation and habitats at a level appropriate for possible future management decisions.
(v) Mapping reliability. Were the aerial photographs, satellite images and site maps available considered adequate to fully understand the area surveyed? Was the mapping generated considered to have a high degree of reliability?	No limitation	Colour aerial photography at a scale of 1:10,000 was used to locate the survey area and to assist in navigation and delineation of vegetation and habitat boundaries. The aerial photography was of good resolution and, in general, accurately represented ground conditions.
(vi) Timing. When was the survey conducted in terms of season, rainfall and severe weather events? Was the survey conducted at an appropriate time for access, observation of the optimal suite of species and for flora the identification of flowering and fruiting species?	Minor limitation	The flora surveys were conducted at what would normally be considered the optimal time for both dry and post-wet season surveys in the Pilbara. During the first post-wet season survey of 2016 (Astron Environmental Services 2016b), quadrat species richness was lower than might be expected. Due to the range of surveys informing this assessment, and the variety of conditions involved, the total floristic diversity was in line with what may be expected. The majority of flora species had adequate identification material present. The rainfall in the three months preceding the fauna survey was well below average. This was evident in the lack of surface water present specifically in the Riverine habitats. This is likely to reduce the number of waterbirds recorded. Due to the range of surveys informing this assessment, and the variety of conditions involved, the total fauna diversity is well known. As stated above, the aquatic sampling was timed to correspond with recessional flow conditions at the end of the wet (April-May) season as this would be a more ecologically important time of year to sample, as biological diversity would be at its highest.
(vii) Disturbance. Had the survey area been impacted by any disturbance which may have limited the survey, i.e. fire, flood,	No limitation	A history of pastoral activity and cattle grazing was evident within the survey area. Uprooted mature *Eucalyptus* and *Melaleuca* trees, and associated debris provided evidence of flood waters flowing

Potential limitation	Degree of limitation	Statement regarding potential limitations
accidental human intervention?		through the river after significant rainfall. Small sections of the survey area had been burnt within five years, although this did not compromise the vegetation mapping for these locations. Two small areas of stressed riparian vegetation were noted within the Robe River, where mature trees had senesced. Vehicle tracks were abundant in open areas of the Robe River where shingle substrate supported very sparse vegetation. None of these disturbances limited the outcomes of this survey.
(viii) Intensity. In retrospect, was the intensity considered to be adequate?	No limitation	The intensity of the survey was considered adequate to compile a representative species list for flora, fauna and aquatic components and to map the vegetation and fauna habitats of the survey area. The vegetation mapping was completed to association level with adequate quadrat replication achieved. The intensity of the survey was adequate to conduct targeted flora searches in potential habitat for likely and potential Priority flora species.
(ix) Resources. Were the appropriate tools and materials available to complete the task effectively?	No limitation	Resources were adequate to complete the survey and all appropriate tools and materials required to complete the task were available.
(x) Access. Were there any factors limiting access to the survey area?	No limitation	Much of the survey area was able to be accessed by vehicle; areas that were unable to be reached by vehicle were accessed and traversed by foot.
(xi) Experience. Were personnel undertaking the field survey and plant identification trained and/or experienced in undertaking the required tasks?	No limitation	The scientists responsible for undertaking the field surveys have considerable experience in conducting biological surveys in the Pilbara. The identification of specimens brought back from the field was conducted by scientists with extensive experience.

4 Results

4.1 Desktop Assessment

4.1.1 Vegetation and Flora

No State or Commonwealth listed TECs are known to occur within or adjacent to the survey area (Department of the Environment and Energy 2016d; Department of Parks and Wildlife 2015b).

Two PECs, '*Triodia sp. Robe River assemblages of mesas of the West Pilbara*' P3 and '*Four plant assemblages of the Wona Land System*' P1, have been previously recorded within 50 km of the Mesa H (Astron Environmental Services 2016b) survey area (Department of Parks and Wildlife 2016b) (Figure I.1, Appendix I). Several mapped occurrences of '*Triodia sp. Robe River assemblages of mesas of the West Pilbara*' are located between approximately 16 km and 19 km south-west of the Mesa H survey area (Astron Environmental Services 2016b). The '*Four plant assemblages of the Wona Land System*' PEC is mapped as occurring approximately 21 km north-east of the Mesa H (Astron Environmental Services 2016b) survey area (Department of Parks and Wildlife 2015b).

The Parks and Wildlife TPFL (Department of Parks and Wildlife 2015c) and WAHerb (Department of Parks and Wildlife 2015e) database searches indicated that no species listed as Threatened have been recorded within 20 km of the Mesa H (Astron Environmental Services 2016b) survey area. The Parks and Wildlife TP List (Department of Parks and Wildlife 2015d), which is searched according to place names rather than coordinates, listed two Threatened species: *Lepidium catapycnon* T and *Thryptomene wittweri* T. Since receiving the TP List database search results, *L. catapycnon* has been removed from the Threatened flora list and is currently listed as P4 (Western Australian Government 2015). A review of recorded specimens of *T. wittweri* T, held by the WAHerb (Western Australian Herbarium 1998-2016), indicates that the closest occurrence of this species to the survey area is approximately 270 km to the south-east. In addition, this species has not been identified during previous surveys conducted within, or in close proximity to, the survey area (Astron Environmental Services 2011, 2016a, 2016b; Biota Environmental Sciences 2003, 2006a, 2011a, 2012).

Fourteen Priority flora species have been previously recorded within 20 km of the Mesa H (Astron Environmental Services 2016b) survey area (Table J.1, Appendix J) (Department of Parks and Wildlife 2015c, 2015d, 2015e, 2015f). Of these, two are P1, four are P2, six are P3 and two are P4 status. The pre-survey desktop assessment indicated that two of the listed Priority flora species were considered likely to occur within the riparian community survey area; a further six were considered to have the potential to occur (Table J.1, Appendix J).

4.1.1.1 Literature Review

Results of the literature review indicate that no TECs have been previously recorded within, or in the vicinity of, the survey area (Astron Environmental Services 2011, 2016a, 2016b; Biota Environmental Sciences 2003, 2006a, 2011a, 2012). Vegetation representing the PEC '*Triodia sp. Robe River assemblages of mesas of the West Pilbara*' was recorded within close proximity to the Robe River and adjacent to the riparian community survey area (Astron Environmental Services 2016a, 2016b) (Table 10). This PEC occurred in association with mesa landforms, where either *Acacia pruinocarpa* or *Acacia citrinoviridis* occurred in conjunction with *T.* sp. Robe River (M.E. Trudgen et al. MET 12367) P3.

Results of the literature review identified eight currently listed Priority flora species as having been previously recorded within, or within close proximity to, the survey area: *Pentalepis trichodesmoides* subsp. *hispida* P2, *Eragrostis surreyana* P3, *Gymnanthera cunninghamii* P3, *Indigofera* sp. Bungaroo

Creek (S. van Leeuwen 4301) P3, *T.* sp. Robe River (M.E. Trudgen et al. 12367) P3, *Livistona alfredii* P4, *Ptilotus mollis* P4 and *Rhynchosia bungarensis* P4 (Table 10) (Astron Environmental Services 2016a, 2016b, 2016c; Biota Environmental Sciences 2003, 2006a, 2011a, 2012).

Of these species, *R. bungarensis* P4, was recorded in the greatest number of surveys, and species such as *P. trichodesmoides* subsp. *hispida* P2 and *P. mollis* P4 were recorded from non-riparian landforms (Astron Environmental Services 2016a, 2016b, 2016c; Biota Environmental Sciences 2003, 2006a, 2011a, 2012) (Table 10).

Table 10: Summary of relevant vegetation and flora surveys which overlap the current survey area.

Survey parameter	Astron Environmental Services (2016a)	Astron Environmental Services (2016b)	Astron Environmental Services (2016c)	Biota Environmental Sciences (2012)	Astron Environmental Services (2011)	Biota Environmental Sciences (2011a)	Biota Environmental Sciences (2006a)	Biota Environmental Sciences (2003)
Survey Location	Middle Robe and East Deepdale	Mesa H	Mesa H riparian monitoring	Greater Bungaroo	Mesa J	Robe Valley Mesas	Mesa A, Warramboo, Yarraloola	Mesa J
Survey area size (ha)	11,816	4,930	N/A	8,765	79	9,494	Not specified	~300
Survey focus	Two phase Level 2	Two phase Level 2	Riparian vegetation baseline monitoring	Two phase Level 2	Level 1	Baseline vegetation and flora	Baseline vegetation and flora	Single phase Level 2
Survey timing	June and September/October 2015	October 2014, September 2015, May and July 2016	June 2016	July 2009 and June 2011	June 2011	October 2010	7 surveys between July 2004 and September 2005	September 2003
Seasonal conditions	Excellent	Dry - Average	Average	Excellent	Excellent	Dry	Excellent (all surveys)	Dry
Survey effort (quadrats/relevés/transects)	106 quadrats 13 relevés	138 quadrats 16 relevés	21 transects	37 quadrats	9 relevés	51 quadrats 2 relevés	50 quadrats	10 quadrats
Total vegetation associations mapped	37	38	N/A	16	9	50	72	10
Conservation significant ecological communities recorded	1 PEC	1 PEC	N/A	0	0	1 PEC	0	0
Total species recorded	399	310	118	284	73	221	437	119
Conservation significant flora species recorded (currently listed)	6	3	1	3	0	3	1	1

Survey parameter	Astron Environmental Services (2016a)	Astron Environmental Services (2016b)	Astron Environmental Services (2016c)	Biota Environmental Sciences (2012)	Astron Environmental Services (2011)	Biota Environmental Sciences (2011a)	Biota Environmental Sciences (2006a)	Biota Environmental Sciences (2003)
Eragrostis surreyana P3				✓				
Gymnanthera cunninghamii P3	✓							
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301) P3	✓	✓		✓				
Livistona alfredii P4	✓							
Pentalepis trichodesmoides subsp. *hispida* P2	✓							
Ptilotus mollis P4						✓		
Rhynchosia bungarensis P4	✓	✓	✓			✓	✓	✓
Triodia sp. Robe River (M.E. Trudgen et al. 12367) P3	✓	✓		✓		✓		✓ (undescribed at the time of survey)

4.1.2 Environmentally Sensitive Areas

No ESAs occur within or adjacent to the survey area. The nearest ESA is the Duck Creek Gorge Area, located approximately 78 km south (Landgate 2016). The Millstream-Chichester National Park is the nearest conservation reserve to the survey area, located approximately 79 km to the north-east. The Murujuga National Park is approximately 120 km north and Karijini National Park is approximately 180 km south-east of the survey area.

Springs and pools of the Robe River are listed as 'Wetlands of Subregional Significance' in Kendrick (2001). These springs and pools occur from 40 km east of Pannawonica, downstream to North West Coastal Highway. The significant wetlands are described as 'running spring ecosystems with large deep permanent pools and consist of seasonal and irregular rivers and streams, and freshwater springs, oases and rock pools' (Kendrick 2001).

4.1.3 Terrestrial Fauna

The database searches and literature review results indicate that 318 vertebrate fauna have been previously recorded within 40 km of the survey area, including six amphibian species, 102 reptile species, 160 bird species (including one introduced bird species) and 50 mammal species (including 10 introduced mammal species) (Table K.1-K.4, Appendix K). Of these, 28 species are of conservation significance, including three reptile species, 16 bird species and nine mammal species. Of these, six species were considered to have a 'high' likelihood (inclusive of those previously recorded within the survey area), nine species were considered to have a 'moderate' likelihood and 13 were considered to have a 'low' likelihood of occurrence (Table L.1, Appendix L). This is based on their respective ecology, habitats considered likely to be present and any previous records from historic survey and database records.

4.1.3.1 Literature Review

Previous surveys undertaken for Rio Tinto in the vicinity of the survey area recorded 12 conservation significant vertebrate fauna species: Northern Quoll (*Dasyurus hallucatus),* Pilbara Leaf-nosed Bat (*Rhinonicteris aurantia*), Ghost Bat (*Macroderma gigas*), Western Pebble-mound Mouse (*Pseudomys chapmani*), Eastern Great Egret (*Ardea modesta*), Rainbow Bee-eater (*Merops ornatus*), Wood Sandpiper (*Tringa glareola*), Common Sandpiper (*Actitis hypoleucos*), Sharp-tailed Sandpiper (*Calidris acuminata*), Pilbara Olive Python (*Liasis olivaceus barroni*), Blind Snake (*Anilios ganei*) and Lined Soil-crevice Skink (*Notoscincus butleri*) (Table 11).

Table 11: Summary of literature review results from terrestrial fauna surveys conducted within the vicinity of the survey area.

Author (year)	Survey area size (ha)	Survey level	Survey timing	Survey effort	Conservation significant vertebrate fauna recorded
Astron (2011)	Mesa J Mine 78.63 ha	Level 1	June 2011	Desktop survey and site reconnaissance.	*Merops ornatus* (Rainbow Bee-eater)
Astron (2014)	Mesa H 2,582 ha	Level 1	October 2014	Targeted searches of suitable habitat, motion sensor cameras and SM2 acoustic bat call recorders were used to detect the presence of conservation significant fauna species.	*Dasyurus hallucatus* (Northern Quoll) *Rhinonicteris aurantia* (Pilbara Leaf-nosed Bat) *Macroderma gigas* (Ghost Bat) *Pseudomys chapmani* (Western Pebble-mound Mouse) *Ardea modesta* (Eastern Great Egret) *Merops ornatus* (Rainbow Bee-eater)
Astron (2016e)	Bungaroo 9,795 ha	Level 2 (dual phase)	May - June 2015 August 2015	Habitat assessments, eight trapping sites, avifauna censuses at each trapping site, foot traverses, targeted searches for both vertebrates and short range endemic (SRE) invertebrates, and the use of motion sensitive cameras and SM2BAT ultrasonic bat detectors.	*Dasyurus hallucatus* (Northern Quoll) *Liasis olivaceus barroni* (Pilbara Olive Python) *Rhinonicteris aurantia* (Pilbara Leaf-nosed Bat) *Macroderma gigas* (Ghost Bat) *Pseudomys chapmani* (Western Pebble-mound Mouse) *Notoscincus butleri* (Lined Soil-crevice Skink) *Anilios ganei* (Blind Snake) *Merops ornatus* (Rainbow Bee-eater)
Astron (2016f)	Middle Robe and East Deepdale 11,816 ha	Level 2 (dual phase)	June 2015 August 2015	Habitat assessments, 15 trapping sites, avifauna censuses at each trapping site, foot traverses, targeted searches for both vertebrates and SRE invertebrates, and the use of motion sensitive cameras and SM2BAT ultrasonic bat detectors.	*Dasyurus hallucatus* (Northern Quoll) *Liasis olivaceus barroni* (Pilbara Olive Python) *Rhinonicteris aurantia* (Pilbara Leaf-nosed Bat) *Macroderma gigas* (Ghost Bat) *Pseudomys chapmani* (Western Pebble-mound Mouse) *Notoscincus butleri* (Lined Soil-crevice Skink) *Ardea modesta* (Eastern Great Egret) *Merops ornatus* (Rainbow Bee-eater)

Author (year)	Survey area size (ha)	Survey level	Survey timing	Survey effort	Conservation significant vertebrate fauna recorded
Biologic (2014)	Yarraloola Size not stated	Level 1	December 2013	A Level 1 targeted survey for Northern Quolls, Pilbara Olive Pythons and Pilbara Leaf-nosed Bats.	*Dasyurus hallucatus* (Northern Quoll) *Liasis olivaceus barroni* (Pilbara Olive Python) *Pseudomys chapmani* (Western Pebble-mound Mouse) *Rhinonicteris aurantia* (Pilbara Leaf-nosed Bat) *Macroderma gigas* (Ghost Bat) *Merops ornatus* (Rainbow Bee-eater)
Biota (2005)	Mesa A and G, near Pannawonica 1,305 ha	Level 2 (single phase)	May 2004	Ten trapping sites utilising various combinations of pitfall traps (both PVC tubes and 20 L buckets), Elliott traps and/or funnel traps. Avifauna censuses at each trapping site and Anabat echolocation recordings.	*Dasyurus hallucatus* (Northern Quoll) *Macroderma gigas* (Ghost Bat)
Biota (2006b)	Mesa A Transport Corridor and Warramboo 7,045 ha	Level 2 (dual phase)	April - May 2005 July - August 2005	Ten trapping sites, including pits (buckets and PVC tubes), medium sized Elliotts and funnels. Harp traps targeting bat species, avifauna census at each trapping site and targeted searches for both vertebrates and SRE invertebrates.	*Notoscincus butleri* (Lined Soil-crevice Skink) *Macroderma gigas* (Ghost Bat) *Pseudomys chapmani* (Western Pebble-mound Mouse)
Biota (2007)	Bungaroo Trial Pit and Transport Corridor to Mesa J Size not stated	Level 2 (dual phase)	March 2005 June 2006	Sixteen trapping sites, avifauna census, harp traps targeting bat species, and targeted searches for both vertebrates and SRE invertebrates.	*Dasyurus hallucatus* (Northern Quoll) *Notoscincus butleri* (Lined Soil-crevice Skink) *Pseudomys chapmani* (Western Pebble-mound Mouse) *Tringa glareola* (Wood Sandpiper)

Author (year)	Survey area size (ha)	Survey level	Survey timing	Survey effort	Conservation significant vertebrate fauna recorded
Biota (2009)	Mesa G Size not stated	Level 2 (single phase)	August 2009	Six trapping sites, avifauna census, harp traps and echoloaction recordings targeting bat species, and targeted searches for both vertebrates and SRE invertebrates.	*Rhinonicteris aurantia* (Pilbara Leaf-nosed Bat) *Macroderma gigas* (Ghost Bat)
Biota (2010a)	Greater Bungaroo 8,765 ha	Level 2 (dual phase)	August 2009 March 2010	Trapping at 14 locations, avifauna census, harp traps and echoloaction recordings targeting bat species, and targeted searches for both vertebrates and SRE invertebrates.	*Rhinonicteris aurantia* (Pilbara Leaf-nosed Bat) *Macroderma gigas* (Ghost Bat) *Notoscincus butleri* (Lined Soil-crevice Skink) *Merops ornatus* (Rainbow Bee-eater)
Biota (2011b)	Robe Valley 9,354 ha	Level 2 (single phase)	October 2010	Trapping at 18 locations, avifauna census, harp traps and echoloaction recordings targeting bat species, and targeted searches for both vertebrates and SRE invertebrates.	*Dasyurus hallucatus* (Northern Quoll) *Macroderma gigas* (Ghost Bat) *Notoscincus butleri* (Lined Soil-crevice Skink) *Merops ornatus* (Rainbow Bee-eater)
ecologia Environment (2013)	Middle Robe and East Deepdale 6,092 ha	Level 2 (single phase)	September 2012	Eight fauna trapping sites, avifauna censuses, targeted searches for vertebrate fauna and SRE invertbrates and Anabat echolocation recordings.	*Dasyurus hallucatus* (Northern Quoll) *Rhinonicteris aurantia* (Pilbara Leaf-nosed Bat) *Ardea modesta* (Eastern Great Egret) *Actitis hypoleucos* (Common Sandpiper) *Calidris acuminata* (Sharp-tailed Sandpiper) *Tringa glareola* (Wood Sandpiper) *Merops ornatus* (Rainbow Bee-eater)

4.1.4 Aquatic Fauna

Numerous aquatic ecological surveys have been undertaken within the vicinity of the survey area and were used for the desktop assessment and literature review. A more comprehensive description of the aquatic surveys and studies are provided in Appendix A. A summary of previously recorded species of conservation significance and/or scientific interest are presented in Table 12.

Table 12: Summary of literature review results from aquatic surveys conducted within the vicinity of the survey area.

Species	Common name	Conservation / scientific value	Occurrence within 100 km of survey area	Likelihood of occurrence within the survey area	Occurrence elsewhere
Microinvertebrates					
Lecane noobjupi	Rotifer	WA endemic	Nyeetbury Spring, Red Hill Creek	High, in surface waters	Weeli Wolli Creek, Marillana Creek, Coondiner Creek, Mindy Mindy Creek, Kalgan Creek and Un-named Creek, DeGrey River. Also in south-west Western Australia
Paracyclops sp. 6	Copepod (micro-crustacean)	Pilbara endemic	Chalyarn Pool	High, in surface waters	20+ locations Pilbara-wide
Vestalenula matildae	Ostracod (micro-crustacean)	Pilbara endemic	Chalyarn Pool	High, in surface waters	Various systems of the Ashburton River, DeGrey River, Fortescue River and Sherlock River.
Hyporheos					
Paramelitidae spp.	Stygobitic amphipods	Stygobitic SREs	Yalleen Pool, Red Hill Creek, Mungarathoona Creek.	High in ground-waters and hyporheos	Unknown given family level identification
Melitidae spp.	Stygobitic amphipods	Stygobitic SREs	Bores across the Robe River catchment area	High in ground-waters; Low-moderate in hyporheos	Unknown given family level identification
Haptolana yarraloola	Stygobitic isopod	Stygobitic SRE	Bores in the lower Robe River catchment area – Mesa A/ Warramboo/ Yarraloola	Low	Recently described species; known only from Mesa A/ Warramboo/ Yarraloola bores
Kagalana tonde	Stygobitic isopod	Stygobitic SRE	Bores in the lower Robe River catchment area – Mesa A/ Warramboo/ Yarraloola	Low	Recently described genus and species; elsewhere known from Cane River and Hardey River catchments

Species	Common name	Conservation / scientific value	Occurrence within 100 km of survey area	Likelihood of occurrence within the survey area	Occurrence elsewhere
Pilbarophreatoicus platyarthricus	Stygobitic isopod	Stygobitic SRE	Chalyarn Pool, Nyeetbury Spring, bores in the Robe River catchment area	High in ground-water and hyporheos	Weeli Wolli Creek, Coondiner Creek, Bobswim Pool (Ashburton River)
Pygolabis sp.	Stygobitic isopod	Stygobitic SRE	One undescribed species known from the Robe River catchment	High in ground-water and hyporheos	Uncertain. Members of this genus restricted to either Fortescue, Ashburton or Robe catchment groundwater and hyporheos
Tainisopus sp.	Stygobitic isopod	Stygobitic SRE	Nyeetbury Spring	Low-moderate; only known from Nyeetbury Spring hyporheos	Unknown given genus level identification
Parabathynellidae spp.	Stygobitic syncarids	Stygobitic SREs	Unknown given genus level identification	High in ground-waters; Low-moderate in hyporheos	Unknown given genus level identification
Macroinvertebrates					
Hemicordulia koomina	Pilbara Emerald Dragonfly	IUCN, Near Threatened	Robe River pools, Red Hill Creek	High in surface waters	Fortescue River, Coondiner Creek; now known to be widespread throughout the Pilbara, though infrequently collected
Eurysticta coolawanyah	Pilbara Pin Damselfly	IUCN, Near Threatened	Chalyarn Pool, Robe River pools, Yalleen Pool	High in surface waters	Ashburton River (Bobswim Pool); Kalgan Creek, Coondiner Creek, Fortescue River; now known to be widespread throughout the Pilbara, though infrequently collected
Ictinogomphus dobsoni	Pilbara Tiger Dragonfly	Pilbara endemic; restricted distribution	Chalyarn Pool, Robe River pools, Red Hill Creek	High in surface waters	Fortescue, Ashburton, Yule, DeGrey and Sherlock Rivers
Nannophlebia injibandi	Pilbara Archtail Dragonfly	Pilbara endemic; restricted distribution	Robe River pools, Red Hill Creek	Low-Moderate in surface waters	Fortescue River catchment, but uncommonly collected
Agriocnemis kunjina	Pilbara Wisp Damselfly	Pilbara endemic; restricted distribution	Robe River Pools, Yalleen Pool	Low-Moderate in surface waters	Millstream, Harding River, Tanberry Creek; rarely collected

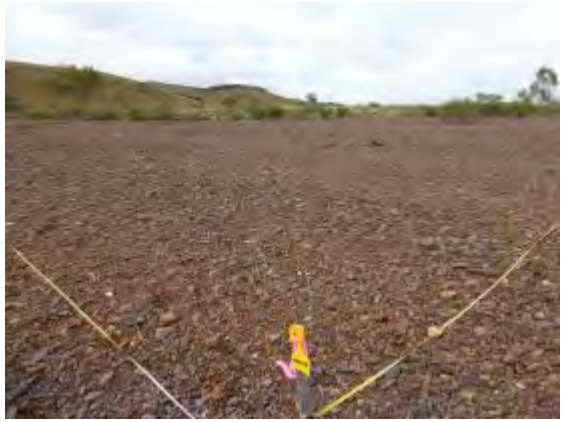
Species	Common name	Conservation / scientific value	Occurrence within 100 km of survey area	Likelihood of occurrence within the survey area	Occurrence elsewhere
Haliplus halsei	Aquatic beetle	Pilbara endemic; relatively new to science	Chalyarn Pool, Myannore Creek	Low-Moderate in surface waters	Uncommonly collected from ephemeral systems and claypans, e.g. the Fortescue Marsh and Coondiner Pool
Haliplus pilbaraensis	Aquatic beetle	Pilbara endemic; relatively new to science	Red Hill Creek	Low-Moderate in surface waters	Uncommonly collected from ephemeral systems and claypans, e.g. the Fortescue Marsh and Coondiner Pool
Sternopriscus pilbaraensis	Diving beetle	Pilbara endemic; restricted distribution	Red Hill Creek	Moderate in surface waters	A range of systems across the Pilbara, fairly commonly collected
Tiporus tambreyi	Diving beetle	Pilbara endemic; restricted distribution	Chalyarn Pool, Robe River pools, Red Hill Creek	Moderate-High in surface waters	A range of systems across the Pilbara, very commonly collected
Tiporus lachlani	Diving beetle	Pilbara endemic; restricted distribution	Red Hill Creek	Low-Moderate in surface waters	A range of systems across the Pilbara, infrequently collected
Laccobius billi	Aquatic beetle	Pilbara endemic; restricted distribution	Mungarathoona Creek, Red Hill Creek	Low-Moderate in surface waters	Yule River and Fortescue River
Fish					
Leiopotherapon aheneus	Fortescue Grunter	IUCN Near Threatened; P4	Robe River pools, Mungarathoona Creek, Red Hill Creek	High in surface waters	Fortescue River (below Fortescue Marsh); Ashburton River

4.2 Field Survey

4.2.1 Vegetation

There were five vegetation associations described within the survey area, which are summarised in Table 13. Some modifications were made to the vegetation association boundaries and descriptions from Astron (2016b) during this assessment to assist in amalgamating the vegetation associations between the previous and current survey areas. There was 16.9 ha of disturbance within the survey area. Vegetation association mapping is provided in Figure M.1 (Appendix M) and the data collected from each quadrat is presented in Appendix N.

Table 13: Vegetation associations recorded for the survey area.

Vegetation associations and descriptions	Sites	Vegetation condition	Total area (ha)	Representative photograph
Es *Euphorbia schultzii* scattered herbs **Associated species:** *Acacia trachycarpa, Petalostylis labicheoides, Hybanthus aurantiacus, Argemone ochroleuca* subsp. *ochroleuca*	MH388, MH394, MH397, MH398, E09 (Astron Environmental Services 2016a)	Very good - Excellent	114.2	 **Plate 1: Vegetation representing Es – facing south-east from GPS co-ordinate 411162mE and 7594904mN (MGA Zone 50).**

Vegetation associations and descriptions	Sites	Vegetation condition	Total area (ha)	Representative photograph
AtrPl *Acacia trachycarpa*, *Petalostylis labicheoides* tall open scrub **Associated species:** *Acacia ancistrocarpa, A. bivenosa, A. pyrifolia*, *Euphorbia schultzii, Ptilotus astrolasius, Tephrosia rosea* var. Fortescue Creeks (M.I.H Brooker 2186), *Triodia wiseana*, *T. epactia*	MH389, MH203, MH321, MH354 (Astron Environmental Services 2016a)	Very good - Excellent	796.1	 **Plate 2: Vegetation representing AtrPl – facing south-east from GPS co-ordinate 410478mE and 7594630mN (MGA Zone 50).**

Vegetation associations and descriptions	Sites	Vegetation condition	Total area (ha)	Representative photograph
MaEcCv *Melaleuca argentea, Eucalyptus camaldulensis* subsp. *refulgens* open forest over *Cyperus vaginatus* scattered sedges to very open sedgeland **Associated species:** *Acacia trachycarpa, *Cenchrus ciliaris, Eucalyptus victrix, *Passiflora foetida subsp. hispida, Petalostylis labic*heoides, *Rhynchosia bungarensis* P4*, Tephrosia rosea* var. Fortescue Creeks (M.I.H. Brooker 2186), *Typha domingensis* and *Vigna lanceolata*	MH381, MH385, MH387, MH204, MH332, MH337r, MH363, AM215 (Astron Environmental Services 2016a)	Very good - Excellent	527.4	 **Plate 3: Vegetation representing MaEcCv – facing south-east from GPS co-ordinate 413079mE and 7595454mN (MGA Zone 50).**

Vegetation associations and descriptions	Sites	Vegetation condition	Total area (ha)	Representative photograph
EcEvAtrApyPlTw *Eucalyptus camaldulensis* subsp. *refulgens* woodland over *E. victrix* low woodland over *Acacia trachycarpa, A. pyrifolia* var. *pyrifolia, Petalostylis labicheoides* tall open shrubland over mixed open herbland and *Triodia wiseana* scattered hummock grasses **Associated species:** *Acacia ancistrocarpa, A. bivenosa, A. colei, *Cenchrus ciliaris, *C. setiger, Cyperus vaginatus, Eulalia aurea, Euphorbia schultzii, Melaleuca argentea, M. glomerata, Tephrosia rosea* var. Fortescue Creeks (M.I.H. Brooker 2186)	MH43, MH44, MH303, MH373, MH379, MH384, E07, E09 (Astron Environmental Services 2016a)	Poor – Very Good	620.5	 **Plate 4: Vegetation representing EcEvAtrApyPlTw – facing south-east from GPS co-ordinate 410331mE and 7594931mN (MGA Zone 50).**

Vegetation associations and descriptions	Sites	Vegetation condition	Total area (ha)	Representative photograph
EvAtrTwCspp *Eucalyptus victrix* low open woodland over *Acacia trachycarpa* tall open shrubland over *Triodia wiseana* open hummock grassland and **Cenchrus* spp. very open tussock grassland **Associated species:** *Acacia bivenosa, A. pyrifolia var. pyrifolia, Boerhavia coccinea, Gossypium robinsonii, Rhynchosia minima, Triumfetta appendiculata and Waltheria indica*	MH392, MH393, MH401	Good	52.9	 **Plate 5: Vegetation representing EvAtrTwCspp – facing south-east from GPS co-ordinate 424829mE and 7592502mN (MGA Zone 50).**

4.2.1.1 Vegetation Condition

Vegetation in the survey area ranged from 'poor' to 'excellent' (Trudgen 1988) condition (Table 14; Figure O.1, Appendix O). Indications of multiple disturbances such as pastoral and mining activity, flood waters uprooting mature trees (Plate 6) and extensive vehicle tracks throughout the open shingle landform were evident. Weed proliferation was extensive in areas of deeper soils, and often in conjunction with evidence of cattle grazing and mining activities. Less than 17 ha (1% of the survey area) was mapped as 'disturbed'.

Occasional patches of mature *Melaleuca argentea* and *Eucalyptus camaldulensis* subsp. *refulgens* trees were noted to be in a deteriorating condition. Evidence of fire in the vicinity of a permanent water hole approximately 9 km downstream of Mesa J may be attributed to the stressed vegetation (Plate 7); however, there was no indication of fire in a separate location of unhealthy trees that was 1 km further downstream.

Plate 6: Debris and uprooted trees from flood waters in the main channel.

Plate 7: Stressed trees, exhibiting fire damage within the Robe River.

Table 14: Vegetation condition recorded for the survey area, based on the Trudgen (1988) scale.

Vegetation condition	Total mapped area within the survey area (ha)
Excellent	124.2
Very Good	1,169.5
Good	717.2
Poor	100.1
Disturbed	16.9

4.2.1.2 Conservation Significance of Vegetation

No TECs or PECs were recorded in the survey area.

Vegetation which may be considered indicator species for a GDE was consistently recorded within the survey area. *Melaleuca argentea* and *E. camaldulensis* subsp. *refulgens* are the dominant upper stratum species of MaEcCv and while *E. camaldulensis* subsp. *refulgens* and/or *E. victrix* are the dominant upper stratum species of EcEvAtrApyPlTw and EvAtrTwCspp. *Melaleuca argentea* is considered an obligate phreatophyte and therefore highly dependent on groundwater, while *E. camaldulensis* subsp. *refulgens* and *E. victrix* are facultative phreatophytes and use groundwater

opportunistically during periods of drought or some life stages. Vegetation association MaEcCv is likely to be most reliant on groundwater.

4.2.2 Flora

There were 124 plant species from 37 families and 82 genera recorded in the survey area. The dominant plant family was Fabaceae, with 23 species confirmed, while *Acacia* was the most frequently recorded genus (Table 15). A species list and a site by species matrix for the survey area are presented, respectively, in Tables P.1 and P.3 (Appendix P).

Table 15: Families and genera with the greatest number of taxa in the survey area.

Family	Number of taxa
Fabaceae	23
Poaceae	20
Malvaceae	17
Genus	**Number of taxa**
Acacia	9
Ptilotus	8
Euphorbia	5

4.2.2.1 Conservation Significant Flora

No State or Commonwealth listed Threatened flora were recorded, or are likely to occur, within the survey area.

Targeted searches in potential habitat within the survey area identified three state-listed Priority flora species (Table 16). Detailed location information and abundance data for each recorded occurrence, along with representative photographs of each species, are presented in Tables Q.1-Q.2 (Appendix Q). Conservation significant flora locations, for both this survey and previous surveys, are also mapped in Figure Q.1.A (Appendix Q).

Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3 was recorded at three locations within the survey area. Typically, *T.* sp. Robe River (M.E. Trudgen et al. MET 12367) P3 occurs along rocky slopes and crests of hills, occasionally also occurring within rocky drainage gullies. *Triodia* sp. Robe River (M.E. Trudgen et al. MET 12367) P3 has previously been recorded in close proximity to the survey area (Biota Environmental Sciences 2003, 2011a).

One individual of *L. alfredii* P4 (Millstream Fan Palm) was recorded in a broad section of the Robe River, during the Middle Robe and East Deepdale survey (Astron Environmental Services 2016a). *Livistona alfredii* P4 has not been previously recorded within a 20 km radius of the survey area (Astron Environmental Services 2011; Biota Environmental Sciences 2003, 2006a, 2011a, 2012; Department of Parks and Wildlife 2015c, 2015d, 2015e).

Rhynchosia bungarensis P4 was recorded in the survey area, typically occurring in the Robe River. *Rhynchosia bungarensis* P4 was generally recorded from densely shaded vegetation in the river channels, under *E. camaldulensis* subsp. *refulgens* and *M. argentea* woodlands and forests. *Rhynchosia bungarensis* P4 has previously been recorded within the survey area and also adjacent to and in close proximity to the survey area (Biota Environmental Sciences 2003, 2006a, 2011a).

Table 16: Conservation significant flora recorded in the survey area.

Species	Vegetation association/s	Source data		
		Astron 2016a	Astron 2016b	Astron 2016c
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	MaEcCv, EvAtrTwCspp	✓	✓	
Livistona alfredii P4	EcEvAtrApyPlTw	✓		
Rhynchosia bungarensis P4	MaEcCv, AtrPl, Es, EcEvAtrApyPlTw	✓	✓	✓

4.2.2.2 *Post-survey Likelihood of Occurrence of Conservation Significant Flora*

Following the surveys, and with greater understanding of the soils and habitats of the survey area, four priority flora species, *Euphorbia australis* var. *glabra* P2, *Stylidium weeliwolli* P2, *E. surreyana* P3 and *I.* sp. Bungaroo Creek (S. van Leeuwen 4301) P3 are considered to have potential to occur but were not recorded. These species have been previously recorded in close proximity to the survey area and suitable habitat for all species was identified within the survey area. None of these species would be restricted to the survey area if present, as indicated by the voucher records listed with the WAHerb (Western Australian Herbarium 1998-2016). Survey effort, as shown by tracklog traverses within the survey area, is presented in Figure R.1 (Appendix R).

4.2.2.3 *Introduced Flora*

Weed diversity in the survey area is considered high with 23 weed species recorded. Species and abundance details are summarised in Table 17.

**Argemone ochroleuca* subsp. *ochroleuca* (Mexican Poppy) is listed as a declared pest under the BAM Act, however it is excluded for the Shire of Ashburton (Department of Agriculture and Food Western Australia 2016). The remaining recorded weeds are not listed as declared pests under the BAM Act, or as a WoNS (Australian Weeds Committee 2012). The recorded locations within the survey area and a description of each weed are presented in Tables Q.3 and Q.4 (Appendix Q).

Table 17: Introduced flora species (weeds) recorded in the survey area.

Species	Family	Source data		
		Astron 2016a	Astron 2016b	Astron 2016c
**Aerva javanica* (Kapok Bush)	Amaranthaceae	✓	✓	✓
**Argemone ochroleuca* subsp. *ochroleuca* (Mexican Poppy)	Papaveraceae	✓	✓	✓
**Bidens bipinnata* (Bipinnate Beggartick)	Asteraceae		✓	
**Cenchrus ciliaris* (Buffel Grass)	Poaceae	✓	✓	✓
**Cenchrus setiger* (Birdwood Grass)	Poaceae	✓	✓	✓
**Chloris barbata* (Purpletop Chloris)	Poaceae	✓	✓	
**Citrullus colocynthis* (Colocynth)	Cucurbitaceae	✓	✓	✓
**Cynodon dactylon* (Couch Grass)	Poaceae	✓	✓	✓
**Datura leichhardtii* (Native Thornapple)	Solanaceae	✓		

Species	Family	Source data		
		Astron 2016a	Astron 2016b	Astron 2016c
**Echinochloa colona* (Awnless Barnyard Grass)	Poaceae	✓	✓	✓
**Euphorbia hirta* (Asthma Plant)	Euphorbiaceae	✓	✓	✓
**Flaveria trinervia* (Speedy Weed)	Asteraceae	✓		
**Lactuca serriola* (Prickly Lettuce)	Asteraceae	✓	✓	
**Malvastrum americanum* (Spiked Malvastrum)	Malvaceae	✓	✓	✓
**Melochia pyramidata*	Malvaceae			✓
**Ocimum basilicum* (Basil)	Lamiaceae		✓	
**Passiflora foetida* subsp. *hispida* (Stinking Passion Flower)	Passifloraceae	✓	✓	✓
**Phoenix dactylifera* (Date Palm)	Arecaceae		✓	
**Rumex vesicarius* (Ruby Dock)	Apocynaceae	✓	✓	
**Setaria verticillata* (Whorled Pigeon Grass)	Poaceae	✓	✓	✓
**Solanum nigrum* (Black Berry Nightshade)	Solanaceae	✓	✓	✓
**Sonchus oleraceus* (Common Sowthistle)	Asteraceae	✓	✓	✓
**Vachellia farnesiana* (Mimosa Bush)	Fabaceae	✓	✓	✓

4.2.3 Fauna

4.2.3.1 Fauna Habitats

Two broad fauna habitat types were recorded in the survey area: Riverine and Drainage Line. The habitats are described in Table 18 and mapping is presented in Figure H.1 (Appendix H). Habitat assessments undertaken during the survey are detailed in Table H.1 (Appendix H).

A significant level of disturbance was recorded during the fauna survey; tracks, pastoralism and weed infestation. The majority of Drainage Line and Riverine habitats were generally in 'good' condition due to weed infestation spread through pastoralism; some areas were also heavily impacted from grazing and therefore the introduction and spread of Buffel Grass (Thompson and Thompson 2010).

Riverine habitat is considered to be of high importance to fauna species providing a range of ecological values to a wide suite of species. This habitat type in the survey area was often narrow linear isolated pockets of riparian vegetation which is usually denser, taller and more diverse than the adjacent Drainage Line habitat. The vegetation was complex and diverse and provided a range of micro niches for fauna species to exploit such as shelter and foraging. There were also a significant number of permanent and semi-permanent water bodies providing drinking opportunities to a range of species along with attracting prey for predators. This habitat supports conservation listed fauna species such as the Rainbow Bee-eater and Fortescue Grunter and acts as foraging sites for Ghost Bats and Pilbara Leaf-nosed Bats.

Thirteen permanent pools (approximately 16.4 ha) were recorded within the survey area in the Riverine habitat (Figure H.1, Table H.2, Appendix H). The area of these pools expands during times of inundation and periodically flood with the advent of cyclones. Due to the dry conditions leading up

to the survey, surface water had contracted back to these permanent pools, some of which are groundwater fed (Dobbs and Davies 2009). These pools are considered a significant fauna habitat due to the refuge they provide to fish, amphibians and water fowl during dry times and the dense vegetation they support.

Drainage Line habitat is a commonly recorded habitat for the Pilbara region and considered to be of low to moderate value to a wide spectrum of fauna species. The Drainage Line habitat typically exhibits a moderate diversity of microhabitats, with some tree hollows and woody debris (logs and leaf litter). However, within the survey area this habitat was generally devoid of vegetation when compared to Riverine, with less dense and less complex vegetation associations. There were some locations with water bodies, albeit less significant and less permanent, and would likely be seasonally inundated during large rainfall events only. Conservation listed species including the Rainbow Bee-eater and Lined Soil-crevice Skink may occur in this habitat.

Table 18: Terrestrial fauna habitat types recorded in the survey area.

Habitat type	Extent in survey area (proportion)	Broad habitat description	Vegetation description	Habitat condition	Value (broad faunal assemblage and MNES species)	Representative photos	
Riverine	397.5 ha (18.7%)	Densely vegetated riparian zones of the Robe River often with permanent and semi-permanent water bodies on stony soils	*Eucalyptus camaldulensis* and *Melaleuca argentea* open forest over *Acacia* tall open shrubland over mixed open herbland and open hummock grassland.	Good to High Quality	High value to a wide spectrum of fauna species that are likely to reside in Riverine habitats. Moderate value to target MNES species as they are likely to traverse and forage within this habitat type.		
Drainage Line	1,713.6 ha (80.5%)	Broad open valley floor of the Robe River on stony soils	*Eucalyptus camaldulensis* or *Corymbia hamersleyana* woodland over *Acacia* tall open shrubland over mixed open herbland and *Triodia wiseana* hummock grassland.	Disturbed to Good Quality	Moderate value to a wide spectrum of fauna species that are likely to reside in Drainage habitats. Low value to target MNES species as they do not provide significant refugia or shelter.		

Habitat type	Extent in survey area (proportion)	Broad habitat description	Vegetation description	Habitat condition	Value (broad faunal assemblage and MNES species)	Representative photos	
Disturbed	16.9 ha (0.8%)	Cleared areas from mining and pastoralism activities	N/A	Highly Degraded	Little value as fauna habitat.	No picture available	No picture available

4.2.4 Terrestrial Vertebrate Fauna Species

Thirty-one terrestrial vertebrate fauna species, comprising two reptiles and 29 bird species were recorded within the survey area (Table 19). This includes one conservation significant species; the Rainbow Bee-eater which is listed as Migratory under the EPBC Act and Schedule 5 under the WC Act (Appendix L).

Table 19: Terrestrial fauna species recorded during the survey.

Species name	Common name
Reptiles	
Ctenophorus caudicinctus	Ring-tailed Rock Dragon
Heteronotia binoei	Bynoe's Gecko
Birds	
Anas superciliosa	Pacific Black Duck
Aythya australis	Hardhead
Tachybaptus novaehollandiae	Australasian Grebe
Phaps chalcoptera	Common Bronzewing
Eurostopodus argus	Spotted Nightjar
Phalacrocorax varius	Pied Cormorant
Pelecanus conspicillatus	Australian Pelican
Ardea novaehollandiae	White-faced Heron
Ardea pacifica	White-necked Heron
Haliastur sphenurus	Whistling Kite
Fulica atra	Eurasian Coot
Platycercus zonarius zonarius	Australian Ringneck
Cacatua sanguinea	Little Corella
Chrysococcyx basalis	Horsfield's Bronze Cuckoo
Merops ornatus	Rainbow Bee-eater
Malurus lamberti assimilis	Variegated Fairy-wren
Gerygone fusca	Western Gerygone
Smicrornis brevirostris	Weebill
Ptilotula penicillatus	White-plumed Honeyeater
Lichmera indistincta	Brown Honeyeater
Pomatostomus temporalis	Grey-crowned Babbler
Colluricincla harmonica	Grey Shrike-thrush
Pachycephala rufiventris	Rufous Whistler
Rhipidura albiscapa	Grey Fantail
Rhipidura leucophrys leucophrys	Willie Wagtail
Grallina cyanoleuca	Magpie-lark
Corvus orru	Torresian Crow
Acrocephalus australis	Australian Reed Warbler
Neochmia ruficauda subclarescens	Star Finch (Western)

4.2.5 Conservation Significant Terrestrial Vertebrate Fauna Recorded

Rainbow Bee-eater (*Merops ornatus*)

The Rainbow Bee-eater (Mi; S5) is one of the most common and widespread birds in Australia and was a commonly recorded species during bioregional surveys in the Pilbara (Burbidge, Johnstone, and Pearson 2010). The species winters from the Gascoyne north to Indonesia, moving south mainly in late September and early October and north from February to April (Johnstone and Storr 1998). Rainbow Bee-eaters tend to prefer lightly wooded, preferably sandy country near water (Johnstone and Storr 1998).

The Rainbow Bee-eater was recorded during the field survey at five locations throughout the survey area in both the Riverine and Drainage Line habitats (Figure L.1, Appendix L). Sixteen previous records of this species were made within the survey area (Astron Environmental Services 2014, 2016d, 2016f; Biota Environmental Sciences 2011b; Department of Parks and Wildlife 2015g; ecologia Environment 2013) and numerous records exist in the vicinity of the survey area (Astron Environmental Services 2011, 2016e, 2016f; Biologic Environmental Survey 2014; Biota Environmental Sciences 2010a; ecologia Environment 2013).

4.2.5.1 Conservation Listed Species Potentially Occurring in the Survey Area

Five species, the Pilbara Olive Python (Vu; S3), Eastern Great Egret (Mi; S5), Northern Quoll (En; S2), Ghost Bat (Vu; S3) and Pilbara Leaf-nosed Bat (Vu; S3) have been previously recorded in the survey area and were considered to have a high likelihood of occurring (Table L.1, Appendix L).

Pilbara Olive Python (*Liasis olivaceus barroni*)

The Pilbara Olive Python (VU; S3) prefers escarpments, deep gorges, water holes and rock piles associated with permanent pools in rocky areas in the ranges of the Pilbara region (Pearson 1993; Wilson and Swan 2010). Microhabitat preferences of the Pilbara Olive Python are under rock piles, on top of rocks or under spinifex (Tutt et al. 2004). Individuals spend the cooler winter months within caves and rock crevices away from water sources. In the warmer summer months the pythons are found to move around widely, usually in close proximity to water and rock outcrops (Wilson and Swan 2010). A population is known to exist along the Robe River near Pannawonica (Biota Environmental Sciences 2007). There have been three Pilbara Olive Pythons previously recorded within the survey area in the Riverine habitat (Astron Environmental Services 2016d, 2016f) (Figure L.1, Appendix L). This species occurs within the Riverine habitats particularly in the sites that contain semi-permanent and permanent water. The Pilbara Olive Python has been previously recorded in the vicinity of the survey area (Astron Environmental Services 2016e, 2016f; Biologic Environmental Survey 2014).

Eastern Great Egret (*Ardea modesta*)

The Eastern Great Egret (Mi; S5) is an inland wetland specialist often seen wading in a range of wetlands from lakes, rivers and swamps to estuaries (Johnstone and Storr 1998). Eastern Great Egrets can be seen alone or in small flocks, often with other egret species, and roost at night in small groups. This species has been previously recorded within the survey area in the Riverine habitat (Astron Environmental Services 2014) and in the vicinity of the survey area (Astron Environmental Services 2014, 2016f; ecologia Environment 2013) (Figure L.1, Appendix L). The Eastern Great Egret is likely to be present at permanent pools within the Riverine and Drainage Line habitats of the survey area.

Northern Quoll (*Dasyurus hallucatus*)

The Northern Quoll (EN; S2) occurs in a variety of habitats (Oakwood 2008) but is commonly found in open lowland savannah forest and rocky escarpments. Rocky areas are a particularly important zone for quolls in the Pilbara as these areas retain water and provide a diversity of microhabitats. These areas also tend to have greater floristic diversity and productivity resulting in greater prey density compared to non-rocky areas. These rocky areas also provide refuge from feral cats, fire and livestock (Hill and Ward 2010) and provide breeding potential (Department of the Environment 2013).

The Northern Quoll has previously been recorded for the survey area and within the general vicinity (Astron Environmental Services 2014, 2016d, 2016e, 2016f; Biologic Environmental Survey 2014; Biota Environmental Sciences 2005, 2007, 2011b; ecologia Environment 2013). Within the survey area the Northern Quoll has been recorded at nine locations, in the Riverine habitat type (Astron Environmental Services 2016d, 2016f) (Figure L.1, Appendix L). The Riverine and Drainage Line habitats of the survey area do not contain the rocky habitats this species requires for its den/shelter sites. However, these habitats are likely to be used as foraging sites, in particular when in close proximity to breakaways or gorges.

Pilbara Leaf-nosed Bat (*Rhinonicteris aurantia*)

Pilbara Leaf-nosed Bats (VU; S3) are known to require deep caves characterised by high levels of humidity and stable temperatures (Churchill 2008). This is a result of their limited ability to conserve heat and water (Armstrong 2001; Churchill 1991). Caves deep enough to create this environment are relatively uncommon in the Pilbara, with only 20 to 25 roost sites being known (R. Bullen 2014, pers. comm. 20 Oct 2014). Foraging habitat for the Pilbara Leaf-nosed Bat is diverse and includes riparian vegetation, hummock grassland, and sparse tree and shrub savannah (Duncan, Baker, and Montgomery 1999). Pilbara Leaf-nosed Bats have also been recorded flying over small watercourses amongst granite boulder terrain, over pools and low shrubs in ironstone gorges, and above low shrubs and around pools in gravelly watercourses with *Melaleuca leucadendron*, such as in Barlee Range Nature Reserve (Armstrong 2001). In the Pilbara this bat species has been observed in *Triodia* hummock grasslands covering low rolling hills and shallow gullies, with scattered *E. camaldulensis* along the creeks (Armstrong 2001; Churchill 1991).

The Pilbara Leaf-nosed Bat has previously been recorded in the survey area at seven different locations (Astron Environmental Services 2014, 2016f) (Figure L.1, Appendix L) and within the general vicinity (Astron Environmental Services 2014, 2016d, 2016e, 2016f; Biota Environmental Sciences 2009, 2010a; ecologia Environment 2013). The habitats of the survey area lack the caves required as roost sites for this species. The complex vegetation of the Riverine and Drainage Line habitats provide ideal foraging habitat, especially in areas surrounding permanent water sources.

Ghost Bat (*Macroderma gigas*)

The preferred habitat of Ghost Bats (VU; S3) is considered to be rocky gorges and breakaways that support caves and crevices used as maternity roosts. The Ghost Bat uses different natural formations for various purposes and for groups to persist they generally require habitats that provide:

- a selection of roosting opportunities with night roosts or feeding sites, day roosts and at least one deep cave with characteristics of a maternity roost
- nearby gullies and gorges with vegetation of vertical complexity (diverse vegetation heights and density) and presence of water that would attract prey species

- a productive foraging area within a 5 km to 10 km radius, usually including a good quality riparian drainage line.

The Ghost Bat has been previously recorded within the vicinity of the survey area from past fauna surveys (Astron Environmental Services 2014, 2016e, 2016f; Biologic Environmental Survey 2014; Biota Environmental Sciences 2005, 2006b, 2009, 2010a, 2011b). Within the survey area Astron (2014) has previously recorded the presence of Ghost Bats at a single location (Figure L.1, Appendix L). The habitats of the survey area lack the caves required as roost sites for this species, although the complex vegetation of the Riverine and Drainage Line habitats provides ideal foraging habitat, especially in areas surrounding permanent water sources.

Other Potential Conservation Significant Species

Of the potentially occurring conservation significant fauna species, nine species were not found in the survey area but were all considered to have a moderate likelihood of occurrence: Fork-tailed Swift (Mi; S5), Cattle Egret (Mi; S5), Letter-winged Kite (P4), Australian Painted Snipe (EN; S2), Common Sandpiper (Mi; S5), Sharp-tailed Sandpiper (Mi; S5), Wood Sandpiper (Mi; S5), Common Greenshank (Mi; S5) and Oriental Pratincole (Mi; S5) (Table L.1, Appendix L). Suitable habitat is present for these species within the survey area; however, these species are either seasonal migrants and/or only present at certain times of the year or cryptic species such as Australian Painted Snipe and Oriental Pratincole, making individuals difficult to record during fauna surveys.

An additional 13 species not found in the survey area were considered to have a low likelihood of occurrence due to lack of suitable habitats (Table L.1, Appendix L).

4.3 Aquatic Ecosystem

This section contains a summary of results from the aquatic baseline survey completed by WRM. For more detail on this component refer to Appendix A.

4.3.1 Water Quality

Water quality was highly variable amongst sites, with salinity levels ranging from fresh (592 µS/cm) to brackish (1,700 µS/cm), pH from circum-neutral (6.9) to slightly alkaline (7.9) and dissolved oxygen from hypoxic (14.5%) to supersaturated (134.9%). There were no obvious longitudinal gradients in water quality parameters upstream or downstream of the Mesa H development.

Exceedances of ANZECC/ARMCANZ (2000) default TVs for the protection of 95% of species in slightly-moderately disturbed tropical northern Australian systems were recorded for nitrogen nutrients (N-total, N-NO_x and N-NH_3) at most sites upstream and downstream of the Jimmawurrada-Robe confluence. The majority of heavy metal analytes, with the exception of dissolved zinc at RRU5 and RRD3, did not exceed ANZECC/ARMCANZ (2000) default 95% TV s in the survey area.

4.3.2 Microinvertebrates

A total of 81 microinvertebrate taxa were recorded from the survey area, of which 46 were present at potentially exposed sites downstream of the Jimmawurrada-Robe confluence, and 69 were recorded at upstream reference sites. There were no significant differences in total mean microinvertebrate taxa richness between reference and potentially exposed sites, nor was there any significant difference in richness of any of the major microinvertebrate groups (protists, rotifers, micro-crustaceans) between these reaches.

One microinvertebrate species listed for conservation significance, the calanoid copepod *Eodiaptomus lumholtzi* (International Union for Conservation of Nature (IUCN) Vulnerable), was recorded at potentially exposed site RRD6.

4.3.3 Hyporheic Fauna

A total of 59 taxa were recorded from hyporheic samples, the majority of which were species not specially adapted to groundwater environments (stygoxene). Of these 59 taxa, 8% were considered stygobitic (obligate groundwater inhabitants), 31% occasional hyporheic stygophiles (species that use the hyporheic zone seasonally or during early life history stages), and 2% possible hyporheic taxa.

Stygobitic taxa collected included the amphipod *Nedsia* sp., the thermosbaenacean *Halosbaena tulki*, and the ostracods *Candonopsis* cf. *tenuis* and *Vestalenula marmonieri*. Of these, *Nedsia* sp. is considered a SRE species. *Nedsia* sp. was collected from sites potentially exposed to dewatering discharge (RRD1 – 4), as well as upstream reference sites (RRU3, RRU4 & RRU6).

4.3.4 Macroinvertebrates

A total of 148 macroinvertebrate taxa were recorded from surface waters (117 from upstream reference sites, and 116 from downstream potentially exposed sites). One macroinvertebrate species listed for conservation significance, the Pilbara Pin Damselfly *Eurysticta coolawanyah* (IUCN Near Threatened), was recorded at potentially exposed downstream sites RRD3 and RRD4.

4.3.5 Fish

A total of 3,515 individual fish, representing 11 species, were captured, measured and released in the survey area. True freshwater species included Western Rainbowfish, Spangled Perch, Pilbara Tandan (Eel-tailed Catfish), Fortescue Grunter, Barred Grunter, Terapontidae (Grunter) hybrids and Bony Bream. Estuarine/marine vagrant fish species included Milkfish, Tarpon/Ox-eye Herring, Mullet and Banded Scat/Striped Butterfish, the majority of which were recorded at the downstream reach. The conservation listed Fortescue Grunter (*Leiopotherapon aheneus*; IUCN Lower Risk/Near Threatened; P4) was the second most abundant fish species of the survey area, recorded at all sites both upstream and downstream of the proposed Mesa H development.

4.3.6 Aquatic Species of Conservation Significance

During the aquatic survey, four species of conservation significance were recorded in the survey area. These records are summarised in Table 20 and the locations shown in Appendix A.

Table 20: Aquatic fauna species of conservation significance recorded during the survey.

Species	Common name	Conservation Value	Occurrence within the Mesa H survey area	Occurrence elsewhere
Microinvertebrates				
Eodiaptomus lumholtzi	Calanoid copepod	IUCN Vulnerable	RRD6	Koodaderi Spring, Homestead Tributary, Mindy Mindy Creek, Cane River, Northern Territory and Queensland
Stygobitic/SRE invertebrates				
Nedsia spp.	Stygobitic amphipod	Potential short range endemic (data deficient)	RRD1 – 4, RRU3, RRU4 and RRU5	Uncertain, possibly bores within the Yarraloola area
Macroinvertebrates				
Eurysticta coolawanyah	Pilbara Pin Damselfly	IUCN Near Threatened, Pilbara endemic	RRD3 and RRD4	Widespread throughout the Pilbara, though infrequently collected
Fish				
Leiopotherapon aheneus	Fortescue Grunter	IUCN Near Threatened, P4, Pilbara endemic	All sites	Robe River catchment, Fortescue River (below Fortescue Marsh); Ashburton River

5 Discussion

5.1 Overview of Survey Area

The Robe River supports extensive woodlands of *M. argentea* and *E. camaldulensis* subsp. *refulgens* (River Red Gum) over sedges in the main channels, and is surrounded by sparely vegetated shingle beds and tall shrublands of *Acacia trachycarpa* and *Petalostylis labicheoides*. Tributaries of the river exhibited deeper soils supporting higher vegetation density at the shrub and grass stratum. *Eucalyptus camaldulensis* subsp. *refulgens* and *E. victrix* woodlands, mixed *Acacia* shrubs and **C. ciliaris* and **C. setiger* tussock grasses were common to these drainage lines which flow into the Robe River.

5.2 Vegetation

Five vegetation associations were mapped within the survey area. No vegetation community that represent a Commonwealth or State listed TEC or PEC was recorded within the survey area.

The majority of vegetation within the survey area was considered to be in 'very good' condition, but ranged from 'poor to 'excellent'. There was a relatively high diversity and abundance of weeds, although this is typical of drainage systems in the Pilbara bioregion. Vegetation of the Robe River typically occurs on shingle rock and occasionally soft sand where weed species such as **A. ochroleuca* subsp. *ochroleuca* (Mexican Poppy), **Cenchrus* species (spp.) (Buffel and Birdwood Grasses), and **Passiflora foetida* subsp. *hispida* (Stinking Passion Flower) contribute to a decline in vegetation condition.

A number of permanent and semi-permanent pools (Plate 8 and 9) occur in the survey area and are typically fringed by vegetation association EcMaCv dominated by *M. argentea* and *E. camaldulensis* var. *refulgens*. These vegetation associations are consistent with the vegetation that typically occurs along minor and major channels within the River land system. The River land system accounts for 2.3% of the Pilbara, and the river channels constitute 20% of this area (van Vreeswyk et al. 2004). Vegetation association EcMaCv is considered a GDE due to the dominant species being *M. argentea* and *E. camaldulensis* var. *refulgens*. *Melaleuca argentea* and *E. camaldulensis* var. *refulgens*, and therefore the vegetation they occur within, may be sensitive to changes in water depth and availability.

Plate 8: Permanent water fringed by *Melaleuca argentea*.

Plate 9: Permanent water supporting *Typha domingensis*.

5.3 Flora

The suite of flora species recorded was considered typical of what may be expected in the area (Beard 1975; Payne, Mitchell, and Holman 1988). Rainfall in the weeks preceding four of the seven field surveys informing this assessment was below average. It is likely that some annual and herbaceous species would have been more widespread but were not observed during the below average seasonal conditions experienced during some surveys. Despite this, specimens generally had adequate material to allow for confident identification.

Areas considered 'likely' or 'potential' habitat for Threatened or Priority flora were targeted and searched. Three Priority flora species were recorded within the survey area: *T.* sp. Robe River (M.E. Trudgen et al. MET 12367) P3, *L. alfredii* P4 and *R. bungarensis* P4.

Occasional small clusters of *T.* sp. Robe River (M.E. Trudgen et al. MET 12367) P3 were recorded in the survey area. These were generally the outer extent of a larger population that extended into the riparian zone beyond its favoured habitat of rocky slopes, hillcrests and ledges of mesas. Thirty-eight records of *T.* sp. Robe River (M.E. Trudgen et al. MET 12367) P3 are listed at the WAHerb, with a known range of approximately 175 km (Western Australian Herbarium 1998-2016). Rio Tinto holds 3,443 records consisting of more than 238,000 *T.* sp. Robe River (M.E. Trudgen et al. MET 12367) P3 individuals, with a geographical distribution spanning from Mesa A in the west to Mettawandy, a range of approximately 150 km (Rio Tinto Iron Ore 2016b).

One *L. alfredii* P4 (Millstream Fan Palm) individual was recorded within the Robe River in the Middle Robe and East Deepdale survey area (Astron Environmental Services 2016a). There is no other record of this species in close proximity to the survey area (Astron Environmental Services 2011; Biota Environmental Sciences 2003, 2006a, 2011a, 2012; Department of Parks and Wildlife 2015d, 2016a). There are 13 vouchered specimens for this species at the WAHerb (Western Australian Herbarium 1998-2016), the majority of which are associated with the Fortescue River in the Millstream Chichester National Park, but also extend to Cape Range and Duck Creek near Mount Brockman. Three hundred and fifty-nine individuals of *L. alfredii* P4 are listed on the Rio Tinto database (Rio Tinto Iron Ore 2016b), all of which are approximately 75 km south-east of the survey area.

Rhynchosia bungarensis P4 was recorded throughout the Robe River system, often in sheltered positions under the canopy of *Eucalyptus* and *Melaleuca* woodlands and where mesa landforms were immediately adjacent to the river. *Rhynchosia bungarensis* P4 has previously been recorded from within the survey area (Biota Environmental Sciences 2003, 2006a, 2011a). Seventy records of this species are listed at the WAHerb, with a known range of approximately 545 km (Western Australian Herbarium 1998-2016). The Rio Tinto database lists 10,865 individuals from 1,134 locations, distributed between Mesa A in the west, to Yandi, with a known range of approximately 360 km (Rio Tinto Iron Ore 2016b).

Although some *E. australis* were recorded from the survey area, the specimens observed had hairs on the leaf laminae differentiating them from the priority form. Given the small habit (≤10 cm) and often frequent occurrence of *E. australis*, not all individuals were observed and there is potential that *E. australis* var. *glabra* P2 occurred but was not recorded. *Euphorbia australis* var. *glabra* P2 has previously been recorded from Jimmawurrada Creek, but more typically occurs in the vicinity of Tom Price (Western Australian Herbarium 1998-2016).

Stylidium weeliwolli P2 is a delicate annual species that is difficult to observe when not in flower and may not have been present, should it occur, due to the low rainfall prior to the surveys. *Stylidium*

weeliwolli P2 has previously been recorded in the vicinity of the survey area; however, this location may be erroneous given the unsuitable habitat at the locality.

The small annual tussock grass *E. surreyana* P3 is unlikely to occur during dry conditions and would be difficult to observe post-rainfall if occurring among a grass-dominated lower stratum (such as **Cenchrus* spp. tussock grassland). *Eragrostis surreyana* has previously been recorded in Jimmawurrada Creek (Western Australian Herbarium 1998-2016), which runs through the eastern side of the survey area.

Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301) P3 was recorded within 100 m of the Riparian Community survey area (Astron Environmental Services 2016b). It is possible this species occurs within the survey area, given that suitable habitat is present.

Weed diversity and abundance in the survey area was considered high, with 23 species recorded. **Ocimum basilicum* (Basil) is rarely recorded species in the Pilbara bioregion, with the only record on Florabase being at the junction of the Pannawonica Road and North West Coastal Highway. No other weed species recorded represents a range extension or were atypical to a survey of this scale in the Robe Valley.

5.4 Terrestrial Fauna Habitats

Habitats within the survey area are not restricted at the local, sub-regional or regional scale and no restricted or uncommon geological units or land systems occur within the survey area. The Riverine habitat in the survey area is considered significant for fauna. The deep pools and shallow spring fed pools provide an important permanent water source for drinking and a refuge for amphibians and waterfowl that occur in a wide area up and downstream of the survey area. This habitat contains microhabitats not common in other habitat types such as large tree hollows, hollow logs and moist leaf litter which provide a productive ecosystem attracting and supporting a range of predators and prey. This habitat supports conservation listed fauna species such as the Rainbow Bee-eater and Pilbara Olive Python and acts as foraging sites for Northern Quolls, Ghost Bats and Pilbara Leaf-nosed Bats. The survey area contains some of the most important pools in the area (such as Yeera Bluff) that are significant ecological features to the local fauna both up and downstream. The springs and pools of the Robe River that occur in the survey area are considered wetlands of sub-regional significance (Kendrick 2001).

The Drainage Line habitats within the survey area are mainly the broad valley of the Robe River or minor ephemeral drainage lines that are not likely to provide significant refugia for species. Drainage Line habitats, although not necessarily large in terms of area, are common habitats within the Pilbara region and immediate surrounds, e.g. the Robe River.

5.5 Terrestrial Fauna Species

The fauna species recorded and faunal assemblage expected to occur in the survey area is typical of that from the Hamersley Range subregion as well as a subset of typical fauna assemblages across the Pilbara bioregion. The habitats of the survey area are also considered dispersal habitat for all resident fauna species including conservation significant species. The Riverine and Drainage Line habitats linear shape and complex vegetation form natural corridors that link habitats and provide routes for fauna dispersal.

Based on the number of previous records of the MNES species; Northern Quoll, Pilbara Olive Python, Ghost Bat and Pilbara Leaf-nosed Bat, the survey area and its surrounds potentially supports locally significant populations. These species may be locally common; however, their presence is restricted

to areas of preferred habitat. Although the fauna habitats of the survey area do not support the caves and den sites these species shelter in, they do provide quality foraging habitat in close proximity to an abundance of suitable shelter. This feature is an important component to supporting the populations and presence of the MNES species in the survey area and the surrounding area.

The Rainbow Bee-eater is one of the most widespread bird species in Australia (Barrett et al. 2003) and is commonly recorded in biological surveys. The Riverine and the Drainage Line habitats provide foraging habitat and in areas containing sandy substrate, such as river banks potential breeding habitat. Within the Pilbara this species is classified as a resident, winter visitor and a passage migrant (Johnstone, Burbidge, and Darnell 2013). As such, this species is not reliant upon the habitats found within the survey area.

The Eastern Great Egret occurs across the Pilbara and is considered uncommon to very common throughout that range (Johnstone, Burbidge, and Darnell 2013). This species has been previously recorded within the survey area in the Riverine habitat (Astron Environmental Services 2014) and in the vicinity of the survey area (Astron Environmental Services 2014, 2016f; ecologia Environment 2013).

5.6 Aquatic Ecosystem

5.6.1 Water Quality

Water quality was highly variable amongst sites, with salinity levels ranging from fresh (592 µS/cm) to brackish (1,700 µS/cm), pH from circum-neutral (6.9) to slightly alkaline (7.9) and dissolved oxygen from hypoxic (14.5%) to supersaturated (134.9%). There were no obvious longitudinal gradients upstream or downstream of the Jimmawurrada-Robe confluence.

Exceedance of ANZECC/ARMCANZ default 95% TVs was recorded for nitrogen nutrients (N-total, N-NO_x and N-NH_3) at most sites upstream and downstream of the Jimmawurrada-Robe confluence. Elevated background levels of N-NO_3 and N-NH_3 within the survey area are unsurprising, given that the Robe River catchment is already effected by current and historic pastoral practices, with groundwaters also appearing to be enriched. Cattle, or evidence of high cattle use (e.g. manure, hoof prints and trampled ground), were observed at a number of pools during the current survey. Elevated N-total and N-NO_x downstream of the Jimmawurrada-Robe confluence may also reflect discharge of nitrogen-enriched groundwater from existing mine operations, though the relative contribution of anthropogenic and natural sources to nitrogen enrichment in surface waters of the survey area is unknown. With the exception of dissolved zinc at RRU5 and RRD3, no heavy metal analyte exceeded ANZECC/ARMCANZ default 95% TVs in the survey area.

5.6.2 Aquatic Fauna

Current results indicate little ecological difference between “reference” sites upstream of the proposed Mesa H development, and downstream sites that may be potentially exposed to dewatering discharge operations. As such, these results provide a good starting point to enable the detection of any potential future ecological changes.

5.6.2.1 Microinvertebrates

A total of 81 microinvertebrate taxa were recorded from the survey area, of which 46 were present at potentially exposed sites downstream of the Jimmawurrada-Robe confluence, and 69 were recorded at upstream reference sites. The microinvertebrate fauna was generally typical of that commonly recorded from tropical/sub-tropical freshwater systems, comprising protists, rotifers,

copepods, cladocerans (water fleas) and ostracods (seed shrimp), with Lecanidae dominating within the Rotifera. There were no significant differences in total mean microinvertebrate taxa richness between reference and potentially exposed sites, nor was there any significant difference in richness of any of the major microinvertebrate groups (protists, rotifers, micro-crustaceans) between these reaches.

One microinvertebrate species listed for conservation significance, the calanoid copepod *Eodiaptomus lumholtzi* (IUCN Vulnerable), was recorded at potentially exposed site RRD6. The conservation listing of this species is considered in need of revision because it is now known to occur at numerous locations across the Pilbara region, including sites along the Fortescue River, Coondiner Creek, Kalgan Creek, Weeli Wolli Creek, Mindy Mindy Creek, Koodaideri Springs, Caves Creek, Duck Creek and the Cane River, as well as Papua New Guinea.

5.6.3 Hyporheic Fauna

Hyporheic sampling collected 59 taxa in total, the majority of which were species not specially adapted to groundwater environments (stygoxene). Of these 59 taxa, 8% were considered stygobitic (obligate groundwater inhabitants), 31% occasional hyporheic stygophiles (species that use the hyporheic zone seasonally or during early life history stages), and 2% possible hyporheic taxa. There were no obvious longitudinal gradients or patterns in hyporheic taxa richness between reference and potentially exposed sites, though hyporheic taxa richness was relatively high at RRD1, RRU6, RRD2 and RRU4, suggesting strong connectivity between ground- and surface waters at these sites.

One stygobitic taxa recorded (*Nedsia* sp.) is considered a SRE species. *Nedsia* sp. was collected from sites potentially exposed to dewatering discharge (RRD1 – 4), as well as upstream reference sites (RRU3, RRU4 and RRU6). These amphipods could not be confidently identified to species level due to a current lack of taxonomic resolution within the Melitidae amphipods and would require DNA sequencing.

5.6.4 Macroinvertebrates

A total of 148 macroinvertebrate taxa were recorded from surface waters, with composition typical of freshwater systems throughout the world. There were no clear upstream/downstream gradients in macroinvertebrate richness within the survey area, with no significant difference in mean total taxa richness, and mean richness of most major macroinvertebrate groups, between reference and potentially exposed sites. Similarly, multivariate analysis detected no distinguishable separation of reference or potentially exposed sites based on macroinvertebrate species assemblage structure.

One macroinvertebrate species listed for conservation significance, the Pilbara Pin Damselfly *Eurysticta coolawanyah* (IUCN Near Threatened), was recorded at potentially exposed downstream sites RRD3 and RRD4. It is likely that both RRD3 and RRD4 are important refuge pools for Pilbara Pin Damselfly in the area, as both are persistent waterbodies which support relatively high densities of emergent macrophyte, which are used for perching, mating and oviposition (egg-laying).

5.6.5 Fish

A total of 3,515 individual fish, representing 11 species, were recorded in the survey area. True freshwater species included Western Rainbowfish, Spangled Perch, Pilbara Tandan (Eel-tailed Catfish), Fortescue Grunter, Barred Grunter, Terapontidae (Grunter) hybrids and Bony Bream. Estuarine/marine vagrant fish species included Milkfish, Tarpon/Ox-eye Herring, Mullet and Banded Scat/Striped Butterfish, the majority of which were recorded at the downstream reach. There was no significant difference in mean total abundance of fish between upstream and downstream sites,

nor was there any significant difference in mean abundance of each individual species between the reaches. Healthy (breeding) populations of Western Rainbowfish, the most abundant fish species of the survey area, were recorded from both the upstream and downstream reaches; however, Spangled Perch and Pilbara Tandan recruitment appeared to be low throughout the survey area.

The conservation listed Fortescue Grunter (*Leiopotherapon aheneus*; IUCN Lower Risk/Near Threatened; P4) was recorded at all sites both upstream and downstream of the proposed Mesa H development. This species is endemic to the Pilbara, only known from the Fortescue, Robe and Ashburton River systems. Within this range it is considered to be common and was the second most abundant fish collected during the survey.

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Appendix A: Mesa H Baseline Aquatic Ecosystem Survey – Wet Season Sampling 2016

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Mesa H Project

Baseline Aquatic Ecosystem Survey
Wet Season Sampling 2016

WRM
Wetland Research & Management

Final Report
April 2017

Mesa H Project

Baseline Aquatic Ecosystem Survey
Wet Season Sampling 2016

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Final
April 2017

Frontispiece (left to right): freshwater mussels (*Velesunio* spp.) at RRU6, upstream of the Jimmawurrada-Robe confluence; RRD5 at Gnieraoora/Dthulurat; measuring milkfish (*Chanos chanos*) at RRD4 in the Medawandy Waters area.

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Disclaimer

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EXECUTIVE SUMMARY

This report summarises the results of a baseline sampling program for aquatic ecosystems of the Robe River system, both upstream and downstream of the proposed Mesa H iron ore development ("the Project"), managed by Rio Tinto on behalf of the Proponent (Robe River Mining Co. Pty Ltd) in the West Pilbara region of Western Australia. The aim of the sampling program was to document the current ecological condition of the Robe River prior to the implementation of the Mesa H development, which will require dewatering and surplus water discharge, which will result in a surface discharge footprint along the Robe River. The baseline survey included a number of named permanent pools in the Project area known to have ecological and cultural value, such as Gnieraoora (or Dthulurat) at Yeera Bluff. This report also includes a review of previous aquatic fauna surveys of the Robe River, and other nearby systems (*e.g.* Bungaroo Creek, Jimmawurrada Creek and Mungarathoona Creek), including conservation significant species known to occur in the vicinity of the Project area, which provides regional context for the sampling program.

The sampling design included six sites downgradient of the confluence of Jimmawurrada Creek and the Robe River (immediately upstream of the existing Mesa J operation) (RRD1 - 6), which are likely to fall within the zone of dewatering discharge (*i.e*. 'potentially exposed' sites), and six sites (RRU1 - 6) located upstream of the confluence (*i.e.* 'reference' sites). Sites were surveyed during the late wet season (April/May) 2016. The permanency and consistency of flow in the Robe River is already influenced by groundwater abstraction and dewatering discharge from the existing Mesa J mine operation, and so the current sampling program documents "current" ecological condition, more so than "natural" condition. Water quality, microinvertebrates (zooplankton), hyporheic fauna, macroinvertebrates and fish were successfully sampled at each of the 12 sites.

The main findings of the baseline survey were:

- Water quality was highly variable amongst sites, with salinity levels ranging from fresh (592 µS/cm) to brackish (1,700 µS/cm), pH from circum-neutral (6.9) to slightly alkaline (7.9) and dissolved oxygen from hypoxic (14.5%) to supersaturated (134.9%). There were no obvious longitudinal gradients in water quality parameters upstream or downstream. Site RRU6 (~1 km upstream of the Jimmawurrada-Robe confluence) and the downstream sites tended to have higher salinity (as electrical conductivity and total dissolved solids), alkalinity, hardness and concentrations of associated ions, than sites upstream. Some of this variability was attributed to differences in volume of the remnant pools sampled and evapoconcentration effects under recessional flows, however, higher concentrations of some ions downstream of the Jimmawurrada-Robe confluence (most notably magnesium and sulfate) was considered a possible artefact of current mining operations.
- Exceedances of ANZECC/ARMCANZ (2000) default trigger values for the protection of 95% of species in slightly-moderately disturbed tropical northern Australian systems were recorded for nitrogen nutrients (N-total, N-NO_x and N-NH_3) at most sites upstream and downstream of the Jimmawurrada-Robe confluence. Elevated background levels of N-NO_3 and N-NH_3 within the Project area are unsurprising, given that the Robe River catchment is already effected by current and historic pastoral practices, with groundwaters also appearing to be enriched. Elevated N-total and N-NO_x downstream of the Jimmawurrada-Robe confluence may also reflect discharge of nitrogen-enriched groundwater from existing mine operations, though the relative contribution of anthropogenic and natural sources to nitrogen enrichment in surface and groundwater of the Project area is unknown. The majority of heavy metal analytes, with the exception of dissolved zinc at RRU5 and RRD3, did not exceed ANZECC/ARMCANZ (2000) default 95% trigger values in the Project area.
- A total of 81 microinvertebrate taxa were recorded from the Project area, of which 46 were present at potentially exposed sites downstream of the Jimmawurrada-Robe confluence, and 69

were recorded at upstream reference sites. The microinvertebrate fauna was generally typical of that commonly recorded from tropical/sub-tropical freshwater systems, comprising Protista, Rotifera, Copepoda, Cladocera (water fleas) and Ostracoda (seed shrimp), with species from the family Lecanidae dominating within the Rotifera. There were no significant differences in total mean microinvertebrate taxa richness between reference and potentially exposed sites, nor was there any significant difference in richness of any of the major microinvertebrate groups (protists, rotifers, micro-crustaceans) between these sites. One microinvertebrate species listed for conservation significance, the copepod *Eodiaptomus lumholtzi* (IUCN Vulnerable), was recorded at potentially exposed site RRD6. The conservation listing of this species is considered in need of revision because it is known to occur at numerous locations across the Pilbara region, including sites along the Fortescue River, Coondiner Creek, Kalgan Creek, Weeli Wolli Creek, Mindy Mindy Creek, Koodaideri Springs, Caves Creek, Duck Creek and the Cane River, as well as Papua New Guinea.

- A total of 59 taxa were recorded from hyporheic samples, the majority of which were species not specially adapted to groundwater environments (stygoxene). Of these 59 taxa, 8% were considered stygobitic (obligate groundwater inhabitants), 31% occasional hyporheic stygophiles (species that use the hyporheic zone seasonally or during early life history stages), and 2% possible hyporheic taxa. There were no obvious longitudinal gradients or patterns in hyporheic taxa richness between reference and potentially exposed sites, though hyporheic taxa richness was relatively high at RRD1, RRU6, RRD2 and RRU4, suggesting strong connectivity between ground- and surface waters at these sites. Stygobitic taxa collected included the amphipod *Nedsia* sp., the thermosbaenacean *Halosbaena tulki,* and the ostracods *Candonopsis* cf. *tenuis* and *Vestalenula marmonieri.* Of these, *Nedsia* sp. is considered a potential short range endemic (SRE) species. *Nedsia* sp. was collected from sites potentially exposed to dewatering discharge (RRD1 – 4), as well as upstream reference sites (RRU3, RRU4 and RRU6).
- A total of 148 macroinvertebrate taxa were recorded from surface waters (117 from upstream reference sites, and 116 from downstream potentially exposed sites), with composition typical of freshwater systems throughout the world, being dominated by Insecta, in particular Diptera (true flies) and Coleoptera (aquatic beetles). There were no clear upstream/downstream gradients in macroinvertebrate richness within the Project area, with no significant difference in mean total taxa richness, or mean richness of most major macroinvertebrate groups, between reference and potentially exposed sites. Similarly, multivariate analysis detected no distinguishable separation of reference or potentially exposed sites based on macroinvertebrate species assemblage structure. One macroinvertebrate species listed for conservation significance, the Pilbara pin damselfly *Eurysticta coolawanyah* (IUCN Near Threatened), was recorded at potentially exposed downstream sites RRD3 and RRD4.
- A total of 3,515 individual fish, representing 11 species, were recorded in the Project area. True freshwater species included western rainbowfish, spangled perch, Pilbara tandan (eel-tailed catfish), Fortescue grunter, barred grunter, Terapontidae (grunter) hybrids and bony bream. Estuarine/marine vagrant fish species included milkfish, tarpon/ox-eye herring, mullet and banded scat/striped butterfish, the majority of which were recorded at the downstream reach. The conservation listed Fortescue grunter (*Leipotherapon aheneus*; IUCN Lower Risk/Near Threatened; Parks and Wildlife Priority 4) was the second most abundant fish species of the Project area, recorded at all upstream and downstream sites. Similar to other fauna indices, there was no significant difference in mean total abundance of fish between upstream and downstream sites, nor was there any significant difference in mean abundance of each individual species within the Project area. Healthy (breeding) populations of western rainbowfish, the most abundant fish species of the Project area, were recorded from upstream and downstream reaches; however, spangled perch and Pilbara tandan recruitment appeared to be low throughout the Project area.

1 INTRODUCTION

1.1 Background

Robe River Mining Co. Pty Ltd (the Proponent) is evaluating the potential development of the Mesa H iron ore deposit, located 16 km south-west of Pannawonica, in the West Pilbara region of Western Australia (Figure 1). The development envelope for Mesa H traverses the Robe River and lies adjacent to the existing Mesa J mine operation.

As part of the Mesa H development, dewatering of underlying groundwater will be required to allow mining of sections of ore (~20%) which occur below the water table (BWT). Options for disposal of excess dewatering water from the Mesa H development include discharge to an unnamed ephemeral tributary of the Robe River, between Mesa H and Mesa J, and/or discharge into Jimmawurrada Creek, east of Mesa J (Figure 1, or potentially an additional location north of Mesa H). The former two discharge points are currently used by the Mesa J operation.

The permanency and consistency of flow in the Robe River is already influenced by groundwater abstraction and dewatering discharge from existing mine operations (Aquaterra 2004). Groundwater drawdown and discharge from Mesa H may also affect aquatic ecosystems in the local vicinity. This includes a number of named permanent pools known to have ecological and cultural value, such as Gnieraoora (or Dthulurat) at Yeera Bluff (Figure 1).

Astron Environmental Service Pty Ltd (Astron) commissioned *Wetland Research & Management* (WRM) to design and conduct a baseline sampling program encompassing aquatic ecosystems of the Robe River both upstream and downstream of the Mesa H development (the "Project area"). The aim of the sampling program is to document current ecological condition of the system, and procure benchmark aquatic fauna and water quality data against which any future changes may be assessed post-commencement of the Mesa H development, including cumulative effects from dewatering drawdown ('drying') and discharge (quality and quantity). The permanency and consistency of flow in the Robe River is already influenced by groundwater abstraction and dewatering discharge from the Mesa J mine, and so the current sampling program will document "current" ecological condition moreso than "natural" condition. Where possible, monitoring sites established by Streamtec Pty Ltd (Streamtec) and The University of Western Australia (UWA) on the Robe River (Figure 1) have been included in the program. Since 1991, annual sampling for fish and benthic macroinvertebrates has been conducted by Streamtec/UWA as part of long-term monitoring for the Mesa J Project (Streamtec 1996, 1999, 2003, 2007, 2009, 2010, 2012 and 2014, Dobbs and Davies 2009).

1.1.1 Legislative framework

At a State level, native aquatic fauna are protected under the *Wildlife Conservation Act 1950* (WC Act) and their environment is protected under the *Environmental Protection Act 1986* (EP Act). This includes freshwater turtles, frogs, fish and invertebrates (including hyporheic and stygal invertebrates). Hyporheic invertebrates inhabit subsurface interstitial spaces in coarse creek bed sediments. Stygal invertebrates are aquatic, obligate groundwater-dwelling species known to be present in a variety of rock types and are often also present in the hyporheos.

The EP Act provides for environmental impact assessment (EIA) of proposals (and schemes) likely to have a significant effect on the environment. As part of the EIA process, the Act requires the Environmental Protection Authority of Western Australia (EPA) to report on key environmental factors to the Minister for Environment. Environmental factors and associated objectives are the EPA's basis for assessing whether a proposal (or scheme's) impact on the environment is acceptable. Two key environmental factors relate to water resources:

i) Hydrological Processes - with the objective "To maintain the hydrological regimes of groundwater and surface water so that environmental values are protected".

ii) Inland Waters Environmental Quality - with the objective "To maintain the quality of groundwater and surface water so that environmental values are protected".

Proponents are required to provide baseline information on these two factors (and others) in order to inform the EIA process.

The WC Act provides for species and ecological communities to be specially protected and listed as either 'threatened' because they are under identifiable threat of extinction, or 'priority' because they are rare, or otherwise in need of special protection. This encompasses species with small distributions (occupying an area of less than 10, 000 km^2) defined as short range endemics, or SREs (Harvey 2002, EPA 2009). The EPA's Guidance Statement 20 (EPA 2009) requires that impacts on SRE invertebrates be considered during the EIA process.

It can be difficult to determine whether or not a species belonging to a SRE Group is actually a species with a range <10,000 km^2. The Western Australian Museum (WAM) uses a three-tier classification scheme for SRE species which we have applied to hyporheic fauna in this report:

- **Confirmed SREs** are species with a known distribution range <10,000 km^2. The taxonomy is well known and the group is well represented in collections and/or via comprehensive sampling.

- **Potential SREs** are species that belong to a group where there are gaps in our knowledge of the taxon, either because the group is not well represented in collections, taxonomic knowledge is incomplete, or the distribution is imperfectly understood because sampling has been patchy.

- **Widespread (not SRE) species** have a known distribution range >10,000 km^2. The taxonomy is well known and the species is well represented in collections and/or via comprehensive sampling.

WAM further uses five sub-categories if a species is determined to be a "Potential SRE". These sub-categories are:

1. Data deficient: There are insufficient data available to determine SRE status, either because there is a lack of geographic and taxonomic information, or because the individuals sampled cannot be identified to species level (*e.g.* wrong sex, juvenile, damaged);

2. Habitat Indicators: The status of a species can be elucidated through its association with a particular habitat and vice versa;

3. Morphological Indicators: The status of a species can be determined through its morphological characteristics;

4. Molecular Evidence: DNA sequence data reveal patterns congruent or incongruent with SRE status for a species; and

5. Research & Expertise: Available research data and/or WAM expertise provide the basis for a decision about the species' status.

The Department of Parks and Wildlife (Parks and Wildlife) also maintains a list of priority fauna species that are of conservation importance but, for various reasons, do not meet the criteria for listing as threatened. Parks and Wildlife uses the International Union for Conservation of Nature (IUCN) Red List

criteria for assigning species and communities to threat categories. Not all Western Australian species listed by the IUCN are also listed by Parks and Wildlife.

Objectives for the management of potential impacts on water-dependent ecosystems are also outlined in the Western Australian Department of Water (DoW) Western Australian Water in Mining Guideline (DoW 2013) and include:

- Minimise the adverse effects of the abstraction and release of water on environmental, social and cultural values;
- Ensure the cumulative effects of mining operations are considered and managed;
- Use a monitoring and evaluation process, to adaptively manage the effects of abstractions and releases on the water resources;
- Maximise cooperation in water management activities between nearby water users, to reduce impacts on the environment;
- Plan for, and manage, the effects of climate variability and change.

At a Federal level, the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) provides for native fauna and their habitats to be specially protected and listed as nationally or internationally important. Relatively few aquatic species in Western Australia are listed as threatened or endangered under the WC Act or EPBC Act. Lack of knowledge of their distributions often precludes aquatic invertebrates for listing as threatened or endangered. The EPA has stated that listing under legislation should therefore not be the only conservation consideration in EIA (EPA 2004).

The current baseline sampling constituted a Level 1 survey for EIA, as described under the EPA's Environmental Assessment Guideline (EAG) No. 12 (EPA 2013), and in accordance with EAG No. 8 (EPA 2015), with the focus on hydrological processes and ecosystem maintenance. At the time of the survey (April/May 2016), the aforementioned EAGs were the most up-to-date EAGs availaible.

1.1.2 Other relevant policy - ANZECC/ARMCANZ (2000) Guidelines

The Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ 2000) "… provide an authoritative guide for setting water quality objectives required to sustain current, or likely future, environmental values (users) for natural and semi-natural water resources in Australia and New Zealand". These guidelines form part of the National Water Quality Management Strategy (NWQMS), a joint national approach to improving water quality in Australian and New Zealand waterways. The NWQMS was originally endorsed by two Ministerial Councils - the former Agriculture and Resources Management Council of Australia and New Zealand (ARMCANZ) and the former Australian and New Zealand Environment and Conservation Council (ANZECC).

State regulators have been known to apply the trigger values detailed in the ANZECC/ARMCANZ (2000) guidelines as compliance values for mining companies in the Pilbara, where developments may impact creeklines through dewatering and discharge operations. Yet, in some systems water quality data recorded during baseline surveys, conducted prior to any disturbance, do not actually meet the default ANZECC/ARMCANZ (2000) trigger values. Therefore, it is important to obtain adequate baseline water quality data and develop system-specific guidelines, as recommended in the ANZECC/ARMCANZ (2000) guidelines, to avoid issues with non-compliance as a result of inappropriate trigger values being used by regulators.

The ANZECC/ARMCANZ (2000) guidelines are currently under review and updates are provided by the Joint Steering Committee for the Revision on the Federal Department of the Environment and Energy website (www.environment.gov.au/water/quality/national; downloaded on 30 May 2016).

1.2 Scope of Works for Current Study

The scope of works for the current study was to establish riverine baseline monitoring sites, and to develop a robust dataset to allow statistical testing for potential change over time. Specifically, the scope of work included:

- Identification of baseline and future riverine monitoring sites, and where possible, include long-term monitoring sites established previously by Streamtec/UWA;
- Semi-qualitative sampling for aquatic fauna (microinvertebrates, hyporheic invertebrates, benthic macroinvertebrates, fish) and water quality to allow statistical comparison of any changes overtime;
- Qualitative visual assessment of general habitat conditions at all sites;
- Record opportunistic visual sightings of any turtle and frog species present;
- Identification of all specimens to the lowest taxonomic level practicable;
- An assessment of the conservation status of aquatic fauna recorded;
- Report water quality data against ANZECC/ARMCANZ (2000) guidelines for freshwater ecosystems;
- Preparation of a detailed technical report of all findings.

1.3 Rationale for Sampling Components of Aquatic Fauna

Microinvertebrates

Aquatic microinvertebrate fauna consists of microscopic fauna including micro-crustacea (ostracods, copepods and cladocera), protists and rotifers (nominally <53 μm in size). Aquatic microinvertebrates are used as bioindicators throughout the world for many reasons. The microinvertebrate community holds a strategic position in food webs (Bunn and Boon 1993, Zrum and Hann 1997, Jenkins and Boulton 2003). They provide a food source for higher trophic levels, such as macroinvertebrates (Bunn and Boon 1993, Jenkins and Boulton 2003), fish (King 2004, Vilizzi and Meredith 2009), and waterbirds (Crome 1985). Most fish species depend on microinvertebrates for their first feed after hatching (Geddes and Puckridge 1989). Therefore, any change in the microinvertebrate community will ultimately result in changes to the entire aquatic ecosystem. Microinvertebrates also have intimate contact with the surrounding environment, being planktonic, and continually exposed to the ambient water quality. Hence, they are vulnerable to environmental pollutants and can be a useful biomonitoring tool (Kaur and Ansal 1996).

Hyporheic fauna

The hyporheic zone, comprising subsurface interstitial spaces in coarse creek bed sediments, is recognised as a critical component of many streams and rivers (Edwards 1998). The hyporheic zone creates habitat and connectivity between surface and sub-surface (groundwater) zones, provides a rearing habitat and important refuge for aquatic invertebrates, and importantly in the context of the Pilbara region, buffering from floods (Palmer *et al.* 1992, Dole-Olivier and Marmonier 1992), disturbance in food supply (Edwards 1998) and drought (Cooling & Boulton 1993, Coe 2001, Hose *et al*. 2005). The aquatic fauna of hyporheic zones is collectively referred to as hyporheos. Typically, hyporheos have poor dispersal capabilities, are confined to discontinuous habitats, are highly seasonal (usually more active in the wet season following significant flows) and have low levels of fecundity, and are therefore commonly classified as SRE as defined by Harvey (2002)[1]. A number of taxa frequently encountered in hyporheic zones, including stygal amphipods, isopods and syncarids (crustaceans) are classified as SRE, and are therefore of high conservation value. The subterranean fauna of the Pilbara is characterised by high levels of diversity and short range endemism (Eberhard *et al*. 2005, Halse *et al*. 2014), with increasing aridity and cessation of surface flows over the last 60 – 70 million years causing once epigean

[1] Short range endemic as defined by Harvey (2002): a species occupying an area of less than 10, 000 km^2.

(surface dwelling) fauna to disperse and become isolated in groundwater environments (Finston *et al*. 2011).

Macroinvertebrates

Aquatic macroinvertebrates (nominally 53 - 250 µm in size) typically constitute the largest and most conspicuous component of aquatic invertebrate fauna in both lentic (still) and lotic (flowing) waters. Macroinvertebrates are used as a key indicator group in the bioassessment of the health of Australia's streams and rivers under the National River Health Program (Schofield and Davies 1996), and have inherent value for biological monitoring of water quality (ANZECC/ARMCANZ 2000). Macroinvertebrates are considered to be temporary residents if their life-cycle contains a winged-adult form (*e.g.* dragonflies, damselflies, mayflies, aquatic beetles, caddisflies, *etc.*), therefore being proficient in aerial dispersal between waterbodies (Gray and Fisher 1981). Permanent residents include those which can persist as larvae during periods of drought by aestivating or encysting in sediments (*e.g.* Baetidae, Simuliidae, Ceratopogonidae, Chironomidae), or produce desiccation-resistant propagules or eggs which hatch upon inundation (*e.g*. ciliates, rotifers, flatworms, nematodes, segmented worms and crustaceans) (Radzikowski 2013).

Fish

Historically, fish diversity has been used worldwide as an indicator of ecosystem health (*e.g.* Hugueny e*t al*. 1996, Oberdoff *et al.* 2002, Pont *et al.* 2006). Because fish continually inhabit the receiving water, they integrate the chemical, physical and biological 'histories' of the watercourse. Most fish species have a long life span and therefore reflect both long-term and current water quality. Sampling fish assemblages can be used to assess a range of environmental disturbances, such as changes in habitat, water quality and land use (Hugueny *et al.* 1996). Fish also tend to be the most conspicuous biota in freshwater systems, have significant social amenity and are relatively easy to sample and identify.

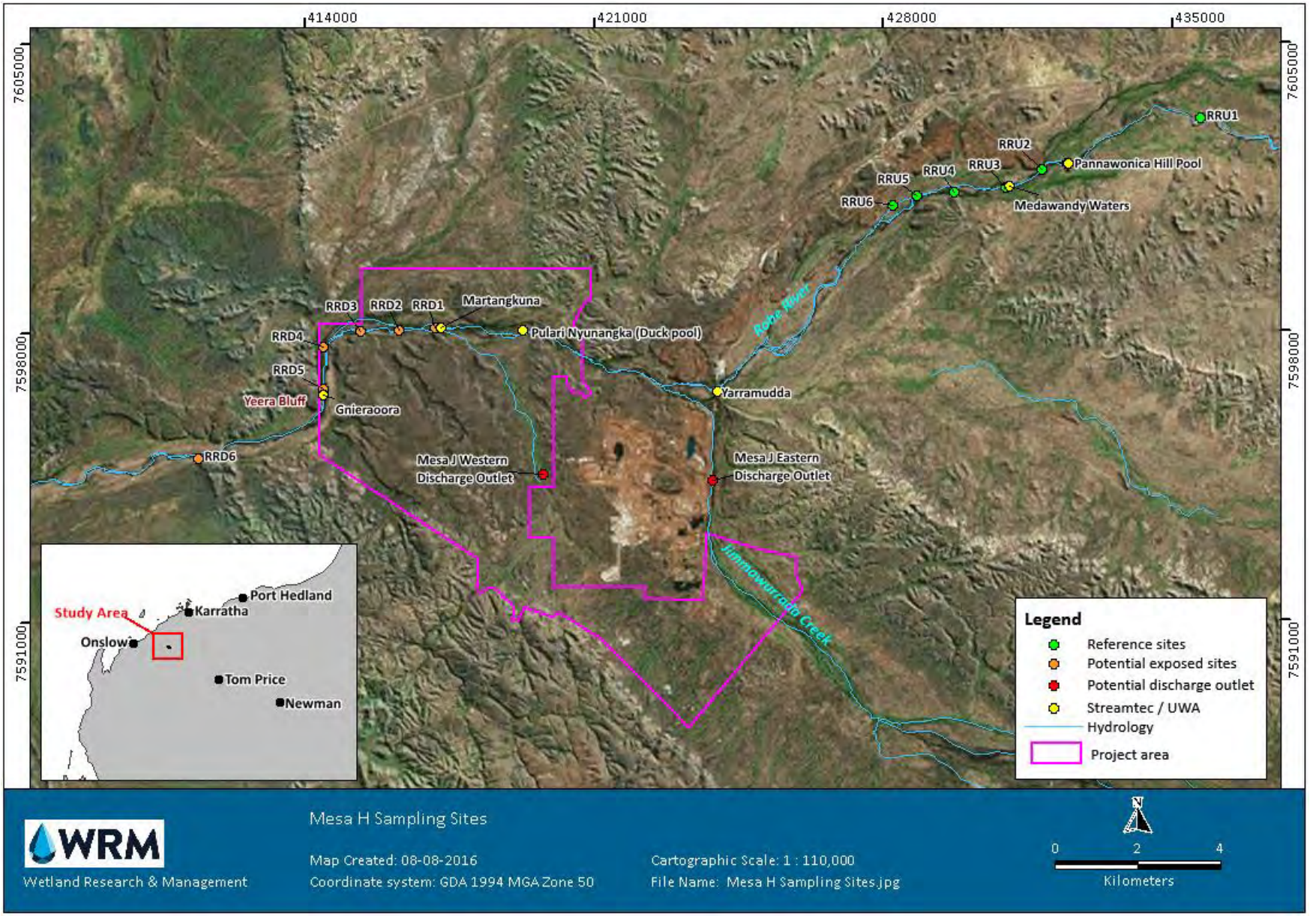


Figure 1. Location of Mesa H Project area and baseline aquatic ecosystem sampling sites (reference, potential exposed) and historic Streamtec/UWA sites ( ).

2 STUDY AREA

2.1 Climate

The Project area is located on the western edge of the Hamersley Ranges, approximately 100 km south-west of Karratha and south-west of Pannawonica. Climate of the region is semi-arid, with relatively dry winters and hot summers. The nearest long-term Bureau of Meteorology (BOM) gauging station is Pannawonica (no. 005069; 1971 - 2016), where total annual rainfall ranges from 113 to 700 mm, and monthly rainfall from 0 to 444 mm. Most rainfall occurs during the summer months (November to March) and is predominantly associated with cyclonic events; when flooding frequently occurs along creeks and rivers. Due to the nature of cyclonic events and thunderstorms, total annual rainfall in the region is highly unpredictable and individual storms can contribute several hundred millimetres of rain at one time.

Prior to sampling in April/May 2016, slightly above-average monthly rainfall was recorded in the latter part of 2015 (October & November) (Figure 2). However, total monthly rainfall was well below the 45-year average in the mid to late wet season of 2016, particularly during February, March and April (Figure 2). As such, there was no surface flow connecting pools along the Robe River at the time of sampling between 1st and 8th May. However, toward the end of the sampling period, a major storm event on the 5th - 6th May caused widespread flooding across the Robe River catchment, resulting in above average total rainfall for May (Figure 2). Pannawonica also recorded above average rainfall in June and July (Figure 2).

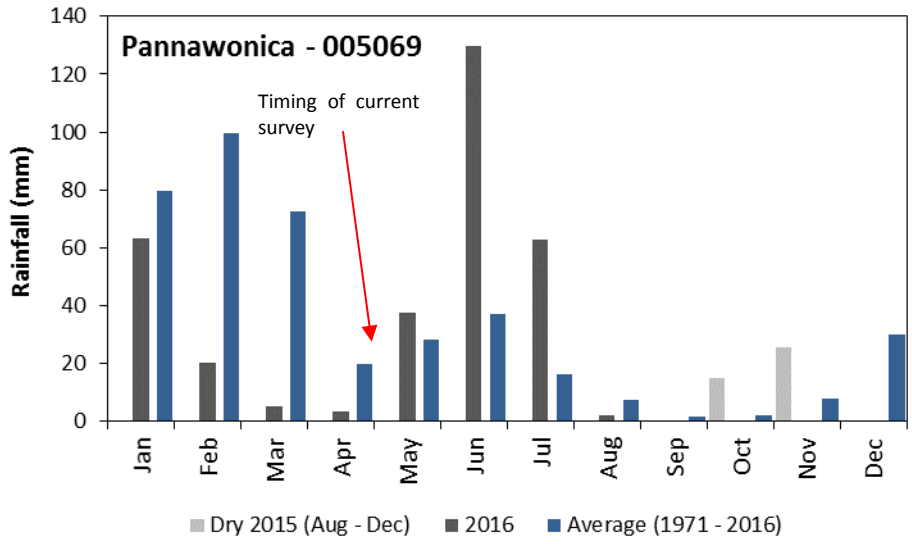


Figure 2. Average monthly rainfall (1971 – 2016) and total monthly rainfall (2016) for Bureau of Meteorology (BOM) Pannawonica Gauging Station (005069).

2.2 Hydrogeology

The Project area lies within the Robe River catchment, a significant river system in the region, with a catchment area of 7,571 km^2 and numerous braided tributaries (DoW 2012). The Robe River channel covers a linear distance of 190 km, 63% of which lies upstream of the Project area (EPA 1991). The immediate valley is 300 - 500 m wide. Jimmawurrada Creek is the only major tributary in the vicinity of the Project area, flowing northward along the eastern flank of Mesa J.

Jimmawurrada Creek joins the Robe River upstream of Mesa J (Figure 1). The Jimmawurrada Creek sub-catchment has an area of approximately 400 km^2 and constitutes the lower section of Bungaroo Creek

catchment, with a combined area of around 1,261 km^2 (DoW 2012). Both the Jimmawurrada and Bungaroo Creek catchments are included in the Bungaroo Creek Water Reserve that protects the water resources in these catchments and underlying aquifer that supply the West Pilbara Water Supply Scheme (WPWSS) (RDA 2013). The WPWSS delivers public drinking water to the towns of Karratha, Dampier, Roebourne, Cape Lambert and Point Samson (DoW 2012).

Surface flow in the Robe and tributary rivers is naturally ephemeral, typically only occurring in response to significant rainfall events and continuing for one to two months. There is one DoW streamflow gauging station on Robe River; Yarraloola (no. 707 002; 1972 - 2016), at the North West Coastal Highway crossing, 36 km west of the Project area. The maximum total monthly river discharge for the period of record at Yarraloola is 773.9 GL (February 2009) and the maximum instantaneous discharge is 12,203 m^3/sec (February 2009). Low or no flow typically occurs from July to December, when the river is reduced to a series of isolated pools. The number and permanence of these pools is dependent on antecedent rainfall and groundwater levels (Antao & Braimbridge 2010). Since streamflow records began at Yarraloola in 1972, 14 zero-flow years have been recorded, including seven in the last two decades (2002, 2003, 2007, 2010, 2012, 2013 & 2014).

The major aquifer underlying the Robe River is the gravelly alluvium which has a saturated thickness of up to 15 m adjacent the main channel and extends laterally up to 5 km across the Robe River Valley (Antao & Braimbridge 2010). Groundwater flow through the gravels maintains permanent pools in the Robe River. The gravelly aquifer is underlain by fractured, permeable Trealla Limestone and highly transmissive Robe Pisolite. Robe Pisolite is an iron-enriched pisolitic alluvial sedimentary rock that fills the broad valley between ridges of the Brockman Iron Formation, originally as ancestral drainage channels (palaeochannels) of the Robe River (commonly known as a Channel Iron Deposits (CID), and forms the target ore deposit at Mesa H (and Mesa J).

Groundwater flow in the Pisolite is towards the Robe River and where the Pisolite is deepest, probably contributes to baseflow within the Robe River (Aquaterra 2005). The gravel and Pisolite aquifers are recharged primarily *via* river discharge. Modelling by DoW indicates the aquifers have the potential to absorb a significant percentage of river flow; however, due to the unpredictable flow regime, recharge is very low in two out of every five years (Antao & Braimbridge 2010). Near the Jimmawurrada-Robe confluence, the Pisolite is very shallow and unsaturated. Stream-aquifer interaction upstream in the Bungaroo and Jimmawurrada valleys contributes to recharge along with direct rainfall infiltration.

2.3 Water Quality

2.3.1 Surface water

Water quality monitoring has been conducted quarterly at five pools in the Robe River and at the existing dewatering discharge point on Jimmawurrada Creek. The Robe River pools are located upstream (Medawandy Waters), adjacent to (Yarramudda) and downstream (Japanese, Martangkuna, Gnieraoora) of the existing mine operation (refer Figure 1 & Section 3). Pools have been monitored for pH, conductivity (EC), total dissolved solids (TDS), nitrogen and phosphorus, turbidity, total suspended solids (TSS) and biological and chemical oxygen demand. Dewatering discharge has been monitored for pH, TDS, TSS and concentration of dissolved metals (Al, As, Cd, Cr, Cu, Fe, Mn, Ni, Pb, Zn). Unfortunately, the limit of reporting for most metals was not sufficiently low to allow comparison against ANZECC/ARMCANZ (2000) default trigger values (TVs) for the protection of freshwater ecosystems. In general, dewatering discharge to Jimmawurrada Creek appeared to be of low salinity (< 800 mg/L TDS), low TSS (< 5 NTU) and with a pH range of 6.2 - 8.5. The water is a predominantly sodium bicarbonate and calcium bicarbonate type, indicative of recharge water (Aquaterra 2004).

Available long-term quarterly monitoring data for the Robe River pools (1992 - 2004) indicates surface waters to be fresh (453 - 1,400 µS/cm EC; 300 - 904 mg/L TDS), with pH values typically in the range 7.0 - 9.0, and relatively low turbidity (< 10 NTU) under baseflow conditions. Maximum salinity levels recorded during quarterly monitoring were in 2003 following two years of low rainfall. Salinity generally tends to be lower in upstream pools than in pools adjacent to, and downstream of Mesa J. Background levels of total nitrogen (N-total) and nitrate-nitrogen ($N\text{-}NO_3$) often exceed default ANZECC/ARMCANZ (2000) TVs for protection against eutrophication (0.15 mg/L N-total; 0.03 mg/L $N\text{-}NO_X$), with levels of up 3.45 mg/L N-total and 3.1 mg/L $N\text{-}NO_3$ recorded at Medawandy waters, upstream of Mesa J. In general $N\text{-}NO_3$ appears to constitute most of the N-total present in surface waters in the pools. There are no data on dissolved metal concentrations in the pools.

Long-term annual monitoring of Robe River pools by Streamtec/UWA indicated similar physicochemical water quality characteristics to those identified from quarterly monitoring by the Proponent; fresh (EC < 1,200 µS/cm), slightly acidic to alkaline (pH 6.6 - 8.3) waters with relatively low turbidity during the dry season (< 8 NTU), becoming markedly more turbid following wet season flood events (often exceeding 70 NTU) (Dobbs & Davies 2009, Streamtec 2014). There was significant spatial and temporal variation in dissolved oxygen (DO) levels (< 2 mg/L to > 12 mg/L), depending on time of day sampled and permanency of pools. N-total and total phosphorus (P-total) often exceeded ANZECC/ARMCANZ (2000) default TVs (Dobbs & Davies 2009, Streamtec 2014).

2.3.1 Groundwater

At the time of reporting, groundwater quality sampling in the Project area had been conducted on three occasions, in December 2015 and twice during 2016. A comprehensive suite of parameters was sampled in 10 bores; MB15MEH001 to 4, 6 to 9, and 13 to 14. This sampling will be followed by more comprehensive groundwater assessment during 2016. The December 2015 sampling suggests groundwater quality in the majority of the bores to be similar to surface waters, *i.e.* fresh (489 - 1,110 µS/cm, 452 - 822 mg/L TDS), circum-neutral to slightly alkaline (pH 7.3 - 7.7) and with relatively high DO levels (7.2 - 9.1 mg/L). Two bores had brackish water; MB15MEH013 (3,040 µS/cm, 2,770 mg/L) and MB15MEH014 (1,920 µS/cm, 1,450 mg/L). Groundwaters in most bores (except MB15MEH001) were enriched in $N\text{-}NO_3$ relative to ANZECC/ARMCANZ (2000) default TVs for surface waters for protection against eutrophication. Maximum concentration was 23.9 mg/L $N\text{-}NO_3$ in MB15MEH014. Default TVs have yet to be developed for groundwaters. In their absence, ANZECC/ARMACANZ (2000) recommend that default TVs for surface waters be applied with caution, acknowledging that they may not be representative of natural background concentrations in groundwater.

In three bores, dissolved concentrations of chromium (Cr), manganese (Mn) and/or zinc (Zn) were also in exceedance of ANZECC/ARMCANZ (2000) default 95% species protection level TVs[2] for surface waters. This included MB15MEH001 (Mn, Zn), MB15MEH004 (Zn), MB15MEH013 (Cr, Zn) and MB15MEH004 (Cr).

2.4 Cultural and Ecological Values

The Project area is located within the Hamersley sub-region of the Pilbara Biogeographic Region as categorised under the national Interim Biogeographic Regionalisation for Australia (IBRA). Existing tenure in the area is a mixture of unallocated and leased Crown land. The Mesa H development would be implemented under Mining Lease ML248SA, which covers the Project area and other deposits

[2] Note, default TV for Ni should be modified for water hardness (as $CaCO_3$) at the time of sampling using algorithms provided in Table 3.4.3 of ANZECC/ARMCANZ (2000).

throughout the Robe River valley. In addition to ML248SA, the Project area lies substantially within Yarraloola Station pastoral lease (PL 3114-1127). The lease is held by Robe River Iron Associates joint venture through the Yarraloola Pastoral Company, and managed by Rio Tinto. The Station was established in 1916 as a sheep station, but currently runs cattle.

Numerous Aboriginal sites of significance have been identified within the Robe River valley. The Native Title Claim of the Kuruma Marthudunera Native Title Claimant Group covers 15,717 km^2 south of Karratha, incorporating the Project area and Yarraloola Station (YMAC 2011). The entire Robe River, also known as Jajiwarra, is of significant cultural value to the Kuruma and Marthudunera people, in particular permanent pools such as Yarramudda and Weedai immediately upstream of the Project area, Dthulurat (Gnieraoora) at Yeera Bluff, Joordi (or Jongardi) 14 km downstream of Yeera Bluff, and Chalyarn Pool on Mungarathoona Creek, a tributary of the Robe River.

As the Pilbara has an arid and variable climate with irregular episodic rainfall events, sources of water are of high ecological value. The permanent pools of the Robe River are an important component of the river ecosystem, supporting a diverse range of aquatic fauna and specialised flora such as yellow bladderwort (*Utricularia australis*) and water chestnut (*Eleocharis dulcis*). The pools act as refuges for fauna during periods of drought (EPA 1991). The riparian zone in the vicinity of the Project area also supports woodlands of silver cadjeput (*Melaleuca argentea*) and eucalypt (*Eucalyptus camaldulensis*, *E. victrix*). Lower tree and shrub layers in these woodlands are atypical of the Fortescue Botanical District, and as such, warrant conservation (EPA 1991). Cyclonic events and associated rainfall can severely affect the riparian vegetation, re-arrange braided channels and alter the size and position of permanent pools through scouring and aggradation (Dobbs & Davies 2009). In March 2004 for example, a rain depression in the wake of tropical cyclone Monty resulted in record rainfalls (376.6 mm) that caused widespread flooding throughout the Robe River valley and its surrounding catchments (Aquaterra 2004). High flows and flash flooding associated with cyclone Monty uprooted much of the Cadjeput woodland along the river channel in the vicinity of the Jimmawurrada-Robe confluence.

A number of potential short range endemic (SRE) aquatic invertebrates are known from the vicinity of the Project area and potentially occur within drawdown and dewatering impact zones. These species include stygal amphipods, isopods and syncarids, which are also known to occur in the hyporheic zones of the Robe River and/or tributary rivers. Further discussion of these species is provided in Section 3.

3 REVIEW OF PREVIOUS AQUATIC FAUNA AND STYGOFAUNA SURVEYS

The most comprehensive surveys of aquatic fauna within the Project area are those of Streamtec/UWA, who have conducted annual sampling of Robe River pools since 1992 (Dobbs & Davies 2009, Streamtec 1996 - 2014). Other recent studies include the Parks and Wildlife Pilbara Biological Survey (PBS); a region-wide survey of aquatic invertebrates conducted between 2003 and 2006, as part of a broader biodiversity survey (see Pinder *et al.* 2010). The PBS featured a number of ephemeral, long-term and permanent waterbodies within the vicinity of the Project area, including Mungarathoona Creek to the west, Myannore Creek and Yarraloola Station Claypan to the north-west, Nyeetbury Spring on upper Bungaroo Creek to the south-east, Kumina Creek in the upper Robe, and two pools on the Cane River to the south-west (Pinder *et al*. 2010). Morgan and Gill (2004) studied the distribution of fishes in inland waters of Pilbara, sampling 171 sites across 21 river systems between 2000 and 2002. Nearby sites included two pools on the Robe River close to the Project area; two on the lower Robe west of Mesa A/Warramboo, two on the lower Fortescue River to the north-west, and one on the Cane River. WRM previously sampled aquatic invertebrates and fish at Nyeetbury Spring (2009 - 2015) and Yalleen Pool (2010 - 2011) on Bungaroo Creek under the Proponent's Regional Aquatic Fauna Program (see WRM 2016). In 2008 and 2009, baseline surveys for the Australian Premium Iron (API) West Pilbara Iron Ore Project (WPIOP) were conducted, including sites on Mungarathoona Creek, Red Hill Creek and the Cane River (WRM 2009).

Additionally, stygofauna[3] have been sampled by Biota Environmental Sciences in the Mesa A/Warramboo Yarraloola Borefield to the west (Biota 2006a), and within the Ken's Bore and Cardo Bore areas along Red Hill Creek to the south-west (Biota 2010). Bennelongia Environmental Consultants surveyed stygofauna within the Bungaroo Creek catchment in the Buckland Hills area (Bennelongia 2013). Stygofauna were also surveyed by Parks and Wildlife as part of the PBS, including 36 bores within the Robe River catchment, sampled between 2002 and 2005 (see Eberhard *et al*. 2009, Halse *et al.* 2014).

A review of previous aquatic fauna surveys conducted within 100 km of the Project area, including sites sampled, methods used, and notable fauna found, is presented in the following sub-sections. A summary of the studies is provided in Table 1 and the sampling locations are shown in Figure 3. Studies referenced in this review were either conducted by WRM for the Proponent, or were publicly available, or records sourced from the Parks and Wildlife database NatureMap (http://naturemap.dpaw.wa.gov.au). In addition, direct requests were therefore made to Parks and Wildlife in order to obtain additional information on distribution of threatened, priority and vulnerable aquatic fauna.

For each species, conservation significance was assessed by reference to the IUCN Red List of Threatened Species, Parks and Wildlife Threatened and Priority Fauna Lists, as well as The Australian Faunal Directory, The Australian National Insect Collection Database and WRM's in-house database for distribution and occurrence information. Collectively, the previous studies have identified a number of species of conservation significance and/or scientific interest, which have the potential to reside, either seasonally or permanently, within the Project area and its expected drawdown zone and/or dewatering discharge footprint (acknowledging hydrological modelling for drawdown and dewatering discharge was not completed at the time of the survey or reporting).

A summary of aquatic species (including hyporheic species) of conservation and/or scientific value known to occur, or likely to occur within the Project area, is provided in Table 2, at the end of Section 3.

[3] Obligate inhabitants of groundwater environments, *e.g.* aquifers, caves and hyporheic (interstitial) spaces. Morphological adaptations to such environments include reduced body size, lack of pigmentation, reduced or absent eyes, and elongated appendages (*e.g.* antennae).

Table 1. Summary of previous recent aquatic fauna studies (invertebrates and fish) conducted within a 100 km radius of the Mesa H Project area, together with methodologies. Studies are listed in chronological order. Stygofauna assessments appropriate to the Project area are also included. Codes for 'Fauna sampled': Macro = macroinvertebrate; Micro = microinvertebrate; Hypo = hyporheos; Stygo = stygofauna).

Program	Sampled by	Locations sampled	Fauna sampled	Methods used	Taxonomic level	Sampling dates	Reference
Aquatic Fauna (Surface Water and Hyporheos)							
Proponent Mesa J Project Aquatic Ecosystem Study (long-term)	Streamtec / UWA	Robe River pools: • Gnieraoora, Martangkuna, Pulari-Nyunangka, Japanese pool, Yarramudda, Medawandy Waters, Pannawonica Hill pool, Chundy Pool, Ngalooin, Mussel Pool.	Macro Fish	• Macro – kick sampling (250 µm net) all habitats, • Fish – seine net and visual observation (mask and snorkel).	Species	Annually between Nov - Mar, 1991 - 2013.	Streamtec (1996, 1998, 2002, 2007-2009, 2011, 2014); Dobbs and Davies (2009)
Fish Fauna of Pilbara inland waters	Murdoch Uni	• Robe River near Mesa H and J, • Lower Robe River, west of Mesa A/Warramboo, • Lower Fortescue River (40 km NE), • Cane River (75 km SW).	Fish	• Fish – seine nets, gill nets, cast nets, rod and line, and visual observation (mask and snorkel).	Species	Once between Dec 2000 - Nov 2002.	Morgan and Gill (2004)
Hyporheos of five Pilbara springs	Parks and Wildlife	• Nyeetbury Spring on Bungaroo Creek, Robe River catchment (33 km SE).	Hypo	• Stirring up sediments and sweeping with a 250 µm mesh dip net, • Digging up sediments to a depth of 30 cm and collecting fauna caught with 50 µm and 250 µm mesh nets (Karaman-Chappuis method).	Species	Sep 2001.	Halse *et al*. (2002)
Pilbara Biological Study (PBS)	Parks and Wildlife	• Chalyarn Pool, Mungarathoona Creek, Robe River catchment (20 km W), • Red Hill Creek Pool, Robe River catchment (30 km SW), • Nyeetbury Spring on Bungaroo Creek (33 km SE), • Duck Creek Pool on Duck Creek, Ashburton River catchment (46 km SE), • Myannore Creek (49 km NNW), • Yarraloola Station Claypan (65 km NNW), • 2 sites on Cane River; House Pool and Creek Pool (70-75 km SW), • Kumina Creek (74 km SW).	Macro Micro	• Macro - kick sampling (250 µm net) all habitats, • Micro – sweep netting (50 µm mesh).	Species	Aug/Sep 2003, Aug/Sep 2004, May 2005, May 2006.	Pinder *et al*. (2010)

Program	Sampled by	Locations sampled	Fauna sampled	Methods used	Taxonomic level	Sampling dates	Reference
Aquatic Fauna (Surface Water and Hyporheos)							
API WPIOP Baseline Aquatic Fauna Survey	WRM	• 2 sites on Mungarathoona Creek (20 km W), • 6 sites on Red Hill Creek, (40 km SW).	Macro Micro Hypo Fish	• Macro – kick sampling (250 µm net) all habitats, • Micro – sweep netting (53 µm net) water column, • Hypo – Karaman-Chappuis method (53 µm net), • Fish – seine nets and gill nets.	Species	Dec 2008, Apr 2009.	WRM (2009)
Proponent Regional Aquatic Program (long-term)	WRM	• Yalleen Pool on Bungaroo Creek (23 km SE), • Nyeetbury Spring on Bungaroo Creek (33 km SE).	Macro Micro Hypo Fish	• Macro – kick sampling (250 µm net) all habitats, • Micro – sweep netting (53 µm net) water column, • Hypo – Karaman-Chappuis method (53 µm net), • Fish – seine nets and gill nets.	Species	Ongoing, wet and dry seasons since 2009.	WRM (2013, 2016)
Stygofauna							
Pilbara Biological Study (PBS)	Parks and Wildlife	• 36 bores across the Robe River catchment	Stygo	• Replicate hauls with weighted plankton nets (50 µm and 150 µm mesh).	Species	3 wet and 3 dry season occasions 2002 - 2005.	Eberhard *et al.* (2005, 2009); Halse *et al.* (2014)
Robe River Mining Co. Mesa A/Warramboo Baseline Stygofauna Assessment	Biota	• 21 bores within the Warramboo area, Robe River catchment (45 km W) • 20 bores within the Yarraloola area, Robe River catchment (40 km W)	Stygo	• Hauls with weighted plankton nets (150 µm mesh).	Species	Oct 2005.	Biota (2006a)
API WPIOP Baseline Stygofauna Assessment	Biota	• 58 bores within the WPIOP tenement areas, Red Hill Creek catchment (40 km SW)	Stygo	• Hauls with weighted plankton nets (70 µm mesh).	Species	Jun 2008, Sep 2009.	Biota (2010)
Iron Ore Holdings Bungaroo South Subterranean Fauna Assessment	Bennelongia	• 61 bores within Bungaroo South tenement, immediately south of the Project area.	Stygo	• Replicate hauls with weighted plankton nets (50 µm and 150 µm mesh).	Species	Jul 2012, Oct 2012.	Bennelongia (2013)

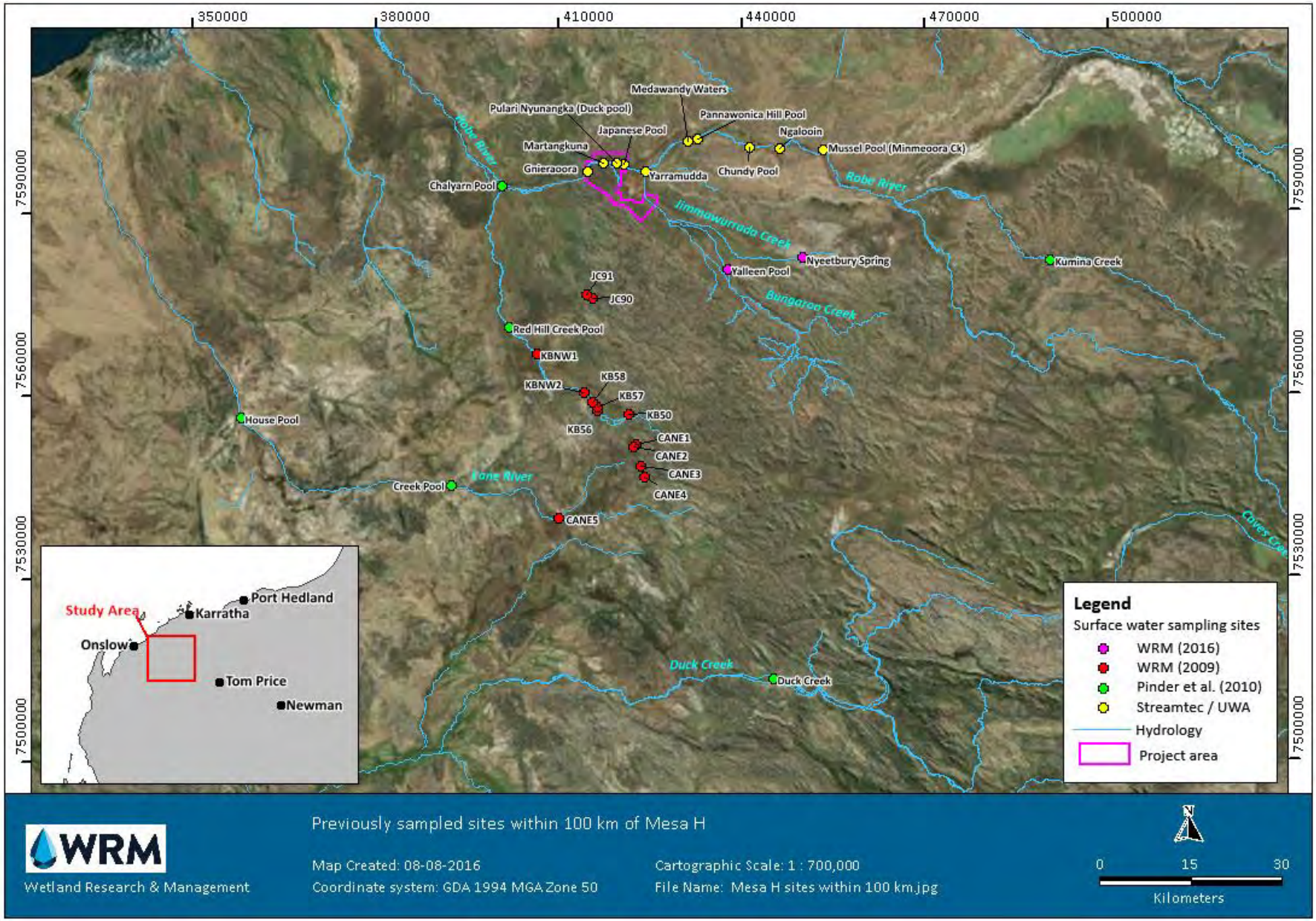


Figure 3. Locations previously sampled for aquatic invertebrates (Streamtec/UWA 1991 - 2014, WRM 2009 - 2016, Pinder *et al.* 2010) and fish (Streamtec 1991 – 2014) within 100 km of the Mesa H project area. Note, individual groundwater bores sampled for stygofauna (Biota 2006a, 2010, Eberhard 2009, Bennelongia 2013, Halse *et al.* 2014) are not detailed. Morgan and Gill (2004) did not provide GPS co-ordinates for their study of Robe River fish fauna.

3.1 Microinvertebrates (zooplankton)

The microinvertebrate fauna within the vicinity of the Project area is poorly known. Eight sites within 100 km of the Project area were sampled for microinvertebrates as part of the Parks and Wildlife PBS (Table 1). Pools sampled within the Robe River catchment included Chalyarn Pool (Mungarathoona Creek) and pools along Red Hill Creek, Myannore Creek, Kumina Creek, Nyeetbury Spring, Yalleen Pool and an ephemeral claypan on Yarraloola Station (Figure 3). Locations sampled outside the Robe River catchment included two pools on the Cane River to the south-west, and one on Duck Creek in the Ashburton River catchment (Figure 3). A combined total of 216 microinvertebrate taxa were recorded from these sites both within and outside of the Robe River catchment, sampled in August and September 2003/2004 (dry season) and May 2005/2006 (wet season). Wet season sampling appeared to favour microinvertebrate richness, with some of the most specious samples taken in May 2005 at House Pool on the Cane River (45 taxa), Red Hill Creek (42 taxa) and Chalyarn Pool (35 taxa).

WRM (2009) surveyed microinvertebrates in Mungarathoona Creek (two sites adjacent to the Jewel Cochrane development, to the south-east) and Red Hill Creek (six sites adjacent to Ken's Bore development) to the south east, as part of baseline aquatic surveys for API's WPIOP (Figure 3). A total 135 microinvertebrate taxa were recorded across two sampling events, conducted in December 2008 and April 2009 (WRM 2009).

WRM also conducts an ongoing aquatic fauna surveys under the Rio Tinto Pilbara Regional Program, which has previously included the microinvertebrate fauna of Yalleen Pool and Nyeetbury Spring on Bungaroo Creek (Figure 3). Biannual surveys collected a total 45 microinvertebrate taxa from Yalleen Pool, sampled between 2010 and 2011 (WRM 2013), and 160 taxa from Nyeetbury Spring, sampled between 2009 and 2016 (WRM 2016).

In each study, the microinvertebrate fauna was generally found to be typical of systems in the arid tropics (*e.g.* Koste and Shiel 1983, Tait *et al.* 1984, Smirnov and De Meester 1996, Segers *et al*. 2004). For example, in the nine featured PBS sites within the Robe River catchment (Table 1), species from the family Brachionidae (Rotifera) were poorly represented (14 taxa). This family tends to dominate temperate rotifer plankton, but is largely replaced by Lecanidae in tropic zones, as appears to be the case in the Pilbara (27 taxa; Pinder *et al.* 2010).

Microinvertebrate fauna of note (*i.e*. of conservation or scientific value) recorded from these studies included the stygal ostracod *Vestalenula matildae*, the rotifers *Colurella oblonga* and *Lecane noobijupi* and the cyclopoid copepod *Paracyclops* sp. 6. All these species have been recorded from within the Robe River catchment.

Vestalenula matildae was recorded at Mungarathoona Creek (Chalyarn Pool) during the PBS (Pinder *et al*. 2010). *V. matildae* is a recently described stygal species of ostracod known from groundwater (bores and wells) in the Ashburton River catchment (Government Well, Divide Well), DeGrey River catchment (Kylena Well, Home Well), and Sherlock River (Muorena Well). It has been recorded from hyporheic zones in the Ashburton (Yindabiddy Pool) and Fortescue River catchments (Weeli Wolli Spring), as well as surface waters in the Ashburton (Horrigans Pool), Fortescue (Gregory Gorge) and DeGrey (Coppin Gap, Chinaman Spring, Running Waters) (Martens and Rosetti 2002, Halse *et al*. 2002, Pinder *et al.* 2010, Schön *et al*. 2010). It appears to be endemic to the Pilbara, with no record to date of occurrence outside the region.

Colurella oblonga was collected at Nyeetbury Spring by WRM in 2012. This constituted the first record of *Colurella oblonga* from the Australian continent. This species is previously known from the southwest islands of Japan and from Europe (Dr Russel Shiel, University of Adelaide, pers. comm.).

Lecane noobijupi was collected from Nyeetbury Spring by WRM in 2011 and 2012, and from Red Hill Creek in 2009. This species is endemic to Western Australia, and appears to have a highly disjunct distribution. It was described from specimens collected from a wetland in the Muir-Unicup catchment in the south-west of the state (Lake Noobijup), and it had been thought to be restricted to that catchment (Segers and Shiel 2003). WRM has since recorded *Lecane noobijupi* from a number of locations throughout the Pilbara region, including Weeli Wolli Creek, Marillana Creek, Coondiner Creek, Mindy Mindy Creek and Kalgan Creek and (WRM 2016). Pinder *et al*. (2010) also recorded it from the DeGrey River. It would now appear that the Pilbara may be the normal locality of this species, and the Muir location in the south-west was an isolated occurrence.

Closer to the Project area, *Paracyclops* sp. 6 was collected from Chalyarn Pool, as well as Nyeetbury Spring and Kumina Creek (Pinder *et al*. 2010). This species is endemic to the Pilbara and is known from only 20 locations across the region, including the Ashburton River (Bobswim Pool, Fork Spring, Whiskey Pool, Cheela Spring, Paperbark Spring, Innawally Pool), Fortescue River (Palm Pool, Gregory Gorge, Palm Spring near Millstream, Joffre Creek), DeGrey River (Pelican Pool, Glen Herring Pool, Chinaman Spring, Minigarra Creek pools, Skull Springs and Bonnie Pool), Harding River (Springs Creek, Harding River Pool) and Sherlock River (Erawallana Spring and Pool Spring) (Pinder et al. 2010, WRM unpub. data).

Of the above-mentioned species, *Lecane noobijupi, Vestalenula matildae* and *Paracyclops* sp. 6 potentially occur within the Project area and its immediate vicinity but have a widespread distribution across the Pilbara.

3.2 Hyporheos

The hyporheos was not sampled by Streamtec/UWA during their long-term study of Robe River pools upstream, nor during the PBS (Pinder *et al.* 2010, Halse *et al.* 2014). However, biannual surveys of the hyporheos of upper Bungaroo Creek by WRM recorded a total of 22 hyporheic taxa from Yalleen Pool (WRM 2013) and 103 from Nyeetbury Spring (WRM 2016). Halse *et al.* (2002) recorded 62 hyporheic taxa from Nyeetbury Spring during one-off sampling in 2001. WRM (2009) also sampled the hyporheos of upper-Mungarathoona Creek and Red Hill Creek in 2008/2009, recording a combined total of 45 taxa.

Fauna of note collected during these studies included stygal amphipods and isopods that are likely SREs. Amphipods from the family Paramelitidae were collected from Yalleen Pool (WRM 2013), one site on Mungarathoona Creek, and three sites on Red Hill Creek (WRM 2009). These specimens were not able to be identified further than family level due to immaturity of life stage; however, they were considered likely to be SREs, given that most stygal Paramelitidae species are restricted to a small number of river systems within close geographical proximity to one-another (Finston *et al.* 2011).

At least three large isopod species are known from the subsurface zone of the Robe River catchment; *Pygolabis* sp. (Tainisopidae), *Tainisopus* sp. (Tainisopidae) and *Pilbarophreatoicus platyarthricus* (Amphisopodidae). Keable and Wilson (2006) documented *Pygolabis* sp. as occurring in the Robe River catchment but did not disclose the specific locality. Bennelongia (2013) also recorded P*ygolabis* sp. from two groundwater bores in the Bungaroo South area. All species of *Pygolabis* appear to be restricted to groundwaters and/or hyporheic zones of one or several creek drainages of the Pilbara region (Fortescue, Ashburton or Robe River catchments) (Keable and Wilson 2003) and at least some appear to be restricted to single sub-basins (Finston *et al.* 2009). Another undescribed, but closely related species, *Tainisopus* sp., is known to occur in the hyporheos of Nyeetbury Spring (Halse *et al.* 2002), as is *Pilbarophreatoicus platyarthricus* (WRM 2016). *P. platyarthricus* was first identified by Knott and Halse (1999) from Robe River specimens (including Chalyarn Pool), which were exclusively collected during the wet season "under cobbles in slow-flowing riffles … maintained by groundwater discharge." This species was also collected in surface water samples at Chalyarn Pool during the PBS (Pinder *at al.* 2010).

Although not specifically targeting hyporheic fauna, there have been a number of surveys of stygal communities in the vicinity of the Project area. These communities have taxa frequently encountered in hyporheic zones including SRE amphipods and isopods. These species may potentially occur in hyporheic zones within dewatering and drawdown zones in the Project area and the immediate vicinity.

The PBS sampled a total of 507 wells and drill holes across the Pilbara between 2002 and 2005, including 36 within the Robe River catchment area (Eberhard *et al.* 2005, 2009, Halse *et al.* 2014). A total of 110 stygal invertebrate taxa were recorded from bores in the Robe River catchment, including taxa belonging to the groups Oligochaeta (segmented worms), Polychaeta (bristle worms), Nematoda (round worms), Turbellaria (flat worms), Gastropoda (snails), Acarina (mites), Rotifera (wheel animals), Copepoda (copepods), Ostracoda (seed shrimps), Isopoda (aquatic slaters), Amphipoda (amphipods/side swimmers), Syncarida (syncarids) and Themosbaenacea (thermosbaenaceans). These taxa are also likey to occur within hyporheic zones of the Robe River. Out of the 110 taxa captured in the Robe River area, 83 were recorded from three or less bores (*i.e*. present at < 10% of bores), while just eight taxa were recorded from more than eight bores (*i.e.* present at > 20% of bores). It is possible that many of the uncommonly recorded stygofauna in this study are SREs.

Biota (2006a) sampled stygofauna from 21 bores within the Mesa A/Warramboo Project area and 20 bores in the Yarraloola area during 2005. In this study, a number of species which are occasionally encountered in hyporheic zones, such as stygal amphipods, copepods, and the themosbaenacean *Halosbaena tulki* were recorded, though it was noted that "there appears to be little in the way of a stygal community present at Warramboo". DNA sequencing delineated four new stygal amphipod species (Melitidae spp.), including two from the bores within the Mesa A/Warramboo Project area (Melitidae sp. A and sp. F), which currently are known only from the Mesa A/Warramboo Project area (Biota 2006a).

Biota (2010) sampled 58 bores in the Cardo East and Ken's Bore areas of the Red Hill Creek catchment. A number of potential SREs were recorded, including Paramelitidae (*Pilbarus* nr *millsi*, Paramelitidae sp. 2 and sp. 6), Melitidae (*Nedsia* spp., nr *Norcapensis* sp.), isopods (*Haptolana yarraloola*, *Kagalana tonde*, *Pygolabis* sp., *Pilbarophreatoicus platyarthricus*) and syncarids (*Bathynella* spp., Billibathynella sp. *Hexabathynella* sp. *Notobathynella sp.*).

Bennelongia (2013) sampled stygofauna in 61 bores within the Bungaroo South area in July and October 2012. Potential SREs recorded included Paramelitidae (Genus 2 sp. B12), Melitidae (*Nedsia* spp.), Neoniphargidae (nr *Wesniphargus*), the isopod *Pygolabis* sp. and syncarids (*Bathynella* spp., *Billibathynella* sp.).

3.3 Macroinvertebrates

Since 1991, Streamtec/UWA have conducted annual surveys for macroinvertebrates at seven long-term pools on the Robe River (Streamtec 1996 - 2014, Dobbs and Davies 2009). Pools include Medawandy Waters, Yarramudda, Japanese Pool, Martangkuna, Pannawonica Hill Pool, Pulari-Nyunangka, Gnieraoora (Figures 1 and 3). Four additional pools were included in the program during the 1990s; Chundy Pool, A1, Ngalooin and Mussel Pool (Figure 3). To date, over 112 macroinvertebrate taxa from 64 families have been recorded by Streamtec/UWA from 16 sampling occasions between February 1991 and December 2013. The most commonly encountered groups were the segmented Oligochaeta, Atyidae (freshwater prawns), Ephemeroptera (mayflies), Chironomidae (non-biting midges) and Dytiscidae (diving beetles). Streamtec/UWA noted that caddisflies (Trichoptera) were susceptible to changes in flow regime and water quality, with a decline in the number of species recorded following 1993, 2005, and 2012 cyclone events (Streamtec 2014).

The macroinvertebrate fauna of Chalyarn Pool (Mungarathoona Creek) was sampled during the PBS (Pinder *et al.* 2010). A total of 70 macroinvertebrate taxa were recorded at Chalyarn Pool in the wet season (May 2005), and 97 taxa were recorded in the dry season (August 2003). Other locations surveyed for macroinvertebrates in the vicinity of the Project area during the PBS included Red Hill Creek pools, Myannore Creek Pool and the Yarraloola Station claypan (Figure 3). A total of 196 macroinvertebrate taxa were recorded across these sites, sampled in August 2003/2004/2005 (dry season) and May 2003/2005/2006 (wet season). The most specious samples among these were collected at Red Hill Creek, with 90 taxa collected in both the wet and dry seasons (Pinder *et al.* 2010).

Macroinvertebrates from Mungarathoona Creek and Red Hill Creek were also sampled as part of baseline aquatic surveys for API's WPIOP area (WRM 2009). A total of 128 macroinvertebrate taxa were recorded across two sampling events; dry season (December) 2008 and wet season (April) 2009 (WRM 2009). The taxonomic list comprised Nematoda (roundworms), Hydrozoa (freshwater hydra), Oligochaeta (segmented worms), Gastropoda (snails and bivalves), Acarina (aquatic mites), Ephemeroptera (mayflies), Odonata (dragonflies and damselflies), Hemiptera (true bugs), Coleoptera (aquatic beetles), Diptera (aquatic fly larvae, including Chironomidae/midges), Trichoptera (caddisflies) and Lepidoptera (aquatic caterpillars).

The macroinvertebrate fauna of Yalleen Pool and Nyeetbury Spring on Bungaroo Creek have been sampled as part of the ongoing Pilbara Regional Aquatic Program for the Proponent (see WRM 2016). A total of 83 macroinvertebrate taxa were collected from Yalleen Pool from a total three sampling occasions; wet (March) and dry season (October) 2010 and wet season (March) 2011 (WRM 2013). A total of 190 macroinvertebrate taxa were recorded from Nyeetbury Spring from a total 13 occasions during biannual sampling (wet and dry seasons) between and October 2009 and May 2016 (WRM 2016).

The composition of macroinvertebrate taxa recorded during all of the above studies was typical of freshwater systems throughout the world (Hynes 1970), being dominated by Insecta (insects), within which Diptera (flies) and Coleoptera (beetles) were particularly well represented.

Of the macroinvertebrate fauna recorded from the Robe River catchment, two species are listed for conservation significance (IUCN Red List), and six are of scientific interest, being Pilbara endemics and/or relatively new to science. All potentially occur within the Project area. Three other Pilbara endemics have the potential to occur within the Project area (having been recorded within 100 km), and based on their known dispersal capabilities (*i.e.* with winged-adult forms with strong capacity for flight). These species are as follows:

- Conservation listed species recorded from the Robe River catchment:

  Eurysticta coolawanyah (Pilbara pin damselfly) (IUCN Near Threatened);
  Hemicordulia koomina (Pilbara emerald dragonfly) (IUCN Near Threatened);

- Pilbara endemic species recorded from the Robe River catchment:

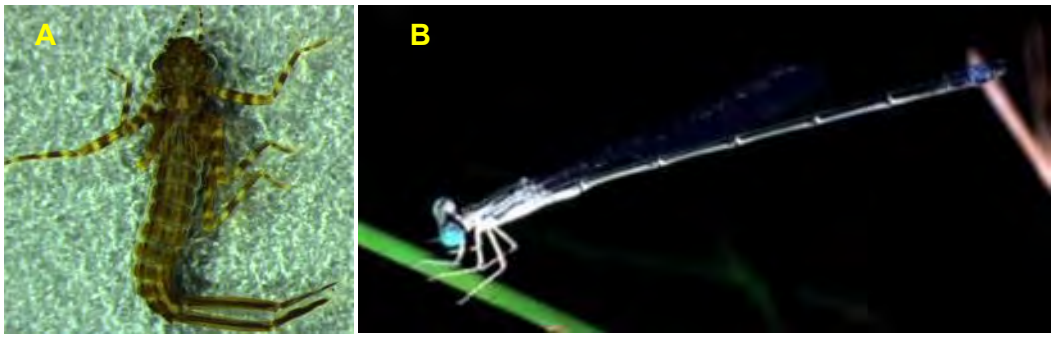
  Agriocnemis kunjina (Pilbara wisp damselfly);
  Ictinogomphus dobsoni (Pilbara tiger dragonfly);
  Nannophlebia injibandi (Pilbara archtail dragonfly);
  Tiporus tambreyi (diving beetle);
  Laccobius billi (water scavenger beetle);
  Haliplus halsei (crawling water beetle);

- Pilbara endemic species recorded from other locations within 100 km of the Project area:
  - *Sternopriscus pilbaraensis* (diving beetle);
  - *Tiporus lachlani* (diving beetle);
  - *Haliplus pilbaraensis* (crawling water beetle).

The Pilbara pin damselfly, *Eurysticta coolawanyah* (Plate 1A-B), is restricted to the Pilbara region, where it prefers riverine pools with an abundance of perching mediums (*e.g.* emergent reeds or overhanging riparian vegetation). *E. coolawanyah* has been collected from Robe River pools by Streamtec/UWA, and from Bungaroo Creek by WRM (2013, 2016). It has also been previously recorded at Chalyarn Pool (Pinder *et al.* 2010). *E. coolawanyah* is listed as Near Threatened[4] on the IUCN Red List of Threatened Species (IUCN 2016), based on its (initially recorded) restricted distribution to an area of less than 500 km^2, and it being thought to occur at less than five locations (Millstream Station, Nanuturra Pools, Palm Pool and the Millstream area); however, it has since been recorded from over 40 locations throughout the Pilbara (Pinder *et al*. 2010). Hawking (2009a) lists no known threats currently, or in the near future, to this species. WRM has encountered *E. coolawanyah* in habitats with a range in frequency of inundation and degree of persistence, including permanent/semi-permanent pools, permanent springs, ephemeral pools and sites permanently inundated and flowing due to dewatering discharge operations, for example at Weeli Wolli Spring.

The Pilbara emerald dragonfly, *Hemicordulia koomina* (Plate 1C-D), has been recorded by Streamtec/UWA from the Robe River, and from Red Hill Creek by Pinder *et al.* (2010). It is known to prefer large, permanent/semi-permanent pools. *H. koomina* is currently listed as Near Threatened on the IUCN Red List (IUCN 2016) but this listing is in need of revision given its more recent collections from numerous localities across several river catchments, including the Fortescue River (Hamersley Gorge, Fortescue Falls, Kalgan Creek), DeGrey River (Bamboo Springs, Minigarra Creek), Ashburton River system (Moreton Pool, Creek Pool near Mt Amy, Henry River pools, Pool at Gorge Junction), Sherlock River (Pool Spring) and Shaw River (Panorama Spring). Despite its widespread occurrence, *H. koomina* is infrequently collected, likely due to its preference for large, permanent pools, which are somewhat uncommon in the Pilbara region and inherently difficult to sample. The major threat to this species is considered to be loss of habitat (*i.e.* drying of permanent pools/waterways) through groundwater abstraction (Hawking 2009b).

Both of these species, particularly the large dragonfly *H. koomina*, are likely to have excellent dispersal capabilities in their winged-adult form (see Plate 1). Dispersal (the movement of individuals from one site to another) is an integral factor in determining the composition of biological communities (Palmer et *al*. 1996, Leibold *et al*. 2004). Aerial dispersal by winged-adult invertebrate fauna (*e.g.* Odonata, Coleoptera, Hemiptera, Ephemeroptera, Diptera and Trichoptera, *etc*.) has been recognised as the most important pathway for colonisation in arid and semi-arid wetlands (Gray and Fisher 1981). Heavy rainfall during the wet season also serves as a cue for many aquatic invertebrate taxa to migrate from perennial wetlands to colonise more ephemeral bodies of water (Lytle and Poff 2004). Given their proficient dispersal capabilities, and the record of these species at multiple locations within close proximity to the Project area, it is considered likely that macroinvertebrate sampling could reveal the presence of one or both of *E. coolawanyah* or *H. koomina* within the Project area.



[4] A species is listed under the IUCN Red List as Near Threatened when it has been evaluated against the criteria but does not qualify for Critically Endangered, Endangered or Vulnerable now, but is close to qualifying for or is likely to qualify for a threatened category in the near future (IUCN 2016).

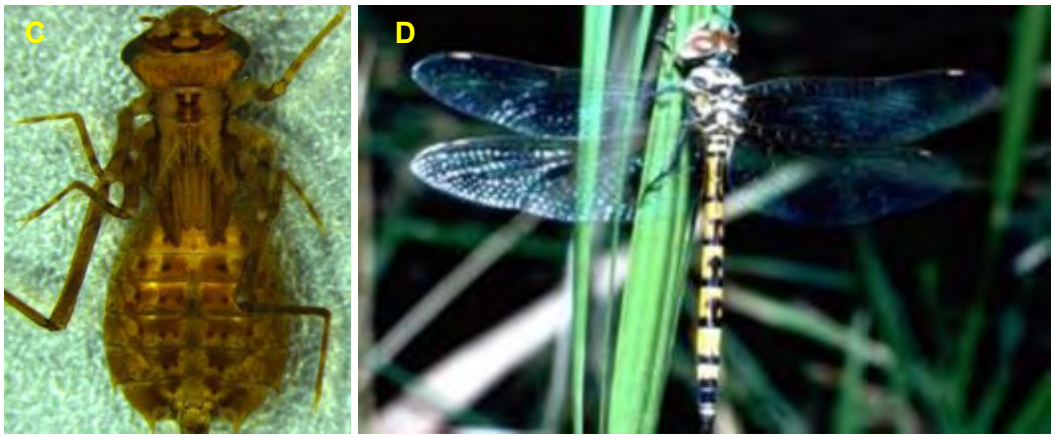


Plate 1. Pilbara pin damselfly, *Eurysticta coolawanyah* (A) nymph and (B) adult, and Pilbara emerald dragonfly *Hemicordulia koomina* (C) nymph and (D) adult (photos A and D courtesy of Jan Taylor ©).

The endemic Pilbara tiger dragonfly, *Ictinogomphus dobsoni*, is recorded infrequently and in low abundances from permanent still or sluggish waters of the Pilbara region (Watson 1991). It is known from a number of sites along the Fortescue, Robe, Ashburton, Yule, DeGrey and Sherlock rivers (DEC 2009, Pinder *et al*. 2010, CSIRO 2015). Near the Project area, *I. dobsoni* has been recorded from pools along the Robe River (Streamtec/UWA), Mungarathoona Creek (Chalyarn Pool) and Red Hill Creek (Pinder *et al*. 2010).

The Pilbara archtail dragonfly, *Nannophlebia injibandi*, is also restricted to the Pilbara region. This species was recorded infrequently during the PBS at Millstream Delta and Gregory Gorge in the Fortescue River catchment (Pinder *et al.* 2010). Within the vicinity of the Project area, *N. injibandi* has been recorded from Robe River pools near Mesa H (Streamtec/UWA) and from Red Hill Creek (WRM 2009).

The Pilbara wisp damselfly *Agriocnemis kunjina,* is a Pilbara endemic rarely encountered. It is previously known from Millstream, Harding River, and Tanberry Creek (ANIC Database); however, it was not recorded during the PBS (Pinder *et al.* 2010). *A. kunjina* is known from both still and flowing waters (Theischinger and Hawking 2006), and has been recorded from Robe River pools in the vicinity of the Project area (Streamtec/UWA) and from Yalleen Pool (WRM 2013).

The aquatic hydrophilid beetle *Laccobius billi* is a Pilbara endemic species that also is rarely collected. *L. billi* was only recorded from one site during the PBS; Cangan Pool on the Yule River (Pinder *et al.* 2010). WRM (2009) recorded *Laccobius billi* at Mungarathoona Creek and from a number of Red Hill Creek sites.

The haliplid beetles *Haliplus halsei* and *H. pilbaraensis* are both endemic to the Pilbara region, and are relatively new to science, having only been recently described (Watts and McRae 2010). Each species appears to occur widely throughout the Pilbara, and have been recorded at localities such as Glen Ross Creek, Coondiner Pool, the Fortescue Marsh, Moreton Pool, Paradise Pool, Munreemya Billabong, Wackilina Creek Pool, West Peawah Creek Pool, Harding River Pool, and an un-named creek in Millstream (Watts and McRae 2010). Closer to the Project area, *Haliplus halsei* has been recorded from Chalyarn Pool and Myannore Creek during the PBS (Pinder *et al*. 2010), while *Haliplus pilbaraensis* has been recorded from Red Hill Creek by WRM (2009).

The dytiscid beetle *Sternopriscus pilbaraensis* is endemic to the Pilbara, is relatively common and known from a range of systems, including Red Hill Creek, the Fortescue River (Gregory Gorge and Kalgan Pool), Ashburton River (Bobswim Pool, Yandabiddy Pool, Whiskey Pool, Ashburton at Gorge Junction, Innawally Pool and Rocky Island Pool), DeGrey River (Pool at Yarrie Homestead, Pelican pool on

Nullagine, Tanguin Rockhole, Paradise Pool, Munereemya Billabong, Carleecarleethong Pool, Minigarra Creek Pools, Bonnie Pool, Cookes Creek Pools, Running Waters and Pool on Tongolock), Rudall River (Watrara Creek Pool), Shaw River (Panorama Spring), Sherlock River (Kangan Pool) and the Harding River (Harding River Pool) (Pinder *et al.* 2010).

The diving beetles *Tiporus tambreyi* and *T. lachlani* are also relatively common and widespread across the region (Pinder *et al.* 2010, WRM unpub. data), though *T. lachlani* is less frequently encountered than its congener (Pinder *et al.* 2010, WRM unpub. data). In the vicinity of the Project area, *T. tambreyi* has been recorded from Robe River pools (Streamtec/UWA), Chalyarn Pool (Pinder *et al.* 2010) and Red Hill Creek (WRM 2009, Pinder *et al.* 2010), while *T. lachlani* has only been previously recorded from Red Hill Creek (Pinder *et al.* 2010).

3.4 Fish

The fish fauna of the Pilbara region is unique, with 13 freshwater species recorded from inland waters to date, including catadromous[5] species (Allen *et al.* 2002, Morgan and Gill 2004). Of the freshwater species, three (or possibly four) are considered endemic to the region. These include the golden gudgeon (*Hypseleotris aurea*), the Murchison River hardyhead (*Craterocephalus cuneiceps*), one undescribed eel-tailed catfish, the Pilbara tandan *Neosilurus* sp.[6], and the conservation listed Fortescue grunter (*Leiopotherapon aheneus*) (Morgan and Gill 2004). *L. aheneus* (Plate 2) is currently listed on the IUCN Red List of Threatened Species as Lower Risk/Near Threatened (IUCN 2016), and as a Priority 4 (P4)[7] species on the Parks and Wildlife Priority Fauna List (Parks and Wildlife 2016). The Fortescue grunter has a restricted distribution within the Pilbara, and is only known from the Fortescue, Robe and Ashburton River systems (Allen *et al*. 2002, Morgan and Gill 2004). This species is considered to be reasonably common within its range.

Plate 2. Fortescue grunter *Leiopotherapon aheneus.* Photo by Chris Hofmeester (WRM) ©.

Other known species from Pilbara inland waters include the spangled perch (*Leiopotherapon unicolor*), barred grunter (*Amniataba percoides*), western rainbowfish (*Melanotaenia australis*), bony bream (*Nematalosa erebi*), flathead goby (*Glossogobius giuris*), empire gudgeon (*Hypseleotris compressa*), Hyrtl's tandan (eel-tailed catfish; *Neosilurus hyrtlii*), blue catfish or lesser salmon catfish (*Arius graeffei*), and the Indian short-finned eel (*Anguilla bicolor*) (Allen *et al.* 2002, Morgan and Gill 2004, Beesley 2006). The most common and widespread species are spangled perch, western rainbowfish and bony bream (Plate 3). The western rainbowfish, for example, has a range extending from the Ashburton River in the Pilbara to the Adelaide River near Darwin, inhabiting rivers, creeks, swamps, lakes and reservoirs

[5] Catadromous fishes live in freshwater as juveniles or sub-adults, but migrate to marine habitats to spawn.

[6] Previously referred to as *Neosilurus hyrtlii*. Recent genetic evidence indicates the Pilbara species is distinct from elsewhere in Australia (Peter Unmack, National Evolutionary Synthesis Centre, North Carolina, pers. comm.).

[7] P4 species are those with limited distributions "in need of monitoring" (Parks and Wildlife 2016).

(Allen *et al.* 2002). Spangled perch and bony bream are considered to be two of Australia's most widespread freshwater fish species, found in drainages throughout the Pilbara, Kimberley, Northern Territory, Queensland, northern New South Wales, as well as in Lake Eyre and the Murray-Darling system (Allen *et al.* 2002).

In addition, the Pilbara Drainage Division contains two endemic cave fishes restricted to the North West Cape region; the blind gudgeon (*Milyeringa veritas*) and the blind cave eel (*Ophisternon candidum*) (Allen *et al.* 2002, Morgan and Gill 2004). Both *M. veritas* and *O. candidum* are listed as Vulnerable under the EPBC Act.

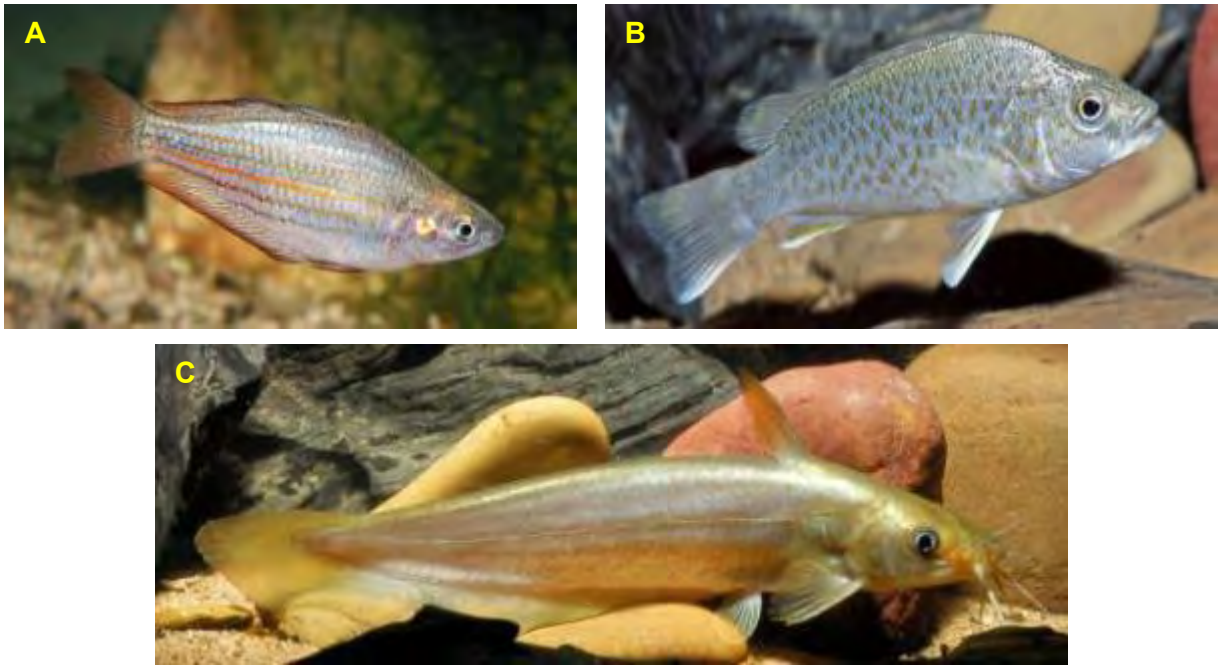


Plate 3. The three most commonly encountered freshwater fish species in the Pilbara; (A) western rainbowfish *Melanotaenia australis*, (B) spangled perch *Leiopotherapon unicolor* and (C) Pilbara tandan *Neosilurus* sp. (photos courtesy of Mark Allen ©).

Freshwater systems of the Pilbara also host a number of species that are considered to be of marine or estuarine origin, most of which have a non-obligatory freshwater juvenile phase. These commonly include barramundi (*Lates calcarifer*), mangrove jack (*Lutjanus argentimaculatus*), sea mullet (*Mugil cephalus*) and tarpon or ox-eye herring (*Megalops cyprinoides*) (Morgan and Gill 2004). The presence of marine/estuarine species in freshwater systems of the Pilbara is likely to be influenced by the frequency, timing and duration of flood events; the species listed above would only enter rivers if flooding coincided with their recruitment phase, while distance moved upstream is governed by the duration of the flood event (Morgan and Gill 2004). As floods recede, it is common for these species to become isolated in permanent upstream pools, forming small remnant populations that are cut-off from marine habitats (Morgan and Gill 2004).

Streamtec/UWA sampled the fish fauna of Robe River pools using seine nets, dip nets, and visual observation. Six freshwater fish species were recorded, including western rainbowfish, spangled perch, Pilbara tandan, barred grunter, bony bream and the conservation listed Fortescue grunter. Additionally, five marine vagrant/estuarine species were recorded, including tarpon, banded scat or striped butterfish (*Selenotoca multifasciata*), threadfin silver-biddy (*Gerres filamentosus*), sea mullet and mangrove jack.

Morgan and Gill (2004) surveyed four Robe River sites for fish using a combination of sampling methods (refer Table 1). Six freshwater species were again recorded (western rainbowfish, spangled perch, Pilbara tandan, barred grunter, bony bream and Fortescue grunter); however, no marine/estuarine

species were reported. Morgan and Gill (2004) also included historic records from the Western Australian Museum (WAM) that list empire gudgeon as occurring in the Robe River in the vicinity of the Project area.

The Department of Water (DoW) conducted a review of the ecological values of the lower Robe River, west of the North West Coastal Highway crossing point and Mesa A/Warramboo deposits, which included a summary of the freshwater and estuarine fish fauna of that reach (Antao and Braimbridge 2010). The review did not document any species from the lower Robe River that were not recorded by Streamtec/UWA or Morgan and Gill (2004).

WRM (2016) has recorded seven species from Nyeetbury Spring on upper Bungaroo Creek; Pilbara tandan, western rainbowfish, flathead goby, spangled perch, Fortescue grunter, barred grunter, and a fish that appears to be a hybrid between two of the three co-occurring terapontids (grunters; spangled perch, barred grunter and Fortescue grunter). At Yalleen Pool on Bungaroo Creek, WRM (2013) recorded only western rainbowfish, spangled perch and Pilbara tandan. WRM (2009) also surveyed the fish fauna of upper-Mungarathoona Creek, recording five species; western rainbowfish, spangled perch, Pilbara tandan, barred grunter and Fortescue grunter.

3.5 Other Fauna

3.5.1 Turtles

Although not typically targeted in aquatic surveys, one species of native turtle is known from the Pilbara region; the flat-shelled *Chelodina steindachneri.* This species has a widespread distribution throughout the Pilbara, having been recorded from most major river systems in the region, from the DeGrey River in the north to the Murchison River in the south (Kuchling 1988, WRM unpub. data). These turtles are adapted to survive drought by burrowing into the dry river beds (Kuchling 1988). Only one clutch of seven to eight relatively small eggs is laid each year; a pattern that appears to be adapted to a relatively long period of aestivation of up to three years (Kuchling 1988).

EPA (1991) note *Chelodina steindachneri* as present at Gnieraoora and Martangkuna, but do not state the source of the records, which was possibly the 1991 survey by Streamtec/UWA. Neither Antao and Braimbridge (2010) nor Pinder *et al.* (2010) document turtles. Similarly, turtles were not recorded or observed at upper-Mungarathoona Creek or Red Hill Creek by WRM (2009); however, given its widespread distribution across the Pilbara region, it is possible that *Chelodina steindachneri* may reside in pools in the vicinity of the Project area.

3.5.2 Frogs

The Pilbara is host to 13 species of frogs, three of which are endemic to the region; *Pseudophryne douglasi* (Gorge toadlet), *Uperoleia glandulosa* (Glandular toadlet) and *U. saxatilis* (Pilbara toadlet) (Tyler and Doughty 2009, Doughty *et al*. 2011). None of these species are currently listed for conservation significance, though *U. saxatilis* has only recently been described (Catullo *et al.* 2011). *U. saxatilis* is broadly distributed throughout the Pilbara, occurring in or near rocky creeks, and appears to be adapted to rocky landscapes (Catullo *et al.* 2011, Doughty *et al*. 2011). *U. glandulosa* has a more restricted distribution in the northern coastal Pilbara but penetrates inland along the Yule River drainage (Catullo *et al.* 2011, Doughty *et al*. 2011). *Pseudophryne douglasi* is a rare species that has an ancient relictual arid distribution separate from other toadlets (Doughty *et al*. 2011, WA Museum).

The Pilbara, Gascoyne and Murchison populations of the desert tree frog, *Litoria rubella*, are separated from Kimberley and Northern Territory populations by the Great Sandy Desert. *L. rubella* is known to

occur in a wide range of habitats across northern Australia, including northern Western Australia, Northern Territory, north-east of South Australia, Queensland, and northern New South Wales (Tyler and Knight 2011). The desert tree frog is commonly found sheltering under stones or bark around creeks and waterholes, and can breed at any time of year if water is present (Tyler and Knight 2011).

Frogs are difficult to survey in the Pilbara region, as captures are typically dependent on rainfall that is spatially and temporally variable (Doughty *et al*. 2011). Many frog species of the Pilbara aestivate over dry periods to avoid desiccation, emerging following rains to opportunistically breed and spawn (Tyler and Doughty 2009). No data were available on targeted frog surveys in the vicinity of the Project area, and although there have been a number of terrestrial vertebrate surveys (*e.g.* Biota 2005, 2006b, 2009, Strategen 2006), few have recorded frogs. Biota (2006a) recorded two species of Hylidae (tree frogs): *L. rubella* and *Cyclorana maini* - and one Myobatrachidae (southern frog) species *Uperoleia russelli* during baseline surveys for the Mesa A/Warramboo project area. In addition to *L. rubella* and *U. russelli*, Biota (2009) recorded the ornate burrowing frog *Platyplectrum ornatus* (formerly *Limnodynastes ornatus)* from the Red Hill Creek catchment.

3.6 Summary of Known Species of Conservation and/or Scientific Interest

Table 2 below provides a summary of known aquatic invertebrates (including hyporheos) and fish of conservation and/or scientific interest.

Table 2. Aquatic species (invertebrates and fish) of conservation and/or scientific value known to occur, or likely to occur, within the Project area.

Species	Common name	Scientific value	Conservation listing	Occurrence within 100 km of Project area	Likelihood of occurrence within the Project area	Occurrence elsewhere
Microinvertebrates						
Lecane noobjupi	Rotifer	WA endemic	N/A	Nyeetbury Spring, Red Hill Creek	High in surface waters	Weeli Wolli Ck, Marillana Ck, Coondiner Ck, Mindy Mindy Ck, Kalgan Ck and Un-named Ck, DeGrey R. Also in SW Western Australia
Paracyclops sp. 6	Copepod (micro-crustacean)	Pilbara endemic	N/A	Chalyarn Pool	High in surface waters	20+ locations Pilbara-wide
Vestalenula matildae	Ostracod (micro-crustacean)	Pilbara endemic	N/A	Chalyarn Pool	High in surface waters	Various systems of the Ashburton R., DeGrey R., Fortescue R. and Sherlock R.
Hyporheos						
Paramelitidae spp.	Stygal amphipods	Potential SRE	N/A	Yalleen Pool, Red Hill Ck, Mungarathoona Ck.	High in ground-waters and hyporheos	Unknown given family level identification.
Melitidae spp.	Stygal amphipods	Potential SRE	N/A	Bores across the Robe River catchment area	High in ground-waters; Low-moderate in hyporheos	Unknown given family level identification
Haptolana yarraloola	Stygal isopod	Potential SRE	N/A	Bores in the lower Robe River catchment area – Mesa A/Warramboo/Yarraloola	Low	Recently described species; known only from Mesa A/ Warramboo/Yarraloola bores
Kagalana tonde	Stygal isopod	Potential SRE	N/A	Bores in the lower Robe River catchment area – MesaA/Warramboo/Yarraloola	Low	Recently described genus and species; elsewhere known from Cane River and Hardey River catchments
Pilbarophreatoicus platyarthricus	Stygal isopod	Potential SRE	N/A	Chalyarn Pool, Nyeetbury Spring, Bores in the Robe River catchment area	High in ground-water and hyporheos	Weeli Wolli Ck, Coondiner Ck, Bobswim Pool (Ashburton R.)
Pygolabis sp.	Stygal isopod	Potential SRE	N/A	One undescribed species known from the Robe River catchment	High in ground-water and hyporheos	Uncertain. Members of this genus restricted to either Fortescue, Ashburton or Robe catchment groundwater and hyporheos
Tainisopus sp.	Stygal isopod	Potential SRE	N/A	Nyeetbury Spring	Low-moderate; only known from Nyeetbury Spring hyporheos	Unknown given genus level identification

Species	Common name	Scientific value	Conservation listing	Occurrence within 100 km of Project area	Likelihood of occurrence within the Project area	Occurrence elsewhere
Parabathynellidae spp.	Stygal syncarids	Potential SRE	N/A	Unknown given genus level identification	High in ground-waters; Low-moderate in hyporheos	Unknown given genus level identification
Macroinvertebrates						
Hemicordulia koomina	Pilbara emerald dragonfly	Pilbara endemic	IUCN, Near Threatened	Robe River pools, Red Hill Ck.	High in surface waters	Fortescue R., Coondiner Ck; now known to be widespread throughout the Pilbara, though infrequently collected
Eurysticta coolawanyah	Pilbara pin damselfly	Pilbara endemic	IUCN, Near Threatened	Chalyarn Pool, Robe River pools, Yalleen Pool	High in surface waters	Ashburton R. (Bobswim Pool); Kalgan Ck; Coondiner Ck; Fortescue R.
Ictinogomphus dobsoni	Pilbara tiger dragonfly	Pilbara endemic	N/A	Chalyarn Pool, Robe River pools, Red Hill Ck.	High in surface waters	Fortescue, Ashburton, Yule, DeGrey and Sherlock rivers
Nannophlebia injibandi	Pilbara archtail dragonfly	Pilbara endemic	N/A	Robe River pools, Red Hill Ck.	Low-Moderate in surface waters	Fortescue R. catchment, but uncommonly collected
Agriocnemis kunjina	Pilbara wisp damselfly	Pilbara endemic	N/A	Robe River Pools, Yalleen Pool	Low-Moderate in surface waters	Millstream, Harding River, Tanberry Ck; rarely collected
Haliplus halsei	Aquatic beetle	Pilbara endemic	N/A	Chalyarn Pool, Myannore Ck.	Low-Moderate in surface waters	Uncommonly collected from ephemeral systems and claypans, *e.g.* the Fortescue Marsh and Coondiner Pool
Haliplus pilbaraensis	Aquatic beetle	Pilbara endemic	N/A	Red Hill Ck.	Low-Moderate in surface waters	Uncommonly collected from ephemeral systems and claypans, *e.g.* the Fortescue Marsh and Coondiner Pool
Sternopriscus pilbaraensis	Diving beetle	Pilbara endemic	N/A	Red Hill Ck.	Moderate in surface waters	A range of systems across the Pilbara, fairly commonly collected
Tiporus tambreyi	Diving beetle	Pilbara endemic	N/A	Chalyarn Pool, Robe River pools, Red Hill Ck.	Moderate-High in surface waters	A range of systems across the Pilbara, very commonly collected
Tiporus lachlani	Diving beetle	Pilbara endemic	N/A	Red Hill Ck.	Low-Moderate in surface waters	A range of systems across the Pilbara, infrequently collected
Laccobius billi	Aquatic beetle	Pilbara endemic	N/A	Mungarathoona Ck, Red Hill Ck.	Low-Moderate in surface waters	Yule R. and Fortescue R.

Species	Common name	Scientific value	Conservation listing	Occurrence within 100 km of Project area	Likelihood of occurrence within the Project area	Occurrence elsewhere
Fish						
Leiopotherapon aheneus	Fortescue grunter	Pilbara endemic	IUCN Near Threatened; Parks and Wildlife P4	Robe River pools, Red Hill Ck., Mungarathoona Ck.	High in surface waters	Fortescue R (below Fortescue Marsh); Ashburton R.

4 METHODS FOR BASELINE SURVEYS

4.1 General

For the current baseline field sampling, WRM employed sampling design, methods and general approaches consistent with the following:

- Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ 2000);
- Environment Protection Authority (EPA) Guidance No. 20, Sampling of Short Range Endemic Invertebrate Fauna for Environmental Impact Assessment in Western Australia (EPA 2009);
- EPA Position Statement No. 3, Terrestrial Biological Surveys as an Element of Biodiversity Protection (EPA 2002);
- EPA Guidance No. 56, Terrestrial Fauna Surveys for Environmental Impact Assessment in Western Australia (EPA 2004).

Aquatic fauna sampling methods were also similar to the following:

- Streamtec/UWA surveys of benthic macroinvertebrates of the Robe River (see Dobbs and Davies 2009, Streamtec 2014);
- Parks and Wildlife surveys of benthic macroinvertebrates for the regional Pilbara Biological Survey (PBS) (see Pinder *et al.* 2010).

4.2 Licences

This study was conducted under Department of Fisheries (DoF) Exemption #2706 (Authority to Take Fish for Scientific Purposes), and Parks and Wildlife Licence SF010732 (Licence to Take Fauna for Scientific Purposes).

As a condition of these licences, taxa lists and reports are required to be submitted to the respective government departments, and have been done so.

4.3 Sampling Design and Sites

The sampling design is an mBACI (multiple Controls - Before/After - Control/Impact) type design (Keough and Mapstone 1995). Location and number of sites were selected to provide data for robust statistical analysis and to meet requirements of such a design. An mBACI design is considered ideal for impact assessment, as impacts may be placed in context with natural temporo-spatial catchment changes. An mBACI type design provides both benchmark information as well as a strong basis to detect future changes. Reference sites upstream of the Project area were selected to serve as the "control" for potentially impacted sites. Surveys conducted in April/May 2016 are part of the benchmark or "before" phase against which to assess any potential future changes.

Sampling was conducted during the late wet season, between 28th April and 7th May 2016.

A total of 12 pools were sampled along the main channel of the Robe River (Table 3 and Figure 1). Sites included six potentially exposed sites within the predicted surface extent of dewatering discharge, and six reference sites upstream of the Jimmawurrada Creek-Robe River confluence.

Table 3. Aquatic ecosystem sampling sites on the Robe River. Equivalent sites monitored by Streamtec/UWA are also indicated.

Type	WRM Site	Description	GPS co-ordinates (zone 50 K)		Date sampled	Maximum wetted width, length and depth of pool (m)			Streamtec/ UWA site
			Easting	Northing		Width	Length	Depth	
Reference	RRU1	Approx. 3.7 km upstream of Pannawonica Hill.	435628	7603253	05-05-16	20	100	1.2	
	RRU2	Approx. 600 m downstream of Streamtec/UWA site at Pannawonica Hill Pool; upper end of Medawandy Waters area, adjacent Mesa N.	431811	7602046	28-04-16	9	55	3.0	Pannawonica Hill
	RRU3	Approx. 1.6 km downstream of Pannawonica Hill, near Mesa N; within the Medawandy Waters area.	430912	7601562	28-04-16	5	3	1.0	Medawandy
	RRU4	Approx. 1.5 km downstream of RRU3; within the Medawandy Waters area, in the vicinity of Mesa M.	429677	7601439	28-04-16	20	120	1.0	
	RRU5	Approx. 1 km downstream of RRU4; within the Medawandy waters area, adjacent Mesa L.	428769	7601342	29-04-16	10	40	1.2	
	RRU6	Approx. 1 km upstream of Jimmawurrada Creek confluence; lower end of the Medawandy waters area, at base of Mesa L.	424573	7597240	07-05-16	12	40	0.6	
Potentially Exposed	RRD1	Martangkuna; approx. 600 m downstream of existing Mesa J dewatering discharge point (*i.e.* western discharge point).	417110	7598094	30-04-16	3	7	0.8	Martangkuna
	RRD2	Approx. 0.9 km downstream of RRD2.	416245	7598031	30-04-16	6	12	0.7	
	RRD3	Approx. 1 km downstream of RRD3.	415309	7598013	30-04-16	5	25	1.0	
	RRD4	Approx. 1.1 km downstream of RRD3; 1 km upstream of Yeera Bluff.	414419	7597633	29-04-16	20	150	2.0	
	RRD5	Gnieraroora / Dthulurat* at Yeera Bluff; 8.6 km downstream of existing Mesa J western discharge point.	414426	7596622	29-04-16	25	45	4.0	Gnieraoora
	RRD6	Approx. 12.5 km downstream of existing Mesa J western discharge point; within projected discharge footprint (at 20 ML/day).	411415	7594924	30-04-16	30	20	1.2	

* Dthulurat = Western Guruma name.

The original intent was that the assessment would utilise, wherever possible, long-term data from sites sampled by Streamtec/UWA; however, only two of these sites are located within the predicted footprint of surface discharge extent; Martangkuna (RRD1) and Gnieraoora/Dthulurat (RRD5). Therefore, four new sites (RRD2, RRD3, RRD4 and RRD6) were added to allow a more robust characterisation of ecological condition within this reach (Table 3 and Figure 1). These sites may also be exposed to any runoff from the Project area.

Of the sites sampled by Streamtec/UWA upstream of the Jimmawurrada-Robe confluence, two were selected as reference sites for the Project area; Medawandy and Pannawonica Hill Pool; however, only Medawandy (RRU3) held surface water at the time of sampling in April-May 2016. Therefore, five new reference sites were established within the Medawandy Waters area; RRU1, RRU2, RRU4, RRU5 and RRU6 (Table 3 and Figure 1). Site photographs are provided in Appendix 1.

The 2016 sampling was timed to correspond with recessional flow conditions at the end of the wet (April-May) season. It was considered that the end of the wet season would be a more ecologically important time of year to sample, as biological diversity would be expected to be at its highest. By comparison, lower biological diversity may be expected at the start of the wet season, as many invertebrate fauna would not yet have emerged/colonised the seasonal creeks.

4.4 Water Quality

At each site, pH, dissolved oxygen and temperature were measured *in situ* using hand-held Wissenschaftlich-Technische-Werkstätten (WTW) field meters. Meters were calibrated immediately prior to field surveys. Water depth was measured using a graduated pole. Undisturbed water samples were collected for laboratory analyses of major ions, alkalinity, dissolved metals, nutrients and total suspended solids (TSS). Water samples for nitrogen and phosphorus nutrient and dissolved metal analyses were filtered in the field through 0.45 µm nitrocellulose filters. To avoid contamination, all sample bottles and filtering equipment used for dissolved metals were acid-washed (0.1% nitric acid) prior to use. Bottles and filters used for nutrients weren't acid washed to avoid nitrogen contamination from nitric acid. Water samples for analysis of dissolved metals and nutrients were collected using nitrile gloves. All samples were double-wrapped in polyethylene zip-lock bags and kept cool on ice-packs in an esky while in the field and during transport. At the end of each field day, samples were either refrigerated (ions and metals) or frozen (nutrients). Samples were stored refrigerated or frozen for a maximum of 10 days prior to transport on ice to analytical laboratories at ChemCentre, Bentley, together with chain-of-custody forms. All water quality variables measured are summarised in Table 4.

4.4.1 Comparison against ANZECC/ARMCANZ Guidelines

Water quality data were compared against default ANZECC/ARMCANZ (2000) guidelines (trigger values) for the protection of freshwater ecosystems (provided in Appendix 2). Default trigger values (TVs) for 95% aquatic species protection were considered more appropriate than default TVs for 99% protection, given that the Robe River catchment in the vicinity of current mining operations is already slightly to moderately disturbed by historic mining and pastoral practices (Strategen 2006). In accordance with ANZECC/ARMCANZ (2000) however, the default 99% TVs were applied to bioaccumulating metals such as selenium. For metals and nutrients, dissolved concentrations (0.45 µm filtered samples) were compared to the default TVs. Filtered concentrations were considered a better reflection of the fraction that may be bioavailable. By contrast, comparison of the default TVs to the total metal or total nutrient concentration may overestimate the risk to the environment (ANZECC/ARMCANZ 2000).

Table 4. Measured and derived water quality and habitat parameters. Metals (Al, As, B, Ba, Cd, Co, Cr, Cu, Fe, Mn, Mo, Ni, Pb, S, Se, U, V, Zn) and nutrients ($N\text{-}NH_3$, $N\text{-}NO_2$, $N\text{-}NO_3$, $N\text{-}NO_X$, N-total, P-total) were measured as dissolved concentration. All units for water quality parameters are mg/L unless stated otherwise.

Water Quality Parameters	Code	Habitat Parameters	Code
Temperature (°C)	Temp	Maximum pool depth (m)	depth
pH (H^+)	pH	Maximum wetted length of pool (m)	length
Dissolved oxygen (%)	DO%	Mean wetted width of pool (m)	width
Dissolved oxygen (mg/L)	DO	Mineral substrates (total % cover within habitat)	min
Conductivity (µS/cm)	EC	Bedrock (% cover)	bedr
Redox (mV)	Redox	Boulders >256 mm (% cover)	boul
Alkalinity (as $CaCO_3$)	Alk	Cobbles 64-256 mm (% cover)	cobb
Ammonia	$N\text{-}NH_3$	Pebbles 16-64 mm (% cover)	pebb
Arsenic	As	Gravel 4-16 mm (% cover)	grav
Barium	Ba	Sand 1-4 mm (% cover)	sand
Boron	B	Silt <1 mm (% cover)	silt
Cadmium	Cd	Mean particle size (from substrate proportions)	phi
Calcium)	Ca	Emergent macrophyte (% cover)	emerg
Carbonate	CO_3	Submerged macrophyte (% cover)	submerg
Chloride (mg/L)	Cl	Floating macrophyte (% cover)	float
Chromium (µg/L)	Cr	Algae (% cover)	algae
Copper (µg/L)	Cu	Detritus (% cover)	detr
Hardness (as $CaCO_3$)	Hard	Riparian vegetation canopy (% canopy cover)	ripvegco
Hydrogen carbonate	HCO_3	Large woody debris (>10 cm diameter) (% cover)	LWD
Iron	Fe	Root mats (% cover)	rootm
Lead	Pb	Trailing riparian vegetation (% cover)	ripveg
Magnesium	Mg	Habitat diversity (total no. of habitat types)	habdiv
Manganese	Mn	Substrate compaction (1 = loose, to 5 = armoured)	compct
Nickel	Ni	Substrate diversity (total no. substrate types)	subdiv
Nitrate-nitrogen	$N\text{-}NO_3$		
Nitrite-nitrogen	$N\text{-}NO_2$		
Nitrogen oxides	$N\text{-}NO_X$		
Nitrogen-total	N-total		
Phosphorus-total	P-total		
Potassium	K		
Selenium	Se		
Sodium	Na		
Sulfate	$S\text{-}SO_4$		
Sulfur	S		
Total dissolved solids	TDS		
Total suspended solids	TSS		
Uranium	U		
Vanadium	V		
Zinc	Zn		

4.5 Habitat Characteristics

Details of habitat characteristics at each site were recorded (Table 4) to assist in explaining any patterns in faunal assemblages, particularly due to existing differences in benthic substrate composition. Habitat parameters were assessed for the approximately 10 m section of river over which each macroinvertebrate sample was collected. Water depth was measured with a graduated pole. Substrate type was visually assessed and recorded as estimated percent cover by bedrock, boulders, cobbles, pebbles, gravel, sand, silt and clay, from which mean particle size was determined using the phi scale. As an indication of habitat heterogeneity, the number of organic and inorganic substrate types

represented at each site was totalled. Habitat characteristics recorded included estimated percent cover by inorganic sediment, submerged macrophyte, floating macrophyte, emergent macrophyte, algae, large woody debris, detritus, roots and trailing vegetation.

WRM has specific worksheets for this task to ensure qualitative habitat recordings between sites are as comparable as possible. To limit variation due to different observers, all estimations were made by the same sampler.

4.6 Microinvertebrates (zooplankton)

Microinvertebrate samples were collected from each site by gentle sweeping over an approximate 15 m distance with a 53 µm mesh plankton net (Plate 4). Care was taken not to disturb the benthos (bottom sediments) during sampling. Samples were preserved in 70% ethanol and sent to Dr Russell Shiel at the University of Adelaide, South Australia, for processing. Dr Shiel is a world authority on microfauna, with extensive experience in fauna survey and impact assessment across Australasia, including the Pilbara.

Plate 4. Microinvertebrate sampling at RRD4.

Microinvertebrate samples were processed by identifying the first 200-300 individuals encountered in an agitated sample decanted into a 125 mm^2 gridded plastic tray, with the tray then scanned for additional missed taxa also taken to species and recorded as 'present'. Specimens were identified to the lowest taxon possible, *i.e*. species or morphotypes. Abundance data were reported as log_{10} scale abundance classes (*i.e.* 1 = individual, 2 = 2-10 individuals, 3 = 11-100 individuals, 4 = 101-1000 individuals, 5 = >1000). Where specific names could not be assigned, vouchers were established. These vouchers are held by Dr Shiel at Adelaide University, Adelaide, Australia.

4.7 Hyporheos

At each site, hyporheic sampling was conducted using the Karaman-Chappuis method (Delamare Deboutteville 1960). This involved digging a hole approximately 20 cm deep and 40 cm diameter in alluvial gravels in dry streambed adjacent to the water's edge, allowing the hole to infiltrate with water, and sweeping the water column with a modified 110 µm mesh plankton net (Plate 5). The water column was swept immediately after the hole had filled, and again after approx. 30 minutes, once other sampling had been conducted.

Plate 5. Hyporheic sampling at RRU3.

Samples were preserved in 70% ethanol and returned to the laboratory for processing. Any aquatic fauna present was removed from samples by sorting under a low power dissecting microscope. In-house expertise was used to identify the majority of hyporheic taxa using available published keys and through reference to the established voucher collections held by WRM. External specialist taxonomic expertise was sub-contracted to assist with Chironomidae (Dr Don Edward, UWA) and micro-crustacea (Dr Russel Shiel, University of Adelaide).

All taxa recorded from hyporheic samples were classified using the categories of Boulton (2001):

- stygobite, *i.e.* obligate groundwater species, with special adaptations to survive such conditions,
- permanent hyporheos stygophile, *i.e.* epigean[8] species that may occur in both surface and groundwaters, but is a permanent inhabitant of the hyporheic zone,
- occasional hyporheos stygophile, *i.e.* species that use the hyporheic zone seasonally or during early life history stages, or
- stygoxene, *i.e.* species that appear rarely and apparently at random in groundwater habitats; there by accident or seeking refuge during spates or drought; not specialised for dwelling permanently underground.

4.8 Macroinvertebrates

Macroinvertebrate sampling was conducted with a 250 μm mesh FBA pond net (Plate 6). All meso-habitats were sampled, including trailing riparian vegetation, woody debris, open water column and benthic sediments with the aim of maximising the number of species recorded. Each sample was washed through a 250 μm sieve to remove fine sediment, while leaf litter and other debris were carefully washed in the sieve and removed by hand. Samples were then preserved in 70% ethanol. In the laboratory, macroinvertebrates were removed from samples by sorting under a low power dissecting microscope.

Plate 6. Macroinvertebrate sampling at RRU5.

Collected specimens were identified to the lowest practicable level (typically genus or species) and enumerated to $\log_{10}$ scale abundance classes (*i.e.* 1 = individual, 2 = 2-10 individuals, 3 = 11-100 individuals, 4 = 101-1000 individuals, 5 = >1000). In-house expertise was used to identify invertebrate taxa using available published keys and through reference to the established voucher collections held by WRM. External specialist taxonomic expertise was sub-contracted to assist with Chironomidae (Dr Don Edward, UWA).

4.9 Fish

A number of fish sampling methods were used at each site in order to collect as many species and individuals as possible. Methods included electrofishing, seine nets and gill nets. Electrofishing was conducted with a Smith-Root Model LR24 battery powered backpack electrofisher (Plate 7A). Electrofishing is an extremely useful and efficient sampling tool in rivers with clear, low salinity, slow flow water. All meso-habitats within a maximum 40 m reach were shocked with the intention of recovering as many species/individuals as possible. Shocking was not continuous, but targeted areas of optimum habitat, whereby the operator would shock, move to a new habitat before shocking again, and so prevent fish being driven along in front of the electrical field.

Duplicate 30 m multi-panel gill nets were set at each site where there was sufficient depth of water (Plate 7B). Each net consisted of 6 x 5 m panels, with panels increasing in size from 1" to 6" stretched mesh size. The nets were set perpendicular to the bank, with the smallest mesh set against the bank, and the large mesh positioned into the channel with a float and weight to keep the nets in place. At

[8] Epigean – living or occurring on or near the surface of the ground.

each sampling location, two nets were set for approximately 2.5 hours. Nets were checked frequently to avoid fish deaths. Catch from the duplicate nets were combined to form one replicate sample from each sampling location.

Smaller species and juveniles were sampled by beach seine (10 m net, with a 2 m drop and 6 mm mesh) deployed in shallow areas where there was little vegetation or large woody debris. Typically, two seine hauls were made at each location to maximise the number of individuals caught.

All fish were identified in the field, measured for standard length (SL)[9], and then released alive. Fish nomenclature followed that of Allen *et al.* (2002). Fish measurements provided information on the size structure, breeding and recruitment of fish populations.

Plate 7. Example of electrofishing (left), and setting gill nets at RRU1 (right).

4.10 Data Analysis

Samples were grouped *a priori* into categories according to exposure; potentially exposed sites downgradient of the Jimmawurrada-Robe confluence (RRD) or reference sites upgradient of the Jimmawurrada-Robe confluence (RRU). Water quality and species richness (number of taxa) data were plotted in order to illustrate spatial differences. For comparison of species richness against previous studies, invertebrate taxonomy was standardised across datasets to account for differences in taxonomic resolution and/or advancements in taxonomic knowledge between studies (*i.e.* some taxa were condensed to family or order level to enable comparison). As such, taxa richness may appear lower than was originally reported in each study. Where sufficient numbers of each fish species were measured, length-frequency histograms of current data were plotted.

Univariate analyses (one-way ANOVA) was used to test for statistically significant (p <0.05) differences in water quality variables and micro- and macroinvertebrate species richness between groups (RRD, RRU). The assumptions of normality and homogeneity of sample variances were checked using Shapiro-Wilk and Levene's tests, respectively. Data were $\log_{10}(x+1)$ transformed where appropriate. All univariate analyses were performed using IBM SPSS Statistics (v21) software package.

Multivariate patterns in micro- and macroinvertebrate species assemblages were analysed using procedures from the PRIMER (v7) software package (Clarke and Gorley 2006). Non-metric Multi-Dimensional Scaling (nMDS) ordination plots (Clarke and Warwick 2001) were constructed to visualise differences between sites. nMDS ordinations were based on Bray-Curtis similarity measures for species abundance ($\log_{10}$ class) data. Ordinations were depicted as two-dimensional plots. The Analysis of

[9] Standard length (SL) - measured from the tip of the snout to the posterior end of the last vertebra or to the posterior end of the mid-lateral portion of the hypural plate (*i.e.* this measurement excludes the length of the caudal fin).

Similarity (ANOSIM) routine within PRIMER was used to test for significant ($p < 0.05$) differences in species assemblages between groups (RRD, RRU), based on both abundance (log_{10} class) and presence/absence data. The SIMPER routine within PRIMER was used to determine those species contributing most to the similarity/dissimilarity between significant site groupings identified by ANOSIM.

Too few taxa were recorded from hyporheic samples to warrant ANOVA or PRIMER analyses of these data.

4.11 Survey Limitations

Inherent physical sampling deficiencies are acknowledged as a barrier to sampling aquatic fauna, and in particular fish. For example, fish catch rates may have been hindered by the abundance of aquatic vegetation (macrophytes and algae) which physically obstructed seine and gill nets at some sites. This was somewhat compensated for by the use of a back-pack electrofisher, which generates a pulsed direct electrical current to draw fish out from under such habitat.

This study provides a snapshot of water quality conditions and faunal communities at a single point in time, and is unlikely to fully capture the range of temporal/seasonal variability within the Project area. Prior to sampling, total monthly rainfall at Pannawonica Gauging Station was well below the 45-year average, particularly during February, March and April. As such, there was no surface flow connecting pools along the Robe River, with pools heavily receded and even some fish mortality evident, possibly due to low overnight dissolved oxygen concentrations. The relative lack of rainfall leading up to the survey may also have caused recordings of some other water quality parameters, such as salinity and nutrients, to be higher than would be expected under “average” wet season baseflow conditions, due to evapo-concrentration effects and lack of flushing within the system. Dry conditions may also have affected aquatic faunal communities, particularly hyporheic fauna, which require saturation of the alluvium and strong connectivity between ground and surface waters, and fish, with many speces known to require higher baseflows and connectivity between pools to enable upstream migration and spawning.

5 RESULTS AND DISCUSSION

5.1 Water Quality

5.1.1 General

Raw data for spot measurements of water quality, made in conjunction with aquatic fauna sampling, are provided in Appendix 3. Water quality was highly variable amongst sites (Figures 4 and 5). Salinity levels ranged from fresh[10] (592 µS/cm, RRD5) to brackish (1,700 µS/cm, RRU6), pH from circum-neutral (6.9, RRU3) to slightly alkaline (7.9, RRU1), hardness from 230 mg/L (RRD2) to 520 mg/L (RRU6), total suspended solids from <1 mg/L (RRD4, RRU3, RRU4) to 34 mg/L (RRD5), and dissolved oxygen from hypoxic[11] (14.5%, RRU5) to supersaturated (134.9%, RRD6).

There were no obvious longitudinal gradients upstream or downstream of the Jimmawurrada-Robe confluence. Site RRU6 (located ~1 km upstream of the confluence), together with the downstream sites, tended to have higher salinity (as EC and TDS), alkalinity, hardness and concentrations of associated ions, than sites upstream (Figure 3). Maximum values for most of these parameters (*i.e.* EC, TDS, hardness, Na^+, Cl^+, Ca^{2+}, $S\text{-}SO_4$, Mg^{2+}) and for nitrogen (as N-total, $N\text{-}NO_X$, $N\text{-}NH_3$) were recorded at RRU6. Average concentration of K^+, $S\text{-}SO_4$ and total dissolved sulfur (S) was significantly higher downstream of the Jimmawurrada-Robe confluence (one-way ANOVA, Table 5).

Table 5. Summary results from one-way ANOVAs testing for significant (p <0.05) differences in mean concentrations of water quality parameters, upstream (RRU) and downstream (RRD) of the Jimmawurrada-Robe confluence. Only significant results are shown. Mean (±SE) vales for untransformed data are also provided.

Water quality parameter	ANOVA (df = 1, 11)			Mean (±SE)	
	MS	F	p	RRD (n = 6)	RRU (n = 6)
Fe	0.005	9.52	0.012	0.05 (0.01)	0.12 (0.005)
K	23.24	21.96	0.001	8.4 (0.52)	5.6 (0.29)
S	352.08	35.62	<0.001	25.3 (0.95)	14.5 (1.54)
$S\text{-}SO_4$	2104.10	15.52	0.003	70.2 (4.67)	43.7 (4.83)

The significantly higher concentrations of some ions, most notably $S\text{-}SO_4$, and to a lesser extent Mg (Figure 4), downstream of the Jimmawurrada-Robe confluence, may reflect the influence of dewatering discharge from current mining operations. Some inter-site variability could also be attributed to differences in volume of the remnant pools sampled, and evapoconcentration effects under recessional flows. For example RRU6, where maximum values for a number of parameters were recorded, was the shallowest of the pools sampled (maximum water depth of 0.6 m), and supported extensive organic deposits and abundant macrophyte growth (*Typha* and *Potamogeton*) (Appendix 4). The relative abundance of macrophytes, algae and accumulated organics would also be expected to have varying effect on DO levels, pH and rates of nutrient recycling within each of the pools. The higher level of TSS recorded at Gnieraoora (RRD5) compared to all other sites (Figure 5) was likely due to recent cattle activity, which caused the physical disturbance and suspension of benthic sediments.

At most sites, Na^+ was the dominant cation, with Ca^{2+} sub-dominant, and HCO_{3-} the dominant anion, with Cl^- sub-dominant. The exception was RRU6, where Cl^- was dominant and HCO_{3-} sub-dominant. This suggests groundwater ingress had less influence on the water chemistry of the remnant pool at RRU6

[10] Fresh defined as < 1,500 µS/cm; brackish = 1,500 – 4,500 µS/cm; saline = 4,500 - 50,000 µS/cm; hypersaline > 50,000 µS/cm (DoE 2003). Classifications were presented as TDS (mg/L) in DoE (2003) so a conversion factor of 0.68 was used to convert to conductivity µS/cm as recommended by ANZECC/ARMCANZ (2000).

[11] Dissolved oxygen (DO) levels of zero percent saturation = anoxic; < 20% = defined as hypoxic; 100% = saturated; >100% = super-saturated; more oxygen is dissolved than would be in a state of equilibrium.

than at other pools, which may help to also explain the relatively higher salinity at RRU6 (*i.e*. less groundwater inflow to offset effects of evapoconcentration).

5.1.2 Exceedance of ANZECC/ARMCANZ default TVs

Exceedance of ANZECC/ARMCANZ default 95% TVs was recorded for EC, DO, dissolved zinc, N-total, N-NO_x and N-NH_3 at a number of sites upstream and downstream of the Jimmawurrada-Robe confluence (refer Appendix 3). No exceedance of ANZECC/ARMCANZ (2000) default TVs was recorded for any other parameter. Exceedances are discussed in the following sub-sections.

Electrical Conductivity (EC)

EC values were in exceedance of the ANZECC/ARMCANZ (2000) TV (250 μS/cm) at all sites sampled, although surface waters could still be classified as "fresh" (<1,500 μS/cm) at most sites (Figure 4). The relatively higher EC at RRU6 (1,700 μS/cm) constitutes "brackish" conditions, and was above EC levels reported during long-term monitoring of Robe River pools by Streamtec/UWA and the Proponent (*i.e.* 453 - 1,400 μS/cm). Elevated EC was again considered due to high levels of evapoconcentration in these isolated pools, a process common to surface waters in arid/semi-arid zones (Jolly *et al.* 2008). Although some dilution may occur following wet season rains, salinity can often remain high in arid-zone surface waters due to the variability of flows and flushing of stored salts (Jolly *et al.* 2008). ANZECC/ARMCANZ (2000) acknowledge that the default TV for EC may not be representative of local background levels in all areas of Australia. In such instances, ANZECC/ARMCANZ (2000) recommend developing site-specific trigger values (SSTVs) relevant to local conditions.

Dissolved Oxygen (DO)

Daytime DO saturation was below the ANZECC/ARMCANZ (2000) lower TV (80%) at the majority of sites, and above the upper TV (120%) at RRD6 (134.9%) (Figure 5 andAppendix 3). In aquatic ecosystems, low DO levels are typically considered of greater concern than high levels; however, super-saturated levels (>100%) during the day are often indicative of anoxic or hypoxic conditions at night. Low DO is commonly associated with standing pools (with little physical aeration) that support heavy organic loads (*e.g.* aquatic vegetation, algae, bacteria, *etc.*) (Caraco and Cole 2002). DO saturation is typically lowest in the early morning, following overnight consumption of oxygen through the respiratory processes of aquatic biota (Caraco and Cole 2002, Connolly *et al.* 2004, Flint *et al.* 2014). Sites which exhibited particularly low DO in the current study (*e.g.* RRU3 16.1%, RRU5 14.5%) were sampled early in the morning (*i.e.* between 0700 hrs and 0830 hrs), and also tended to support relatively high abundances of macrophytes and/or algae (Appendix 4). While the oxygen needs of aquatic biota differ between species and life history stages, values less than 50% saturation are associated with chronic responses in fish and macroinvertebrates (Connolly *et al.* 2004, Flint *et al.* 2014).

Super-saturation can occur when net photosynthesis exceeds total oxygen consumption in waterbodies, and is common in areas of high algal and macrophyte growth, particularly if spot measurements are taken later in the day (Caraco and Cole 2002). The organic habitat at RRD6, (134.9% DO) comprised emergent and submerged macrophyte (covering 50% of the site area; Appendix 4), and the spot measurement of DO was taken at 1230 hrs, when photosynthetic processes were likely near their peak. Waterbodies with super-saturated daytime DO are likely to experience overnight hypoxia or anoxia, as respiration by plants, algae, bacteria and other aquatic fauna deplete DO (Caraco and Cole 2002, Connolly *et al.* 2004, Flint *et al.* 2014).

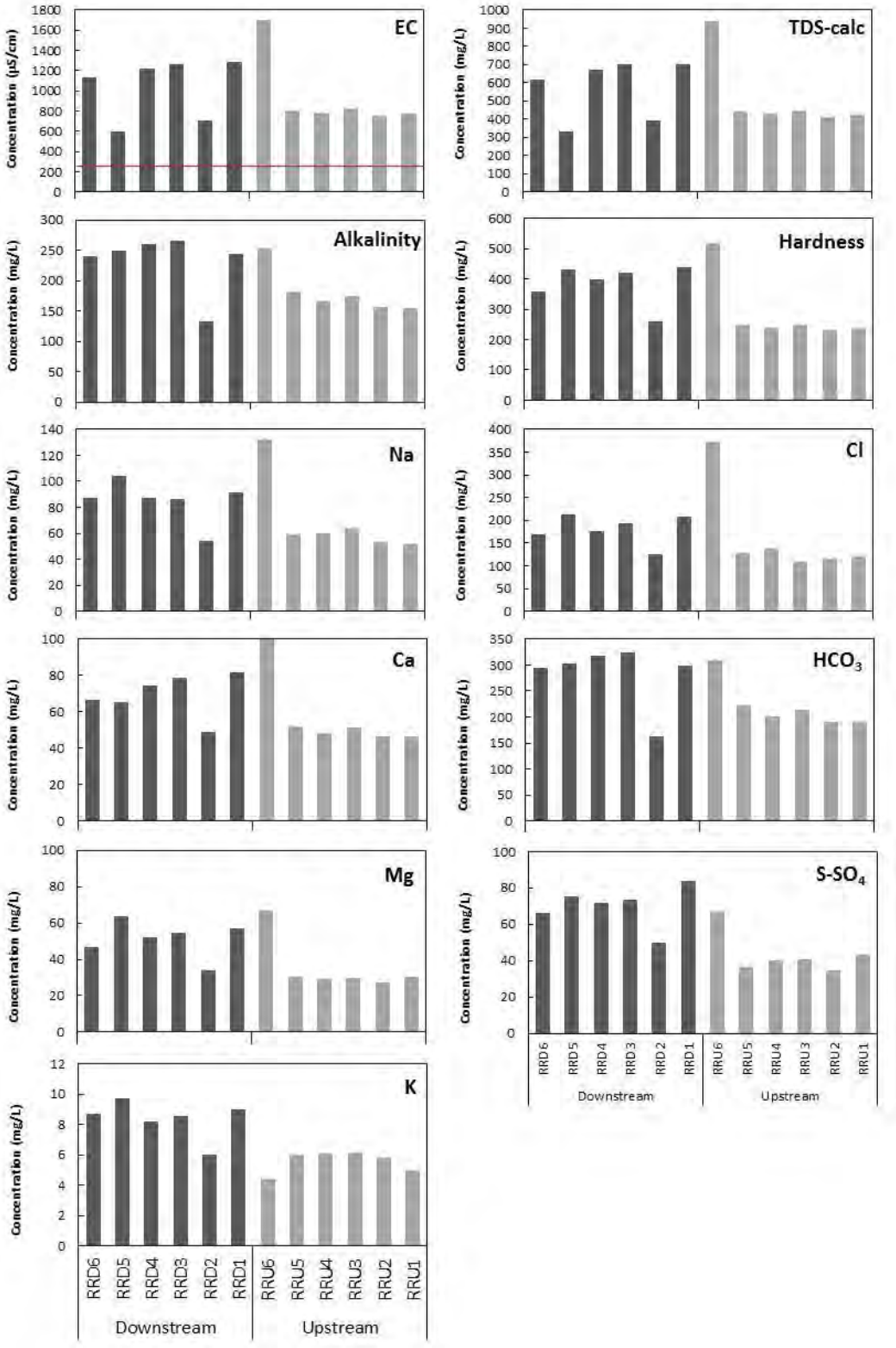


Figure 4. Comparison of EC, alkalinity, hardness and concentration of major ions amongst surface water sampling sites upstream (RRU1 to 6) and downstream (RRD1 to 6) of the Jimmawurrada-Robe confluence. Refer Table 1 for explanation of site codes and Figure 1 for location of sites. ANZECC/ARMCANZ (2000) default 95% species protection level TV (unbroken red line) is indicated for relevant parameters.

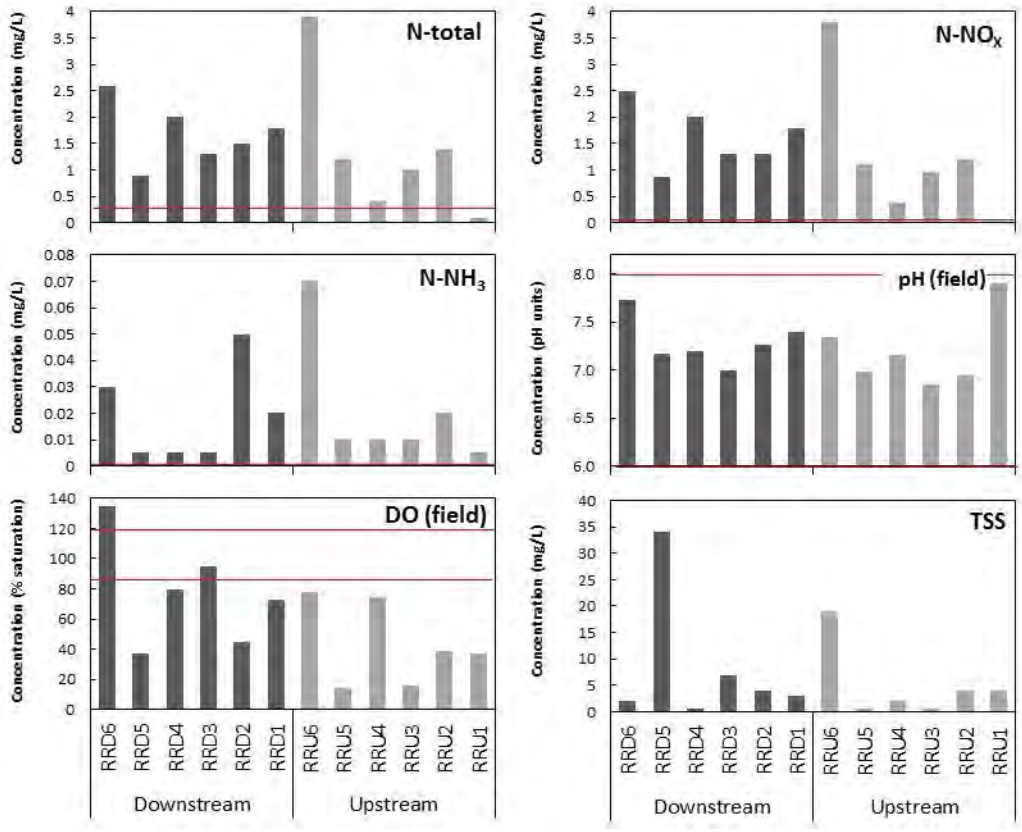


Figure 5. Comparison of N-total, N-NO_X, N-NH_3, pH, DO and TSS amongst surface water sampling sites upstream (RRU1 to 6) and downstream (RRD1 to 6) of the Jimmawurrada-Robe confluence. Refer Table 1 for explanation of site codes and Figure 1 for location of sites. ANZECC/ARMCANZ (2000) default 95% species protection level TV (unbroken red line) is indicated for relevant parameters; upper and lower TVs are shown for pH and DO.

Dissolved zinc

Dissolved zinc (dZn) concentration was in exceedance of ANZECC/ARMCANZ (2000) TVs (0.008 mg/L) at RRU5 (0.012 mg/L) and RRD3 (0.011 mg/L) (Appendix 3). ANZECC/ARMCANZ (2000) provide algorithms to calculate hardness modified TVs (HMTVs), as hardness has an ameliorating effect on the toxicity of a number of metals including cadmium, lead, nickel and zinc[12]. However, once the algorithm was applied, concentrations of dZn at RRU5 and RRD3 still excceded HMTVs. Although elevated, it is unknown what proportion of dZn was labile (bioavailable) or unavailable through processes such as complexing with dissolved organic carbon. Where dissolved levels are elevated, ANZECC/ARMCANZ (2000) recommends testing for labile concentrations/bioavailability to assess if levels are likely to be toxic to aquatic fauna. Given that exceedances of the ANZECC/ARMCANZ (2000) TV were recorded at sites both upstream (reference) and downstream of the Jimmawurrada-Robe confluence, it is unlikely that current Mesa J discharge operations are influencing dZn levels in the Project area.

Nitrogen (N-total, N-NO_X, N-NH_3)

At most sites (except RRU1), N-total, N-NO_X and N-NH_3 exceeded ANZECC/ARMCANZ (2000) default 95% TVs for protection against eutrophication (0.3 mg/L N-total, 0.01 mg/L N-NO_X, 0.01 mg/L N-NH_4[13])

[12] HMTV algorithm for zinc = Default TV*(Hardness/30)^0.85.
[13] Ammonia was analysed as nitrogen-ammonia (N-NH_3), so a conversion factor of 1 was used to convert to nitrogen as ammonium (N-NH_4) for comparison against ANZECC/ARMCANZ (2000) default TV for protection against eutrophication.

(Figure 5 and Appendix 3). N-NO_X levels were greatly in exceedance, *i.e.,* 10 times the default TV at most sites. N-NO_3 constituted nearly all of the measured N-NO_X and N-total (Appendix 3).

In order to compare against the default 95% TV for nitrate as a toxicant (0.7 mg/L NO_3), N-NO_3 concentrations were converted to NO_3 concentration by multiplying by a factor of 4.4. NO_3 exceeded the default 95% TV for nitrate as a toxicant at most sites (except RRU1); however, the default toxicant TV is currently under review as being too conservative. The new ANZECC/ARMCANZ 95% TV for NO_3 as a toxicant is likely to be around 2 - 2.5 mg/L N-NO_3 (~11 mg/L NO_3) (R. van Dam, *eriss*, pers. comm.), and will incorporate most recent data from acute and chronic toxicity testing in New Zealand. Recently published guidelines for Canada also recommend a higher guideline of 2.9 mg/L N-NO_3 (~13 mg/L NO_3) for freshwaters (CCME 2014). In comparison to the proposed ANZECC/ARMCANZ TV of 2 - 2.5 mg/L N-NO_3, only the concentration at RRU6 (3.8 mg/L) was still in exceedance, though the concentration at RRD6 (2.5 mg/L) was close to exceedance. Similar elevated levels of N-NO_3 have been recorded at Medawandy Waters (3.1 mg/L N-NO_3, 3.45 mg/L N-total) during previous monitoring in the Project area (Rio Tinto unpub. data).

Elevated background levels of N-NO_3 and N-NH_3 within the Project area are unsurprising, given that the Robe River catchment is already effected by current and historic pastoral practices (Strategen 2006). Cattle, or evidence of high cattle use were observed at a number of pools during the survey. Elevated N-NO_3 and N-NH_3 in waterbodies caused by livestock disturbance can reduce acid-neutralising capacities of waterbodies, adversely affect the growth, survival and reproduction of aquatic fauna, and most notably stimulate eutrophication and algal blooms (Camargo and Alonso 2006). Another potential anthropogenic source is ammonium nitrate used in mine explosives, though groundwaters in arid zone areas across Australia are often naturally enriched in nitrate, as is the case in the current Project area (Magee 2009).

Significantly higher concentrations of some ions, most notably S-SO_4, and to a lesser extent Mg, as well as elevated N-total and N-NO_x downstream of the Jimmawurrada-Robe confluence (Figures 4 and 5), may also reflect the influence of current mining operations discharges on the water quality of the downstream reach. The elevated S-SO_4 and Mg may indicate presence of geochemical reactions, resulting in the release of these elements downstream of the existing discharge points. The elevated nitrogen levels may indicate discharge of groundwater elevated in nitrates, with groundwaters in the vicinity of current mining operations appearing to be enriched (*e.g.* up to 23.9 mg/L N-NO_3 in bore MB15MEH014) (Rio Tinto unpub. data). The relative contribution of anthropogenic and natural sources to nitrogen enrichment in surface and groundwater of the Project area is unknown, but discharge of nitrogen-enriched groundwater has resulted in elevated nitrate levels in surface waters downstream of other BWT mining operations in the Pilbara.

5.2 Microinvertebrates

5.2.1 Species richness and abundance

A total of 81 microinvertebrate taxa were recorded from the Project area in May 2016, of which 46 were present at potentially exposed sites downstream of the Jimmawurrada-Robe confluence, and 69 were recorded at upstream reference sites (Table 6 and Appendix 5). The list includes groups which could not be identified to species level due to unresolved taxonomy and/or immature specimens. Therefore, the total microinvertebrate species richness is likely to be greater than that reported. Microinvertebrate composition included Protista (protists), Rotifera (rotifers), Copepoda (copepods), Cladocera (water fleas) and Ostracoda (seed shrimp) (Table 6). Generally, Rotifera dominated microinvertebrate taxa at each site, with comparatively few Copepoda, Ostracoda and Cladocera. The microinvertebrate fauna was generally typical of that commonly recorded from tropical/sub-tropical freshwater systems

(*e.g.* Koste and Shiel 1983, Tait *et al.* 1984, Smirnov and De Meester 1996, Segers *et al*. 2004), with Lecanidae dominating within the Rotifera, with Brachionidae and other families less prominent (Appendix 5).

Table 6. Summary of higher-order microinvertebrate taxa composition in the Robe River, upstream (RRU) and downstream (RRD) of the Jimmawurrada-Robe confluence. Refer Appendix 5 for full species list.

Microinvertebrates		Number of Taxa	
Scientific name	Common name	RRD (*n* = 6)	RRU (*n* = 6)
Protista	Protists	7	12
Rotifer	Rotifers	20	33
Micro-crustacea			
Cladocera	Water fleas	5	11
Copepoda	Copepods	9	6
Ostracoda	Seed shrimps	5	7
Total taxa richness		**46**	**69**

Microinvertebrate taxa richness ranged from 33 taxa at RRD6 and RRU5, to just one taxa at RRD5 (Figure 6). There was no significant difference in mean total taxa richness between downstream potentially exposed sites and upstream reference sites (one-way ANOVA, Table 7). Nor were there any significant upstream-downstream differences in taxa richness of major groups of microinvertebrate (rotifers, protists, micro-crustacea) (Table 7).

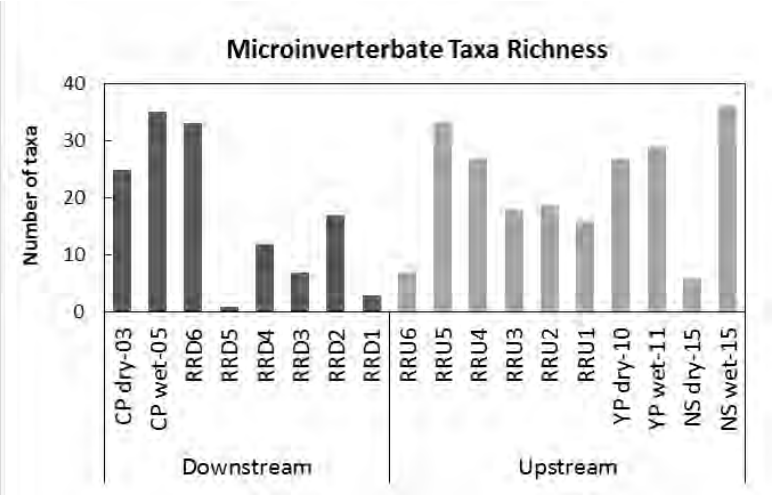


Figure 6. Microinvertebrate taxa richness recorded during the current study, upstream (RRU1 to 6) and downstream (RRD1 to 6) of the Jimmawurrada-Robe confluence, compared with most recent data for nearby Chalyarn Pool (CP; Pinder *et al.* 2010), Yalleen Pool (YP; WRM 2013) and Nyeetbury Spring (NS; WRM 2016). Refer Figure 1 for location of sites.

Table 7. Summary results from one-way ANOVAs testing for significant (p <0.05) differences in taxa richness of major microinvertebrate groups, upstream (RRU) and downstream (RRD) of the Jimmawurrada-Robe confluence. Mean (±SE) vales for untransformed data are also provided.

Microinvertebrate metric	ANOVA (df = 1, 11)			Mean (±SE)	
	MS	F	*p*	RRD (*n* = 6)	RRU (*n* = 6)
Total taxa richness	184.1	1.672	0.225	12.17 (4.81)	20.00 (3.69)
Protista richness	8.333	1.168	0.305	2.33 (0.92)	4.00 (1.24)
Rotifera richness	80.08	2.313	0.159	3.67 (2.46)	8.83 (2.34)
Micro-crustacea richness	3.000	0.183	0.183	6.17 (2.01)	7.17 (1.20)

5.2.2 Comparison against previous surveys

To provide spatial context for microinvertebrate fauna within the Project area, total taxa richness at each site within the Project area was compared against most recent data for nearby pools upstream and downstream of the Project area, *i.e.* Yalleen Pool and Nyeetbury Spring on upper Bungaroo Creek (WRM 2013, 2016), and Chalyarn Pool on Mungarathoona Creek (Pinder *et al.* 2010) (Figure 6). Each of these previous studies used similar microinvertebrate sampling techniques (sweep netting using 50 - 53 μm mesh FBA pond net) and taxonomic resolution to those approaches for the current study.

Some temporal variation was observed between wet and dry season sampling events, with the wet season favouring microinvertebrate taxa richness at Chalyarn Pool, Yalleen Pool and Nyeetbury Spring (Figure 6). At sites upstream of the Jimmawarruda-Robe confluence, taxa richness was spatially variable, with richness at RRU4 and RRU5 similar to that recorded at Yaleen Pool (both seasons) and Nyeetbury Spring in the wet-15 (Figure 6), and slightly higher than that recorded at RRU1, RRU2 and RRU3. Richness was lowest at Nyeetbury Spring in the dry-15, comparable to that recorded at RRU6 in the current study (Figure 6). Within the potentially exposed downstream reach, taxa richness at sites closest to the confluence (RRD1 to RRD5) was generally lower than that recorded at sites further downstream (RRD6 and Chalyarn Pool in both seasons) (Figure 6).

Large spatial (and temporal) variability in species richness and abundance are commonly reported for freshwater systems world-wide. Variation typically depends on factors such as flow regime (with lotic habitat generally favouring taxa richness), pool size, primary production rates and water quality parameters (Miquelis *et al.* 1998, Schiemer *et al*. 2001, Schöll *et al.* 2012). In Pilbara surface waters, microinvertebrate taxa richness is known to fluctuate markedly between sites and seasons (Pinder *et al.* 2010, WRM unpub. data). It is possible that below-average rainfall in the months prior to the current survey may have contributed to the somewhat lower microinvertebrate taxa richness recorded at sites such as RRD1, RRD3, RRD5 and RRU6. Pinder *et al.* (2010) found the wet season (higher rainfall) to generally favour taxa richness during the PBS, as was the case at Chalyarn, Yalleen and Nyteetbury (Figure 6); however, as these studies only provide a snapshot of the microinvertebrate fauna at pools within the Project area, the specific factors driving taxa richness and composition remain unknown.

5.2.3 Spatial variation in species assemblages

Multivariate analysis (ANOSIM) detected no significant difference in microinvertebrate species assemblage composition between upstream reference and downstream potentially exposed sites (Table 8), suggesting there was a high degree of natural variability and overlap amongst assemblages both upstream and downstream of the Jimmawarruda-Robe confluence. Although SIMPER analysis found only a 21% similarity of species assemblages between the upstream and downstream reaches, nMDS plotting displayed no discernible separation of upstream/downstream sites based on Bray-Curtis similarity (Figure 7). SIMPROF analysis did detect some clustering of sites, though with no clear patterns in relation to upstream/downstream location (Figure 7). For example, the upstream sites RRU1, RRU2 and RRU3 clustered with downstream site RRD2, and upstream sites RRU5 and RRU6 clustered with downstream site RRD6, based on similarity of microinvertebrate species assemblages (Figure 7). RRD1 and RRD3 also clustered with a high degree of similarity (Figure 7).

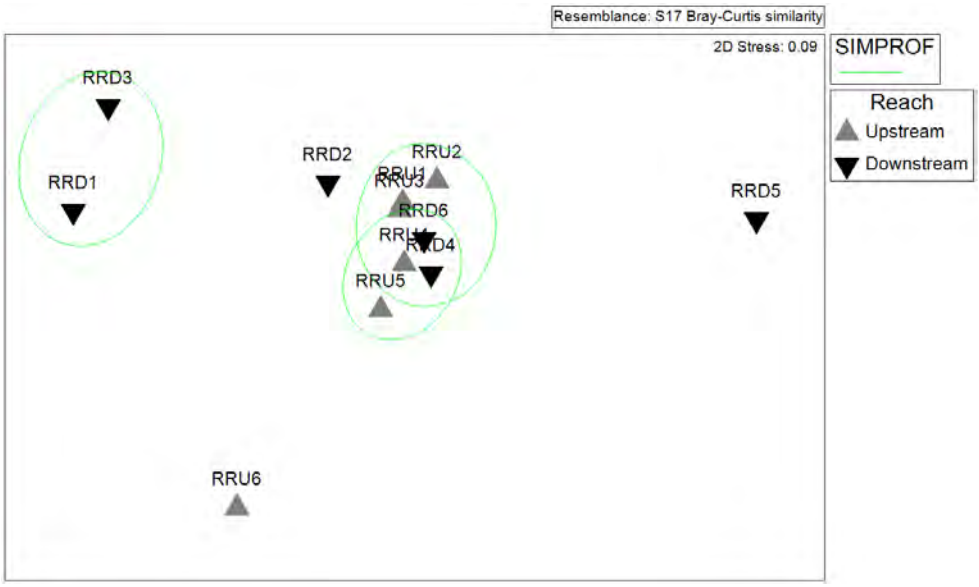


Figure 7. Plot of nMDS ordination on microinvertebrate species assemblages (log_{10} abundance class) upstream (RRU) and downstream (RRD) of the Jimmawurrada-Robe confluence. Ordination based on Bray-Curtis similarity, with SIMPROF analysis as green circles overlain demonstrating significant clustering of sites. Refer Table 1 for explanation of site codes and Figure 1 for location of sites.

Table 8. Summary results from ANOSIM testing for significant (p <0.05) differences in microinvertebrate assemblages (Bray-Curtis similarity) upstream (RRU) and downstream (RRD) of the Jimmawurrada-Robe confluence.

Microinvertebrate assemblage similarity (Bray-Curtis)	ANOSIM	
	R-statistic	*p*
Abundance (log_{10} class)	0.115	0.108
Presence/absence	0.137	0.097

The sampling design allows comparison of change in the similarity (Bray-Curtis) of microinvertebrate assemblages over time between reference and potential exposed sites. The premise being that if the degree of similarity between exposed and reference sites differs significantly over time (compared with pre-mine similarity), this would indicate mine-related response rather than stochastic variability due to factors such as climatic change.

5.2.4 Conservation significance of microinvertebrate fauna of the Project area

The majority of microinvertebrate taxa recorded from the Project area were common, ubiquitous species with Australasian or cosmopolitan distributions; however, the calanoid copepod *Eodiaptomus lumholtzi*, currently listed on the IUCN Red List of Threatened Species as Vulnerable (Reid 1996), was recorded at potentially exposed site RRD6. *E. lumholtzi* was assessed as Vulnerable in 1996 (IUCN ver. 2.3), as it was then known only from a few localities; Lake Woods in Northern Territory, Collinson's Lagoon at Ayr and Saltern Lagoon in the Valley of Lagoons, west of Ingham, Queensland. IUCN (2016) states this assessment requires updating because *E. lumholtzi* has since been recorded from many localities across the Australasian region. *E. lumholtzi* has been recorded previously by the authors at locations across the Pilbara region, including sites along Fortescue River, Coondiner Creek, Kalgan Creek, Weeli Wolli Creek, Koodaideri Springs, Caves Creek, Duck Creek and Cane River (WRM unpub. data). *E. lumholtzi* has also been found in Papua New Guinea, and is considered to have a pan-tropical distribution (Vlaardingerbroek 1989, WRM unpub. data).

Of scientific interest was the collection of an undescribed species of Lecanidae rotifer, *Lecane* n. sp., recorded both upstream and downstream of the Jimmawarruda-Robe confluence (RRU5 and RRD6). Morphologically, this species is similar to the described *Lecane quadridentata*, with the two variants synonymized by Segers (1995); however, the smaller Australian variant recorded in the current study is now recognised as a separate species, and forms part of a wider *L. quadridentata* species complex (Dr Russel Shiel, University of Adelaide, pers. comm.).

5.3 Hyporheic Fauna

5.3.1 Species richness and abundance

A total of 59 taxa were recorded from the hyporheic zone of pools in the Project area (Appendix 6). The majority of these taxa were classified as stygoxene (54%), *i.e.* species that appear in groundwater habitats by accident or seeking refuge during drought, and not specially adapted to subterranean inhabitation. Of these, 8% were classified as stygobitic, *i.e.*, obligate groundwater inhabitants with specialised morphological adaptations to survive in such environments (stygofauna). Of the remaining taxa, 31% were considered occasional hyporheic stygophiles (species that use the hyporheic zone seasonally or during early life history stages), 2% were possible hyporheic taxa, and 5% were unable to be classified (Appendix 6). Although classifications followed those of Boulton (2001), this type of analysis should be treated with some caution, as results are likely affected by available information on life history, taxonomic resolution, and interpretation of classification categories.

Hyporheic taxa richness (combined richness of stygobites, occasional hyporheic stygophiles and possible hyporheic fauna) ranged from two taxa at upstream reference site RRU2, to 12 taxa at potentially exposed downstream site RRD1 (Figure 8). Relatively high hyporheic taxa richness was also recorded at RRU6 (nine taxa), RRU4 and RRD2 (eight taxa), and RRU3 and RRD5 (seven taxa) (Figure 8). The high taxa richness encountered in the hyporheos of these sites, and because surface water was present at these sites despite below average rainfall in the months prior, suggests at least some connectivity between ground- and surface waters (*i.e.* they may be groundwater-supported pools).

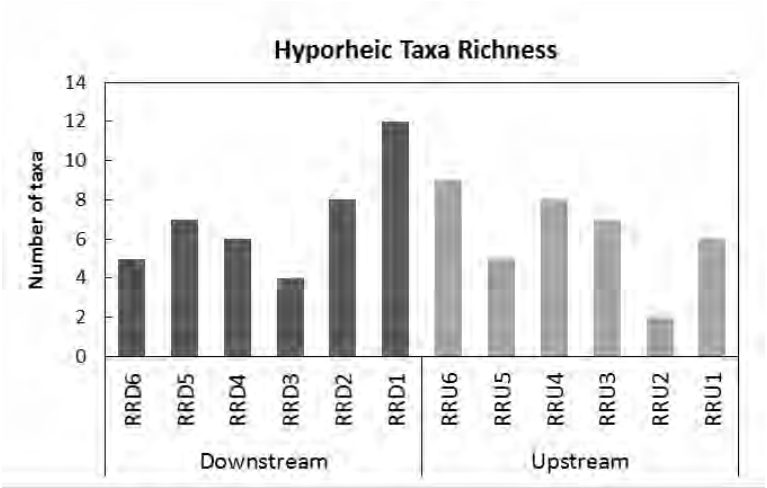


Figure 8. Hyporheic taxa richness (combined richness of stygobites, occasional hyporheic stygophiles and possible hyporheic fauna) of sites upstream (RRU) and downstream (RRD) of the Jimmawurrada-Robe confluence.

5.3.2 Conservation significance of hyporheic fauna of the Project area

Of the fauna collected in hyporheic samples of the Project area, only the amphipod, *Nedsia* sp. is considered likely to be a potential SRE species.

Nedsia sp. (family Melitidae) was recorded from the hyporheic zones of RRU3, RRU4 and RRU6 upstream of the Jimmawurrada-Robe confluence, and RRD1, RRD2, RRD3 and RRD4 downstream of the confluence (Appendix 6). *Nedsia* amphipods were also recorded in the surface water macroinvertebrate samples of RRD3 and RRD4 (Appendix 7). These amphipods could not be confidently identified to species level due to a current lack of taxonomic resolution within the Melitidae amphipods and would require DNA sequencing.

Biota (2006a) recorded four genetically-distinct amphipods of the family Melitidae from bores in the Yarraloola area, downstream (west) of the Project area. A fifth distinct Melitidae lineage was recorded from the Bungaroo Creek area to the southeast (Biota 2006a). Interestingly, based on genetic evidence, each of the four Melitidae lineages from the Yarraloola area have been isolated from one-another for between 2.4 and 6.65 million years, highlighting the extreme degree of amphipod short-range endemism that can occur amongst aquifers in the region despite close geographical proximity (Biota 2006a). Biota (2010) and Bennelongia (2013) also recorded a high abundance of Melitidae amphipods from bores to the south of the current Project area. The majority of these specimens belonged to the genus *Nedsia* (*Nedsia* nr. *hulberti* and *Nedsia* spp.). It is currently unknown whether the *Nedsia* recorded in the current study represent one or more of the *Nedsia* species or Melitidae halotypes recorded by Biota (2006a, 2010) and Bennelongia (2013) or a separate species previously unrecorded.

Although not conservation listed or considered SRE species, the following are stygal species, with their presence indicating some connectivity between ground- and surface-waters. As such, they are of some interest.

The Thermosbaenacean *Halosbaena tulki* was recorded both upstream (RRU3) and downstream (RRD2, RRD3 and RRD4) of the Jimmawurrada-Robe confluence. *Halosbaena tulki* is the single species of Thermosbaenacean known from the Southern Hemisphere, where it appears to be restricted to the Pilbara region (Poore and Humphreys 1992). Thermosbaenacea are a rare order of crustacean, with approximately 16 species known worldwide, all of which are restricted to groundwater environments (Poore and Humphreys 1992). In the vicinity of the Project area, this species was previously collected from seven bores in the Yarraloola area by Biota (2006a).

The ostracod *Candonopsis* cf. *tenuis* is known to occur widely across Australia (DeDeckker 1982, Karanovic and Marmonier 2002), including groundwaters of the Pilbara (Halse *et al.* 2002). WRM has recorded *C.* cf. *tenuis* from the hyporheic zone of a number of sites in the Weeli Wolli Creek catchment, Coondiner Creek, Kalgan Creek, Hamersley Gorge and the Ashburton River (WRM unpub. data). During the current study, *C.* cf. *tenuis* was collected from the hyporheic zone of upstream reference site RRU6 (Appendix 6).

Vestalenula marmonieri is a stygal ostracod species known only from Western Australia and New Caledonia (Schön *et al.* 2010). This species is relatively widespread across the Pilbara region (being collected from over 50 locations by Pinder *et al.* (2010) during the PBS), though due to its preference for phreatic[14] environments, is most commonly associated with groundwater-fed systems such as Weeli Wolli Creek (WRM unpub. data). In the current study, *V. marmonieri* was recorded from potentially exposed downstream sites RRD1 and RRD5, and upstream reference site RRU1 (Appendix 6). *V.*

[14] Groundwater environments.

marmonieri was also collected in microinvertebrate samples of RRU1, RRU2, RRU3, RRU6, RRD2, RRD4 and RRD5 (Appendix 5).

5.4 Macroinvertebrates

5.4.1 Species richness and abundance

A total of 148 macroinvertebrate taxa were recorded from the Project area, of which 116 were present at sites downstream of the Jimmawurrada-Robe confluence, and 117 at upstream reference sites (Table 9, Appendix 7). In this context, "taxa" includes groups which could not be identified to species level, due to unresolved taxonomy and/or immaturity of specimens. Therefore, the total macroinvertebrate taxa richness at each site is likely greater than reported herein. The macroinvertebrate fauna comprised Cnidaria (freshwater hydra), Mollusca (freshwater snails and bivalves), Oligochaeta (aquatic segmented worms), Crustacea (amphipods and freshwater shrimp), Acarina (water mites), Collembolla (springtails), Odonata (dragonflies and damselflies), Ephemeroptera (mayflies), Hemiptera (true bugs), Coleoptera (aquatic beetles), Diptera (two-winged or "true" fly larvae), Trichoptera (caddisflies) and Lepidoptera (aquatic moth larvae; Table 9). Macroinvertebrate composition was typical of freshwater systems throughout the world (Hynes 1970), being dominated by Insecta (comprising 89% of all taxa), with Diptera (29%) and Coleoptera (32%) most prominent within this class. There were 46 singleton taxa recorded (*i.e.* those recorded from only one site), and 12 taxa were considered common taxa, *i.e.* they were present at over 80% of sites. These included the snail *Melanoides* spp., segmented worms (Oligochaeata spp.), the freshwater shrimp *Caridina indistincta*, the mayflies Baetidae spp. and *Cloeon* sp. Red Stripe, the pygmy backswimmer *Paraplea* spp., and the midge larvae/pupae Ceratopogonidae spp., Dasyheleinae spp., Chironomidae spp., *Polypedilum* sp. 1, *Larsia albiceps* and *Paramerina* sp. (Appendix 7).

Table 9. Summary of higher-order microinvertebrate taxa composition in the Robe River, upstream (RRU) and downstream (RRD) of the Jimmawurrada-Robe confluence. Refer Appendix 7 for full species list.

Macroinvertebrates		Number of Taxa	
Scientific name	Common name	RRD (*n* = 6)	RRU (*n* = 6)
Cnidaria	Freshwater hydra	1	0
Oligochaeta	Aquatic worms	1+	1+
Gastropoda	Freshwater snails	4	5+
Bivalvia	Freshwater bivalves	0	1
Amphipoda	Stygal amphipods	2	0
Decapoda	Freshwater shrimps	1+	1+
Acarina	Water mites	1+	1+
Ephemeroptera	Mayflies	6	5
Odonata	Dragonflies and damselflies	14	14
Hemiptera	True bugs	18	16
Coleoptera	Aquatic beetles	30	35
Diptera	Two-winged flies	30	31
Trichoptera	Caddisflies	7	4
Lepidoptera	Aquatic moth larvae	2	2
	Total taxa richness	**116**	**117**

+ indicates a taxa could only be identified to genus/family/order level (not species level), and as such more than one species is likely to be present within this taxonomic group.

Macroinvertebrate taxa richness at upstream sites ranged from 34 taxa at RRU3 and RRU5, to 72 taxa at RRU1 (Figure 9). Richness at sites downstream of the Jimmawarruda-Robe confluence ranged from 38 taxa at RRD3 and RRD5, to 56 taxa at RRD2 (Figure 9). There was no significant difference in total

taxa richness between downstream potentially exposed sites and upstream reference sites (one-way ANOVA, Table 10). Nor were there any significant upstream-downstream differences in taxa richness of most major macroinvertebrate groups (Table 10). The exception was Ephemeroptera (mayflies), where mean richness was significantly higher at sites downstream of the confluence (4.3) compared to those upstream (2.5) (Table 10). This was largely due to the lower richness/absence of *Tasmanocoenis* sp. P/*arcuata* (Caenidae) and *Cloeon fluviatile* (Baetidae) at upstream sites, particularly RRU4 to 6 closest to the confluence.

Table 10. Summary results from ANOVAs testing for significant (p <0.05) differences in taxa richness of major macroinvertebrate groups (indicated by *), upstream (RRU) and downstream (RRD) of the Jimmawurrada-Robe confluence. Mean (±SE) vales for untransformed data are also provided.

Macroinvertebrate metric	ANOVA			Mean (±SE)	
	MS	F	p	RRD (n = 6)	RRU (n = 6)
Total taxa richness	0.083	0.001	0.982	46.2 (3.5)	46.3 (6.1)
Diptera richness	0.000	0.000	1.000	14.0 (1.8)	14.0 (4.6)
Coleoptera richness	18.75	0.587	0.461	8.5 (2.4)	11.0 (2.2)
Hemiptera richness	0.333	0.035	0.855	6.3 (1.1)	6.0 (1.4)
Odonata richness	1.333	0.377	0.553	5.33 (0.6)	6.0 (0.9)
Trichoptera richness	1.333	1.429	0.260	1.7 (0.4)	1.0 (0.4)
Ephemeroptera richness	10.08	6.798	0.026*	4.3 (0.5)	2.5 (0.5)
Mollusca richness	0.083	0.068	0.799	2.7 (0.4)	2.8 (0.5)
Crustacea richness	0.750	-0.738	0.411	2.7 (0.5)	2.2 (0.3)

5.4.2 Comparison against previous studies

To provide spatial context for macroinvertebrate fauna within the Project area, total taxa richness at each site was compared against most recent data for nearby pools upstream and downstream, *i.e.* Yalleen Pool and Nyeetbury Pool on upper Bungaroo Creek (WRM 2013, 2016), and Chalyarn Pool on Mungarathoona Creek (Pinder *et al.* 2010) (Figure 9). Each of these previous studies used similar macroinvertebrate sampling techniques (kick-sweep netting using 250 µm mesh FBA pond net) and taxonomic resolution to those of the current study.

Taxa richness within the Project area (34 – 72 taxa) was generally comparable to that previously recorded for Yalleen Pool (39 – 45), Nyeetbury Spring (51 – 52) and Chalyarn Pool (49 – 77) (Figure 9). The lack of spatial variability in macroinvertebrate taxa richness between studies probably reflects the similar hydrological nature and size of these pools (*i.e.* all are either permanent/semi-permanent riverine pools, flowing only after heavy rainfall) because they are all within relatively close geographical proximity to one-another (*i.e.* within 20 – 30 km, and all part of the Robe River catchment). Pinder *et al.* (2010) noted riverine pools of the Pilbara (particularly those of the same catchment) generally display a high degree of homogeneity, in terms of macroinvertebrate species richness and composition, in comparison to similarly sized turbid wetlands and claypans.

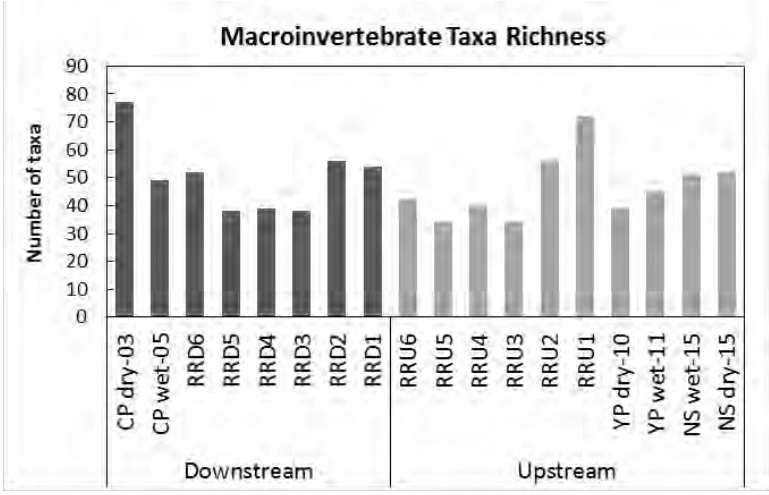


Figure 9. Macroinvertebrate taxa richness recorded during the current study, upstream (RRU1 to 6) and downstream (RRD1 to 6) of the Jimmawurrada-Robe confluence, together with most recent data for nearby Chalyarn Pool (CP; Pinder *et al.* 2010), Yalleen Pool (YP; WRM 2013) and Nyeetbury Spring (NS; WRM 2016). Refer Figure 1 for location of sites.

To provide temporal/seasonal context for macroinvertebrate taxa richness in the current Project area, April/May (wet season) 2016 figures were compared against historic mean dry season taxa richness recorded at Robe River pools by Streamtec/UWA between 2002 and 2011[15]. Again, both studies utilised the same macroinvertebrate sampling technique (sweep netting using a 250 µm mesh FBA pond net), and taxonomy was standardised across datasets to account for inherent variation/advancements in taxonomic knowledge between studies (*i.e.* some taxa were condensed to family or order level to enable comparison). As such, taxa richness may appear lower than was originally reported in each study.

At the reach upstream of the Jimmawarruda-Robe confluence, mean dry season richness at Medawandy Waters (22) and Pannawonica Hill (23) were generally comparable to wet season taxa richness recorded at RRU3 (22), RRU4 (30), RRU5 (20) and RRU6 (26), but slightly lower than taxa richness recorded at RRU1 (54) and RRU2 (38) (Figure 10). Downstream of the confluence, mean dry season richness recorded at Gnieroora, Martangkuna, Pulari, Japanese Pool and Yarramudda (20 – 27 taxa) was also similar to wet season richness recorded at RRD1, RRD3, RRD4 and RRD5 (21 – 33 taxa), and only slightly lower than that recorded at RRD6 (41 taxa) and RRD2 (38 taxa). The apparent lack of seasonal variability in taxa richness likely reflects the capacity for pools of the Project area to hold water year-round (*i.e.* they are either permanent/semi-permanent), acting as refuge pools for migratory macroinvertebrates during the dry season, and generally favouring both temporary and permanent resident macroinvertebrate species over more ephemeral waterbodies (Sponseller *et al.* 2001, Pinder *et al.* 2010). Furthermore, Pinder *et al.* (2010) found there to be little seasonal variation in macroinvertebrate assemblages at permanent/semi-permanent riverine pools of the Pilbara region in comparison to more ephemeral waterbodies, particularly when flooding had not occurred prior to wet season sampling (as was the case in the current study). It must be noted that the current study provides only a snapshot of the macroinvertebrate fauna of the Project area and taxa richness could still vary considerably between time periods.

[15] The most recent round of macroinvertebrate data (2013) was not included in analysis, as Streamtec (2014) did not feature a raw species list. Earlier species lists (1996 & 1998) were not included in the analysis due to the vast improvements in taxonomic knowledge and microscope technology since those studies.

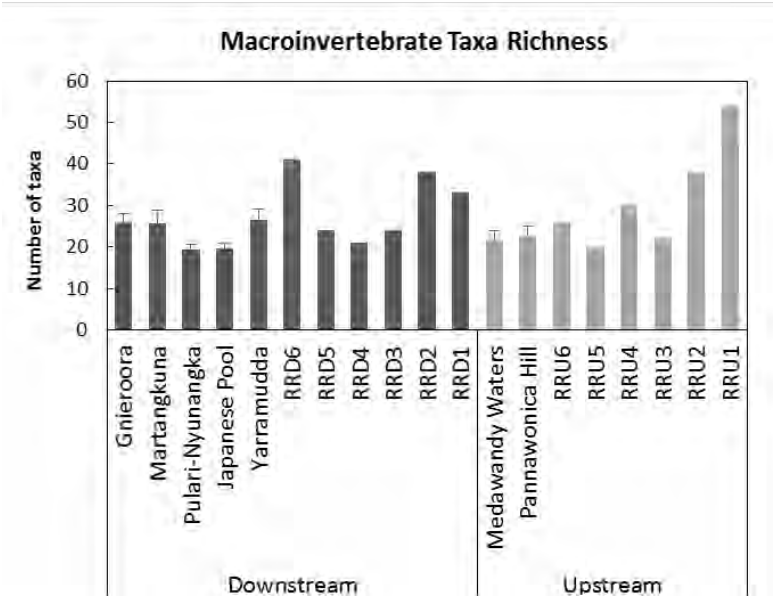


Figure 10. Comparison of standardised macroinvertebrate taxa richness recorded during the current study, with that recorded by Streamtec/UWA during long-term monitoring of Robe River pools. Refer Figure 1 for location of sites.

5.4.3 Spatial variation in species assemblages

Multivariate analysis (ANOSIM) detected no significant difference in macroinvertebrate species assemblage composition between upstream reference and downstream potentially exposed sites (Table 11), suggesting there was a high degree of natural variability and overlap amongst upstream/downstream sites. Although SIMPER analysis found only a 45% similarity of species assemblages between upstream and downstream sites, nMDS plotting displayed no distinguishable separation of upstream/downstream sites based on Bray-Curtis similarity (Figure 11), with SIMPROF analysis (not shown) detecting no clustering of these groups. One site (RRU3) was separate from all other sites, which is attributed to the low overall taxa richness (34) recorded at this site compared to others. As with taxa richness, the lack of variability in upstream/downstream macroinvertebrate assemblages likely reflects the relatively similar hydrological nature (permanent/semi-permanent) of pools in the Project area.

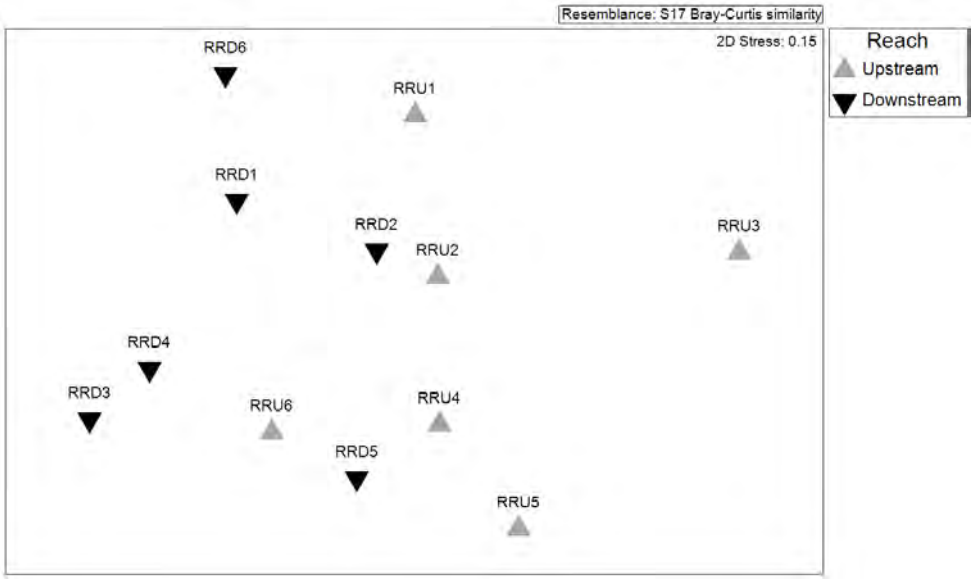


Figure 11. Plot of nMDS ordination on macroinvertebrate species assemblages (log_{10} abundance class) upstream (RRU) and downstream (RRD) of the Jimmawurrada-Robe confluence. Ordination based on Bray-Curtis similarity. Refer Table 1 for explanation of site codes and Figure 1 for location of sites.

Table 11. Summary results from ANOSIM testing for significant (p <0.05) differences in macroinvertebrate assemblages (Bray-Curtis similarity) upstream (RRU) and downstream (RRD) of the Jimmawurrada-Robe confluence.

Macroinvertebrate assemblage similarity (Bray-Curtis)	ANOSIM	
	R-statistic	*p*
Abundance (log_{10} class)	0.154	0.106
Presence/absence	0.111	0.186

5.4.4 Conservation significance of macroinvertebrate fauna of the Project area

The Pilbara pin damselfly, *Eurysticta coolawanyah* (family Isostictidae), is endemic to the Pilbara region, and is currently listed as Near Threatened on the IUCN Red List of Threatened Species (IUCN 2016). *Eurysticta coolawnyah* was recorded from two sites in the current study; RRD3 and RRD4, both downstream of the Jimmawarruda-Robe confluence (Appendix 7). *E. coolawanyah* is known from over 40 locations across the Pilbara (Pinder *et al.* 2010), and has been recorded by WRM from a number of riverine pools and springs along the Fortescue River, DeGrey River, Coondiner Creek, Kalgan Creek and Weeli Wolli Creek (WRM unpub. data). Along the Robe River, this species has been recorded consistently by Streamtec/UWA, as well as from Bungaroo Creek (WRM 2013) and Mugarathoona Creek (Pinder *et al.* 2010).

It is likely that both RRD3 and RRD4 are important refuge pools for *E. coolawanyah* in the area, as both are persistent waterbodies which support relatively high densities of emergent macrophyte (see Appendix 4). Damselflies (such as *E. coolawanyah*) are known to actively select sites with greater concentrations of emergent macrophyte, which are used for perching, mating and oviposition (egg-laying) (D'Amico *et al.* 2004, Rouquette and Thomson 2004, Ward and Mill 2005, Remsburg and Turner 2009).

Although the following species are not listed for conservation significance, they are endemic to the Pilbara region and therefore of some scientific interest. The Pilbara tiger dragonfly, *Ictinogomphus dobsoni* (family Lindeniidae), was collected at reference site RRU3, and potentially exposed sites RRD1, RRD4 and RRD6 (Appendix 7). This species appears to be relatively common across the Robe River

catchment, having been recorded from Chalyarn Pool, Red Hill Creek (Pinder *et al*. 2010) and a number of permanent/semi-permanent Robe River pools (Streamtec/UWA). Elsewhere, *I. dobsoni* has been recorded from many of the other major river systems of the Pilbara, including the Fortescue, Ashburton, Yule, DeGrey and Sherlock rivers (DEC 2009, Pinder *et al*. 2010, CSIRO 2015). Large pools within the Project area epitomise ideal refuge habitats for *I. dobsoni*, which is known to prefer still or sluggish permanent riverine waterbodies (Watson 1991).

The Pilbara endemic dytiscid beetle *Tiporus tambreyi* was recorded at reference sites RRU3, RRU4 and RRU6, and potentially exposed site RRD1 (Appendix 7). This species is common and ubiquitous across the region, and in the vicinity of the Project area, has been recorded from Robe River pools (Streamtec/UWA), Chalyarn Pool (Pinder *et al.* 2010) and Red Hill Creek (WRM 2009, Pinder *et al.* 2010).

The haliplid beetle *Haliplus pilbaraensis,* recorded from reference site RRU1 (Appendix 7), is endemic to the Pilbara region and relatively new to science (Watts and McRae 2010). This species appears to occur fairly widely throughout the Pilbara, and has been recorded at localities such as Glen Ross Creek, Coondiner Pool, the Fortescue Marsh, Moreton Pool, Paradise Pool, Munreemya Billabong, Wackilina Creek Pool, West Peawah Creek Pool, Harding River Pool, and an un-named creek in Millstream (Watts and McRae 2010). Closer to the Project area, *H. pilbaraensis* was previously recorded from Red Hill Creek (WRM 2009).

5.5 Fish

5.5.1 Species composition and abundance

A total of 3,515 individual fish were caught, measured and released in the Project area; 1,578 from upstream reference sites (RRU1 - 6), and 1,937 from sites downstream of the Jimmawarruda-Robe confluence (RRD1 - 6). Seven true freshwater taxa were recorded, including the western rainbowfish, spangled perch, Pilbara tandan (eel-tailed catfish), Fortescue grunter, barred grunter, bony bream, and a hybridised form of Terapontidae (grunter) (Table 12). Four species captured were of estuarine/marine origin, including milkfish, tarpon (ox-eye herring) (Plate 8), mullet and banded scat (striped butterfish) (Plate 8) (Table 12). Each of the freshwater species, with the exception of bony bream, was recorded both upstream and downstream of the Jimmawarruda-Robe confluence (bony bream were only recorded upstream of the confluence) (Table 12). The marine vagrant tarpon and mullet were also recorded both upstream and downstream of the confluence; however, milkfish and banded scat were only recorded from the downstream reach (Table 12). Each of these species, except milkfish, was previously recorded from the Robe River by Morgan and Gill (2004) and Streamtec/UWA.

Table 12. Summary of freshwater and estuarine/marine vagrant fish species recorded in the Project area, including scientific and common names. ✓ = fish species was present.

Origin	Species	Common name	Downstream						Upstream					
			RRD6	RRD5	RRD4	RRD3	RRD2	RRD1	RRU6	RRU5	RRU4	RRU3	RRU2	RRU1
Freshwater	*Melanotaenia australis*	Western rainbowfish	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Neosilurus sp.	Pilbara tandan			✓	✓	✓			✓		✓	✓	✓
	Leipotherapon unicolor	Spangled perch	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Leipotherapon aheneus	Fortescue grunter	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Amniataba percoides	Barred grunter	✓		✓	✓		✓	✓	✓				
	Terapontidae sp.	Grunter hybrid		✓			✓		✓	✓		✓		✓
	Nematalosa erebi	Bony bream											✓	
Estuarine/ marine	*Chanos chanos*	Milkfish	✓		✓									
	Megalops cyprinoides	Tarpon/ox-eye herring	✓	✓		✓	✓	✓		✓	✓		✓	
	Mugil sp.	Mullet		✓				✓			✓		✓	
	Selenotoca multifasciata	Banded scat/striped butterfish	✓	✓	✓	✓	✓	✓						

There was no significant difference in mean abundance of fish upstream and downstream of the Jimmawarruda-Robe confluence (one-way ANVOA, $p = 0.433$), nor was there any significant difference in mean abundance of any of the individual species between the upstream and downstream reaches (one-way ANOVA, $p < 0.05$). There was a significant difference in mean species richness between upstream and downstream sites, with mean richness significantly higher downstream of the Jimmawarruda-Robe confluence (one-way ANVOA, $p = 0.008$). This was mainly due to the greater presence of estuarine species such as banded scat, milkfish and tarpon at the downstream reach (Table 12).

Western rainbowfish were the most abundant fish of the Project area, with a total of 2,401 individuals captured. Western rainbowfish were present at all sites, with 1,019 recorded from upstream reference sites (42%), and 1,382 recorded from downstream sites (48%) (Figure 12). Fortescue grunter (685 individuals) and spangled perch (203 individuals) were the second and third most abundant species of the Project area, respectively. Fortescue grunter were collected from all sites, with similar numbers captured both upstream (320 individuals; 47%) and downstream (365 individuals; 53%) of the Jimmawarruda-Robe confluence (Figure 12). Spangled perch were also present at all sites, with the majority recorded at upstream sites (145 individuals; 71%) (Figure 12). Of the remaining freshwater species, Pilbara tandan (34 individuals) were recorded at upstream sites RRU1, RRU2, RRU3, RRU5, and downstream sites RRD2, RRD3 and RRD4; barred grunter (47 individuals) were recorded at upstream sites RRU5 and RRU6, and at downstream sites RRD3, RRD4 and RRD5. Terapontidae hybrids (12 individuals) were recorded at upstream sites RRU1, RRU3, RRU5 and RRU6, and downstream sites RRD2 and RRD5 (Figure 12). Bony bream (5 individuals) were only recorded at upstream site RRU2.

Of the estuarine/marine fish species, tarpon (39 individuals) (Plate 8) were recorded at upstream sites RRU2, RRU4 and RRU5, and all sites downstream of the Jimmawarruda-Robe confluence (Figure 12). Mullet (33 individuals) were recorded at upstream sites RRU2 and RRU4, and downstream sites RRD1 and RRD5 (Figure 12). Banded scat (53 individuals) (Plate 8) were only recorded downstream of the confluence, but were present at all sites within that reach (Figure 12). Milkfish (7 individuals) were only recorded from downstream sites RRD4 and RRD6 (Figure 12).

Plate 8. The banded scat *Selenotoca multifaciata* (left) and the tarpon *Megalops cyprinoides* (right), captured downstream of the Jimmawarruda-Robe confluence.

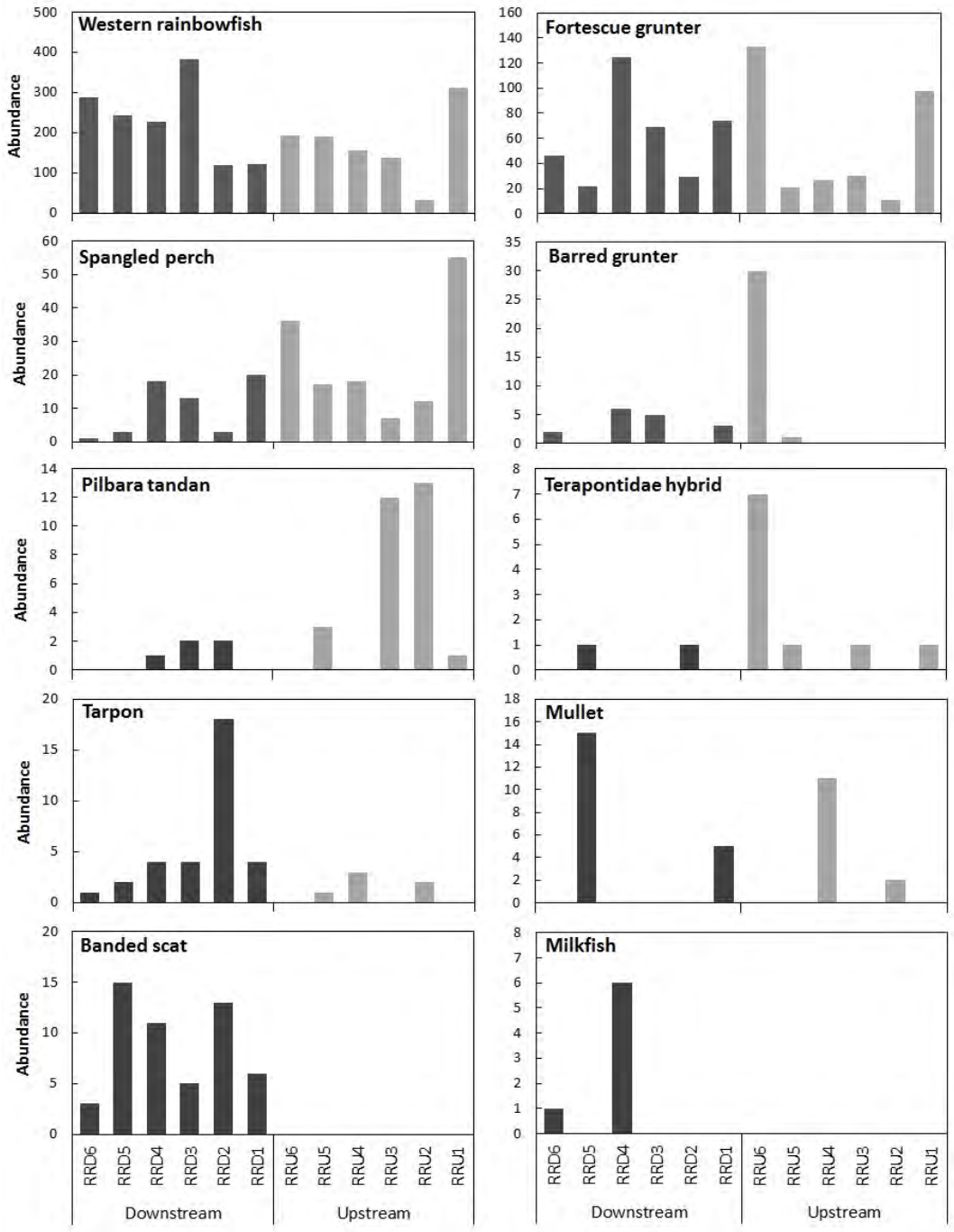


Figure 12. Abundance of each fish species recorded from upstream (RRU1 to 6) and downstream (RRD1 to 6) of the Jimmawurrada-Robe confluence. Note: bony bream (*Nematalosa erebi*) were also recorded from the Project area, but were not plotted due to low overall abundance of this species.

5.5.2 Conservation significance of fish species

One conservation listed freshwater fish species was recorded from the Project area; the Pilbara endemic Fortescue grunter (*Leipotherapon aheneus*). Currently, the Fortescue grunter is listed on the IUCN Red List of Threatened Species as Lower Risk/Near Threatened (IUCN 2016), and as a Priority 4 (P4) species on the Department of Parks and Wildlife (Parks and Wildlife) Priority Fauna List (Parks and Wildlife 2016). This species is only known from the Fortescue, Robe and Ashburton River systems (Allen *et al*. 2002, Morgan and Gill 2004); however, it is considered to be common within this range, as is evidenced

by the ubiquitousness of this species across the current Project area, being the second most abundant fish collected (685 individuals) and occurring at all sites both upstream and downstream of the Jimmawarruda-Robe confluence (Table 12 and Figure 12).

The following species are not listed for conservation significance, but are of some scientific interest:

Individuals which appeared to be hybridised forms of two of the three co-occurring Robe River Terapontidae species (spangled perch, barred grunter and/or Fortescue grunter; Plate 9) were recorded from RRU1, RRU3, RRU5, RRU6, RRD2 and RRD5 (Table 12 and Figure 12). Hybridised grunters have been recorded from other Pilbara systems by the authors and others, including the Fortescue, Murchison and Ashburton rivers (Morgan and Gill 2006, Morgan *et al.* 2009, WRM 2016, WRM unpub. data). Morgan and Gill (2006) propose hybridisation between closely related fish species is not uncommon; however, the hybridisation of grunters in Pilbara river systems is not fully understood, and is of some interest, particularly if hybridisation results in the loss of species through replacement with reproductively unviable individuals, or if there is evidence of incipient speciation (the formation of a new species). Loss or replacement of a species is especially important in the case of the Fortescue grunter, as it is a nationally and internationally listed species of conservation significance.

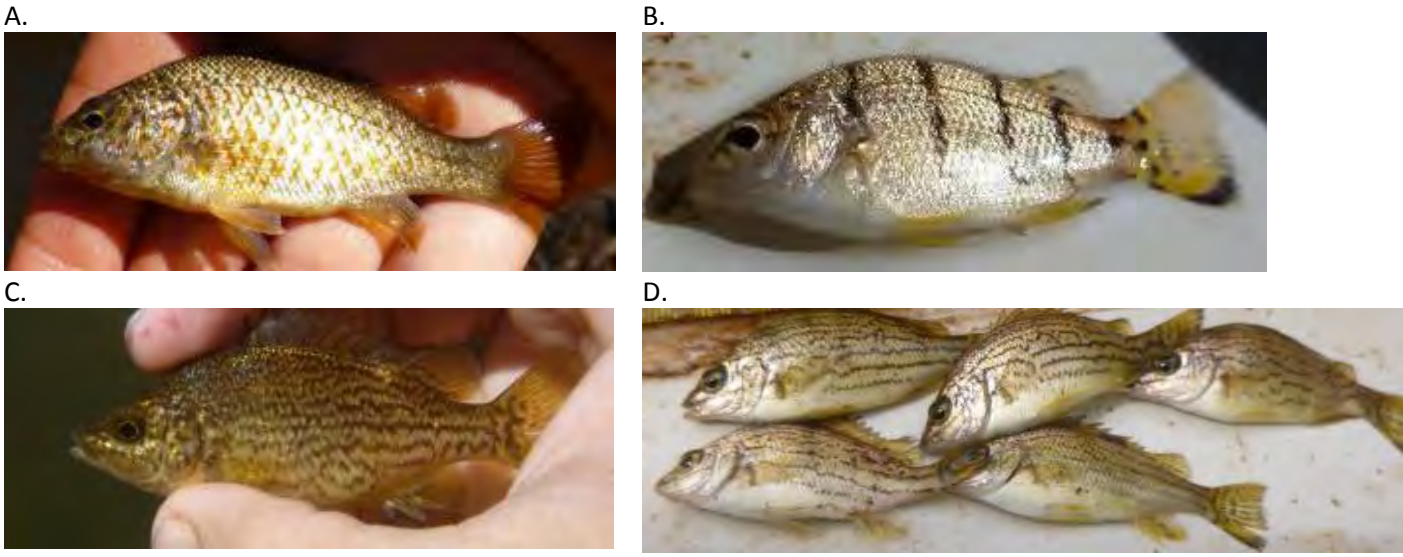


Plate 9. Terapontid hybridisation, illustrating (A) Spangled perch *Leiopotherapon unicolor,* (B) barred grunter *Amniataba percoides*, (C) Fortescue grunter *Leiopotherapon aheneus*, and (D) Terapontidae hybrids from RRU6, possibly sharing the features of barred and Fortescue grunter. Photographs by Chris Hofmeester (A, B and C)/WRM (D) ©.

None of the estuarine/marine fish species recorded in the Project area are endemic to the Pilbara region or currently listed for conservation significance. Milkfish (*Chanos chanos*) were not reported from the freshwater reaches of the Robe River by either Streamtec/UWA, Morgan and Gill (2004) or Antao and Braimbridge (2010). As such, collection of this species during the current study (along with its collection from further downstream) likely establishes a new record for the system. *Chanos chanos* is widely distributed across tropical and sub-tropical climes of the Indo-West Pacific region (Bagarinao 1994, Swanson 1998, Allen *et al.* 2002). This species is known to utilise fresh, brackish, oceanic and hypersaline lagoon environments (*i.e.* are euryhaline), being extremely efficient at osmoregulation during all life-history stages (Swanson 1998, Lin *et al.* 2003). In Australian waters, adult milkfish are pelagic schooling fish, inhabiting shallow, off-shore marine habitats. Spawning typically takes place offshore, following which juveniles migrate to sheltered estuaries. Sub-adult milkfish occasionally penetrate further upstream into freshwater reaches, before returning to the ocean to undergo sexual maturation and spawning (Bagarinao 1994, Allen *et al.* 2002).

5.5.3 Fish population structure

The reproductive strategies of freshwater fish species in the Pilbara are 'opportunistic' and 'periodic', reflecting the seasonal yet unpredictable nature of rainfall and streamflow in the region (Beesley 2006). Breeding of many species occurs during the wet season and during this time, multiple spawning events are known to occur (Beesley 2006). Further, the volume, hydrological regime and habitat complexity of Pilbara waterbodies can have a marked influence on fish population structure, with larger pools and more complex habitat considered generally advantageous for fish communities (Allen *et al.* 2002, Morgan *et al.* 2002, Morgan *et al.* 2009). Therefore, anthropogenically-induced alterations to streamflow patterns, water levels and water quality can have a discernible impact on life-history strategies and assemblage composition of local fish populations (Allen *et al.* 2002). Analysing population structure provides one means of characterising the health of fish assemblages at each site, and by extension the ecological processes driving aquatic communities within the waterbody. The presence of newly recruited and juvenile fish, for example, indicates recent spawning activity (and conditions conducive to such). Conversely, the presence of only sub-adult and adult (larger) fish may indicate a higher amount of predatory pressure on juvenile fish, and/or that conditions in pools are not conducive to spawning.

In order to examine population structures of the most ubiquitous freshwater fish of the Pilbara region (western rainbowfish, spangled perch and Pilbara tandan), length-frequency data for age-classes were estimated from published literature (*i.e.* Lake 1971, Bishop *et al.* 2001, Allen *et al.* 2002, Morgan *et al*. 2002, Beesley 2006; Table 13).

Table 13. Age-classes used in length-frequency analysis of Western rainbowfish, spangled perch and Pilbara tandan from the Project area. Age-classes are adapted from Lake (1971), Bishop *et al.* (2001), Allen *et al.* (2002), Morgan *et al*. (2002) and Beesley (2006).

Species	Age-class	Size mm SL
Western rainbowfish	New recruit	< 30
(*Melanotaenia australis*)	Juvenile	31-40
	Sub-adult	41-50
	Adult	> 51
Spangled perch	New recruit	< 30
(*Leiopotherapon unicolor*)	Juvenile	31-50
	Sub-adult	51-70
	Adult	> 71
Pilbara tandan	New recruit	< 30
(*Neosilurus* sp.)	Juvenile	31-70
	Sub-adult	71-90
	Adult	> 91

Western rainbowfish

Western rainbowfish breed throughout the year, with multiple spawning bouts that take full advantage of the region's intermittent rainfall and streamflow (Beesley 2006). Rainbowfish of the family Melanotaeniidae are usually sexually mature by the end of their first year (Allen *et al.* 2002). The size at sexual maturity can vary between river systems (typically around 50 mm SL), though western rainbowfish generally attain a maximum size of 110 mm total length (TL) (Allen *et al.* 2002).

The population structure of western rainbowfish at most upstream and downstream sites appeared to be healthy, with a variety of age-classes (new recruits, juveniles, sub-adults and adults) represented at RRU1, RRU4, RRU5, and RRD2 – RRD6 (Figure 13). New recruits and juveniles were particularly abundant at upstream site RRU4, and downstream sites RRD2, RRD4 and RRD6 (Figure 13), indicating spawning activity and good recruitment at these waterbodies. No western rainbowfish new recruits were recorded at RRD1, where sub-adults and adults (50 – 90 mm SL) dominated the population (Figure 13). Relatively low numbers of new recruits and juveniles (and low western rainbowfish numbers in general) were also recorded at RRU2 (Figure 13). Low recruitment of rainbowfish at RRD1 was possibly due to the small size of this pool, which also contained piscivorous species such as spangled perch, Fortescue grunter and barred grunter. Reduced depth and volume of small pools such as RRD1 inherently increases the risk of juvenile fishes to teleost (fish) and avian predation (Morgan *et al.* 2009). Conversely, low western rainbowfish abundance (and concurrent low abundance of new recruits and juveniles) recorded at RRU2 may have been related to the large size and volume of this pool, which would enable fish to avoid capture in seine and gill nets. Relatively low abundances of all fish species were recorded at RRU2, with the exception of Pilbara tandan, which are more commonly caught while electrofishing, rather than in seine and gill nets.

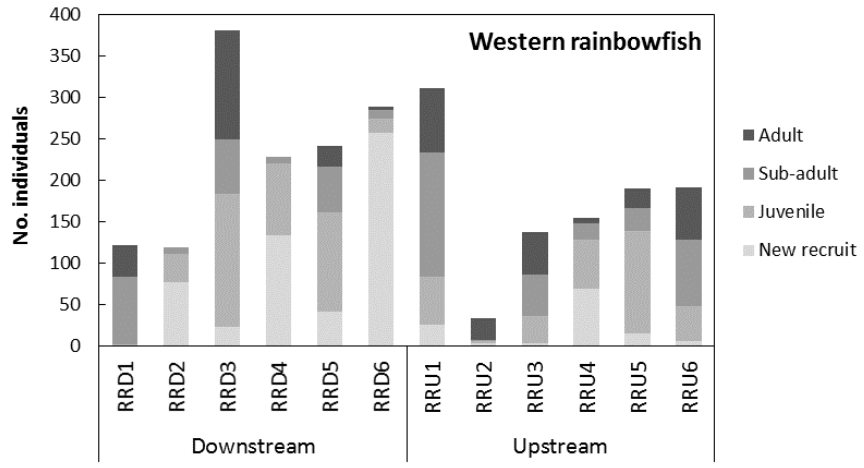


Figure 13. Abundance of western rainbowfish (*Melanotaenia australis*) age-classes recorded from each pool in the Project area.

Spangled Perch

Spangled perch are known to take advantage of wet season flooding to migrate upstream and breed (Bishop *et al.* 1995, Bishop *et al.* 2001, Pusey *et al.* 2004, Marsden and Power 2007). During this time, multiple spawning events are known to occur (Beesley 2006). In the Fitzroy River, Morgan *et al.* (2002) collected mature specimens at the beginning of the wet season, and larvae at the end of the wet season, indicating that spawning coincided with the flooding of the river. Spangled perch mature in their first year, at approximately 58 mm TL for males and 78 mm TL for females, and can reach a maximum size of 300 mm TL (Allen *et al.* 2002, Beesley 2006).

Spangled perch recruitment in the Project area appeared to be low, with new recruits (< 30 mm SL) only recorded at RRU1 and RRU2 upstream of the Jimmawarruda-Robe confluence, and RRD3 and RRD4 downstream of the confluence (Figure 14). Juveniles (31 - 60 mm SL) were also absent or recorded in low numbers at most sites (Figure 14). This reflects the high degree of variability in streamflow in the Project area, with low rainfall and streamflow leading up to the survey likely restricting spangled perch spawning activity. The exception was downstream site RRD3, where the spangled perch population comprised mainly juveniles (227 juveniles) (Figure 14). This suggests spangled perch may have spawned in or upstream of this pool recently following a flood event, with juveniles becoming isolated as waters

receded. RRD3 supported the highest abundance of spangled perch in the Project area (382 individuals), constituting 67% of all spangled perch caught during the survey; however, given the ubiquitousness of this species across the Pilbara, it is likely that larger populations reside at larger pools within the Project area. Catch per unit effort is likely reduced in these pools, such as RRU2, RRU4, RRU5, RRD4, RRD5 and RRD6, due to their size and depth, and presence of submerged debris (*e.g.* logs, branches, snags), which hinders seine and gill netting.

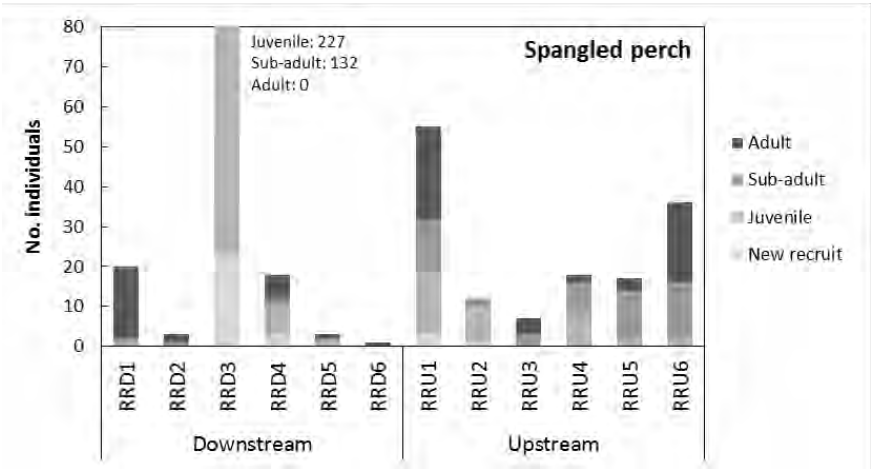


Figure 14. Abundance of spangled perch (*Leipotherapon unicolor*) age-classes recorded from each pool in the Project area. Note: column representing RRD3 is only partially displayed; the remainder of age-classes are given as text (new recruits are still displayed).

Pilbara tandan

Very little is known of the breeding ecology of the Pilbara tandan. Species of *Neosilurus* catfish usually attain a maximum size of only 200 mm SL, whereas similar species, such as *N. hyrtlii* and *N. ater*, can reach up to 400 mm TL (Lake 1971, Bishop *et al.* 2001). Breeding is thought to occur in the early wet season, where adults (> 91 mm SL) build their nests under large cobbles in flowing riffle zones (Bishop *et al*. 2001, Morgan *et al.* 2002). It is at this time when flooding increases the area and diversity of aquatic habitat available, while also initiating increases in plankton and other food sources (Bishop *et al.* 2001).

Pilbara tandan were collected in relatively low abundance throughout the Project area, with no new recruits (< 30 mm SL) recorded (Figure 15). Juvenile Pilbara tandan (31 – 70 mm SL) were only recorded at RRD2, RRU1 and RRU2 (Figure 15). Similar to spangled perch, low Pilbara tandan recruitment likely reflects the lack of streamflow in the Project area prior to the survey. Further, low overall catch rates of Pilbara tandan was likely due to the inherent difficulties in sampling this species. Like most other catfish, the Pilbara tandan is a benthic feeder, with techniques such as gill and seine netting generally limited in their ability to collect specimens due to the bottom-dwelling nature of these fish.

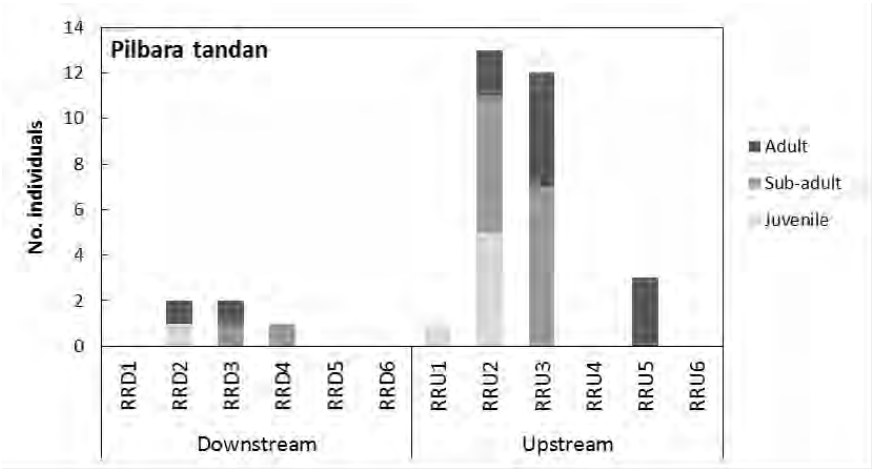


Figure 15. Abundance of Pilbara tandan (*Neosilurus* sp.) age-classes recorded from each pool in the Project area.

5.6 Other Fauna

No frogs or tadpoles were observed at any site in the current study. Although it is expected that some frogs do utilise pools within the Project area, the presence of large predatory fish, waterbirds and other predators (*e.g.* snakes) at these waterbodies would likely reduce survival rates of tadpoles in remnant pools.

No turtles were captured or observed in the Project area. EPA (1991) noted the native flat-shelled turtle, *Chelodina steindachneri,* was present at Gnieraoora and Martangkuna, but do not state the source of the records, which was possibly the 1991 survey by Streamtec/UWA for the Mesa J Project area.

6 SUMMARY AND CONCLUSIONS

This report summarises the results of wet season baseline sampling of aquatic ecosystems of the Robe River, both upstream and downstream of the proposed Mesa H development. The aim of the sampling program was to document the current ecological condition of the Robe River prior to the Mesa H development, which will require mine dewatering and surplus water discharge and may result in a surface discharge footprint along the Robe River. The current sampling program documents "current" ecological condition, moreso than "natural" condition due to the existing mine operations. In general, both water quality and aquatic fauna (microinvertebrate, hyporheic invertebrate, macroinvertebrate and fish) data indicated little ecological difference between "reference" sites upstream of the proposed development, and downstream sites that may be potentially exposed to dewatering discharge.

Water quality was highly variable amongst sites, with salinity levels ranging from fresh (592 µS/cm) to brackish (1,700 µS/cm), pH from circum-neutral (6.9) to slightly alkaline (7.9) and dissolved oxygen from hypoxic (14.5%) to supersaturated (134.9%). There were no obvious longitudinal gradients upstream or downstream of the Jimmawurrada-Robe confluence. Site RRU6, (~1 km upstream of the confluence) and the downstream sites, tended to have higher salinity (as EC and TDS), alkalinity, hardness and concentrations of associated ions, than sites upstream. This inter-site variability was attributed to differences in volume of the remnant pools sampled and evapoconcentration effects under recessional flows.

Exceedances of ANZECC/ARMCANZ default 95% TVs were recorded for nitrogen nutrients (N-total, N-NO_x and N-NH_3) at most sites upstream and downstream of the Jimmawurrada-Robe confluence. Elevated background levels of N-NO_3 and N-NH_3 within the Project area are unsurprising, given that the Robe River catchment is already effected by current and historic pastoral practices, with groundwaters also appearing to be enriched. Cattle, or evidence of high cattle use, were observed at a number of pools. Elevated N-total and N-NO_x downstream of the Jimmawurrada-Robe confluence may also reflect discharge of nitrogen-enriched groundwater from existing mine operations, though the relative contribution of anthropogenic and natural sources to nitrogen enrichment in surface waters of the Project area is unknown. With the exception of dissolved zinc at RRU5 and RRD3, no heavy metal analyte exceeded ANZECC/ARMCANZ default 95% TVs in the Project area.

A total of 81 microinvertebrate taxa were recorded from the Project area, of which 46 were present at potentially exposed sites downstream of the Jimmawurrada-Robe confluence, and 69 were recorded at upstream reference sites. The microinvertebrate fauna was generally typical of that commonly recorded from tropical/sub-tropical freshwater systems, comprising protists, rotifers, copepods, cladocerans (water fleas) and ostracods (seed shrimp), with Lecanidae dominating within the Rotifera. There were no significant differences in total mean microinvertebrate taxa richness between reference and potentially exposed sites, nor was there any significant difference in richness of any of the major microinvertebrate groups (protists, rotifers, micro-crustaceans) between these reaches.

Hyporheic sampling collected 59 taxa in total, the majority of which were species not specially adapted to groundwater environments (stygoxene); however, 8% were considered stygobitic (obligate groundwater inhabitants), 31% occasional hyporheic stygophiles (species that use the hyporheic zone seasonally or during early life history stages), and 2% possible hyporheic taxa. There were no obvious longitudinal gradients or patterns in hyporheic taxa richness between reference and potentially exposed sites, though hyporheic taxa richness was relatively high at RRD1, RRU6, RRD2 and RRU4, suggesting strong connectivity between ground- and surface- waters at these sites.

A total of 148 macroinvertebrate taxa were recorded from surface waters, with composition typical of freshwater systems throughout the world, being dominated by Insecta, in particular Diptera (true flies) and Coleoptera (aquatic beetles). There were no clear upstream/downstream gradients in

macroinvertebrate richness within the Project area, with no significant difference in mean total taxa richness, and mean richness of most major macroinvertebrate groups, between reference and potentially exposed sites. Similarly, multivariate analysis detected no distinguishable separation of reference or potentially exposed sites based on macroinvertebrate species assemblage structure.

3,515 individual fish, representing 11 species, were captured, measured and released in the Project area. True freshwater species included western rainbowfish, spangled perch, Pilbara tandan (eel-tailed catfish), Fortescue grunter, barred grunter, Terapontidae (grunter) hybrids and bony bream. Estuarine/marine vagrant fish species included milkfish, tarpon/ox-eye herring, mullet and banded scat/striped butterfish, the majority of which were recorded at downstream sites. The conservation listed Fortescue grunter (*Leipotherapon aheneus*; IUCN Lower Risk/Near Threatened; Parks and Wildlife Priority 4) was the second most abundant fish species of the Project area, recorded at all upstream and downstream sites. Similar to other fauna indices, there was no significant difference in mean total abundance of fish between upstream and downstream sites, nor was there any significant difference in mean abundance of each individual species between the reaches. Healthy (breeding) populations of western rainbowfish, the most abundant fish species of the Project area, were recorded from both the upstream and downstream reaches; however, spangled perch and Pilbara tandan recruitment appeared to be low throughout the Project area.

Including the Fortescue grunter, four species of conservation significance were recorded in the Project area, all of which were present at sites potentially exposed to dewatering discharge. These are summarised in Table 14 below:

Table 14. Summary of aquatic species of conservation significance (conservation listed or short range endemic) recorded from the Project area.

Species	Common name	Conservation significance	Occurrence within the Project area	Occurrence elsewhere
Microinvertebrates				
Eodiaptomus lumholtzi	Calanoid copepod	IUCN Vulnerable	RRD6	Koodaderi Spring, Homestead Trib., Mindy Mindy Ck., Cane R., NT & QLD.
Stygal / SRE invertebrates				
Nedsia spp.	Stygal amphipod	Potential short range endemic (data deficient)	RRD1 – 4, RRU3, RRU4 and RRU5	Uncertain, possibly bores within the Yarraloola Area
Macroinvertebrates				
Eurysticta coolawanyah	Pilbara pin damselfly	IUCN Near Threatened, Pilbara endemic	RRD3 and RRD4	Widespread throughout the Pilbara, though infrequently collected
Fish				
Leipotherapon aheneus	Fortescue grunter	IUCN Near Threatened, Parks and Wildlife Priority 4, Pilbara endemic	All sites	Robe R. catchment, Fortescue R. (below Fortescue Marsh); Ashburton R.

Current results indicate little ecological difference between "reference" sites upstream of the proposed Mesa H development, and downstream sites that may be potentially exposed to dewatering discharge operations. As such, these results provide a good starting point to enable the detection of potential ecological changes downstream of the Mesa H development caused by an altered abstraction and dewatering discharge regime. Data collected from reference sites upstream of Mesa H serve as the "control" for potentially exposed sites, while April/May 2016 data provide a snapshot of the "before"

condition, against which any future changes following mine development can be assessed. The premise being that if the degree of similarity between exposed and reference sites differs significantly over time (compared with pre-mine similarity), this would indicate mine-related response rather than stochastic variability due to factors such as climatic change.

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8 APPENDICES

Appendix 1. Photographs of sampled sites

Potential impact sites downstream of the Jimmawurrada-Robe confluence in April-May 2016.

RRD1

RRD2

RRD3

RRD4

RRD5

RRD6

Reference sites upstream of the Jimmawurrada-Robe confluence in April-May 2016

RRU1

RRU2

RRU3

RRU4

RRU5

RRU6

Appendix 2. ANZECC/ARMCANZ (2000) trigger values

Table A2-1. ANZECC/ARMCANZ (2000) default trigger values for some physical and chemical stressors for tropical Australia for slightly disturbed ecosystems (TP = total phosphorus; FRP = filterable reactive phosphorus; TN = total nitrogen; NOx = total nitrates/nitrites; NH4+ = ammonium). Data derived from trigger values supplied by Australian states and territories, for the Northern Territory and regions north of Carnarvon in the west and Rockhampton in the east.

	TP ($\mu g\ L^{-1}$)	*FRP ($\mu g\ L^{-1}$)*	*TN ($\mu g\ L^{-1}$)*	*NOx ($\mu g\ L^{-1}$)*	*NH_4^+ ($\mu g\ L^{-1}$)*	*DO % saturation[f]*	*pH*
Aquatic Ecosystem							
Upland River[e]	10	5	150	30	6	90-120	6.0-7.5
Lowland River[e]	10	4	200-300[h]	10[b]	10	85-120	6.0-8.0
Lakes & Reservoirs	10	5	350[c]	10[b]	10	90-120	6.0-8.0
Wetlands[3]	10-50[g]	5-25[g]	350-1200[g]	10	10	90[b]-120[b]	6.0-8.0

b = Northern Territory values are 5µgL-1 for NOx, and <80 (lower limit) and >110% saturation (upper limit) for DO;
c = this value represents turbid lakes only. Clear lakes have much lower values;
e = no data available for tropical WA estuaries or rivers. A precautionary approach should be adopted when applying default trigger values to these systems;
f = dissolved oxygen values were derived from daytime measurements. Dissolved oxygen concentrations may vary diurnally and with depth. Monitoring programs should assess this potential variability;
g = higher values are indicative of tropical WA river pools;
h = lower values from rivers draining rainforest catchments.

Table A2-2. ANZECC/ARMCANZ (2000) Default trigger values for salinity and turbidity for the protection of aquatic ecosystems, applicable to tropical systems in Australia.

Aquatic Ecosystem		*Comments*
Salinity	***(µs/cm)***	
Upland & lowland rivers	20-250	Conductivity in upland streams will vary depending on catchment geology. The fist flush may result in temporarily high values
Lakes, reservoirs & wetlands	90-900	Higher conductivities will occur during summer when water levels are reduced due to evaporation
Turbidity	***(NTU)***	
Upland & lowland rivers	2-15	Can depend on degree of catchment modification and seasonal rainfall runoff
Lakes, reservoirs & wetlands	2-200	Most deep lakes have low turbidity. However, shallow lakes have higher turbidity naturally due to wind-induced re-suspension of sediments. Wetlands vary greatly in turbidity depending on the general condition of the catchment, recent flow events and the water level in the wetland.

Table A2-3. ANZECC/ARMCANZ (2000) default trigger values for toxicants at alternative levels of protection (µg/L).

	Trigger values for freshwater Level of protection (% species)			
Compound	***99%***	***95%***	***90%***	***80%***
METALS & METALLOIDS				
Aluminium pH > 6.5	27	55	80	150
Aluminium pH < 6.5	ID	ID	ID	ID
Arsenic (As III)	1	24	94	360
Arsenic (As IV)	0.9	13	42	140
Boron	90	370	680	1300
Cadmium	0.06	0.2	0.4	0.8
Cobalt	ID	ID	ID	ID
Chromium (Cr III)	ID	ID	ID	ID
Chromium (Cr VI)	0.01	1	6	40
Copper	1	1.4	1.8	2.5
Iron	ID	ID	ID	ID
Manganese	1200	1900	2500	3600
Molybdenum	ID	ID	ID	ID
Nickel	8	11	13	17
Lead	1	3.4	5.6	9.4
Selenium (Se total)	5	11	18	34
Selenium (Se IV)	ID	ID	ID	ID
Uranium	ID	ID	ID	ID
Vanadium	ID	ID	ID	ID
Zinc	2.4	8	15	31
NON-METALLIC INORGANICS				
Ammonia	320	900	1430	2300
Chlorine	0.4	3	6	13
Nitrate	17	700	3400	17000

Appendix 3. Water quality data

Results from spot measurement of surface water quality taken in conjunction with aquatic fauna sampling. ANZECC/ARMCANZ (2000) default TV for protection of 95% of freshwater species is also provided for comparison; ☐ ≥ default TV, ☐ ≥ 2x default TV, ☐ ≥ 10x default TV; note, for DO, values highlighted are less than the lower default TV.

Water Quality Parameter	Method Code	*LOR*	Units	ANZECC TV	RRD1 30-04-16 0815hr	RRD2 30-04-16 1345hr	RRD3 30-04-16 1530hr	RRD4 29-04-16 1415hr	RRD5 29-04-16 1200hr	RRD6 30-04-16 1230hr	RRU1 05-05-16 0845hr	RRU2 28-04-16 1130hr	RRU3 28-04-16 0830hr	RRU4 28-04-16 1500hr	RRU5 29-04-16 0715hr	RRU6 07-05-16 1015hr
Al	iMET1WCICP	*0.005*	mg/L	0.055	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Alkalinity	iALK1WATI	*1*	mg/L	NP	245	133	266	260	249	241	155	156	175	166	183	253
As	iMET1WCMS	*0.001*	mg/L	0.013[A]	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
B	iMET1WCICP	*0.02*	mg/L	0.37	0.29	0.18	0.2	0.28	0.36	0.28	0.19	0.19	0.22	0.2	0.21	0.33
Ba	iMET1WCICP	*0.002*	mg/L	NP	0.051	0.035	0.039	0.04	0.058	0.046	0.043	0.044	0.055	0.039	0.044	0.05
CO_3	iALK1WATI	*1*	mg/L	NP	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Ca	iMET1WCICP	*0.1*	mg/L	NP	81.5	48.9	78.5	74.2	65.6	66.8	46.5	46.3	51.1	48.4	51.8	100
Cd	iMET1WCMS	*0.0001*	mg/L	0.0002	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Cl	iCO1WCDA	*1*	mg/L	NP	209	126	193	176	213	169	120	115	109	138	128	372
Co	iMET1WCMS	*0.0001*	mg/L	ID	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0002	<0.0001	<0.0001	<0.0001
Cr	iMET1WCMS	*0.0005*	mg/L	0.001	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Cu	iMET1WCMS	*0.0001*	mg/L	0.0014	0.0002	0.0002	0.0002	0.0002	0.0002	0.0007	0.0003	0.0002	0.0002	0.0002	0.0002	0.0003
DO (field)	TPS WP-82Y logger	*0.01*	% sat.	90 - 120	72.7	44.6	94.6	79.2	37.4	134.9	37.2	38.5	16.1	74.1	14.5	77.8
DO (field)	TPS WP-82Y logger	*0.01*	mg/L	NP	5.8	3.6	8.0	5.8	2.7	8.4	2.4	2.9	1.2	5.8	0.9	5.3
EC	iEC1WZSE	*2*	µS/cm	250	1280	711	1260	1220	592	1130	772	748	824	782	802	1700
Fe	iMET1WCICP	*0.005*	mg/L	0.3*	0.007	0.013	<0.005	<0.005	0.012	0.036	0.058	0.022	0.099	0.059	0.061	0.018
HCO_3	iALK1WATI	*1*	mg/L	NP	299	162	324	317	303	294	190	191	214	202	223	309
Hardness	iHTOT2WACA	*1*	mg/L	NP	440	260	420	400	430	360	240	230	250	240	250	520
K	iMET1WCICP	*0.1*	mg/L	NP	9	6	8.6	8.2	9.7	8.7	5	5.8	6.2	6.1	6	4.4
Mg	iMET1WCICP	*0.1*	mg/L	NP	57.2	33.7	54.3	52.4	63.6	46.7	30.3	27	29.7	29.3	30.3	66.5
Mn	iMET1WCICP	*0.001*	mg/L	1.9	<0.001	0.002	<0.001	<0.001	0.003	0.004	0.002	0.009	0.099	0.002	0.004	0.004
Mo	iMET1WCMS	*0.001*	mg/L	ID	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001
N-NH_3	iAMMN1WFIA	*0.01*	mg/L	0.01[N]	0.02	0.05	<0.01	<0.01	<0.01	0.03	<0.01	0.02	0.01	0.01	0.01	0.07
N-NO_2	iNTRN1WFIA	*0.01*	mg/L	NP	<0.01	0.02	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.04
N-NO_3	iNTAN1WCALC	*0.01*	mg/L	NP	1.8	1.3	1.3	2	0.86	2.5	<0.01	1.2	0.95	0.38	1.1	3.7

Water Quality Parameter	Method Code	*LOR*	Units	ANZECC TV	RRD1 30-04-16 0815hr	RRD2 30-04-16 1345hr	RRD3 30-04-16 1530hr	RRD4 29-04-16 1415hr	RRD5 29-04-16 1200hr	RRD6 30-04-16 1230hr	RRU1 05-05-16 0845hr	RRU2 28-04-16 1130hr	RRU3 28-04-16 0830hr	RRU4 28-04-16 1500hr	RRU5 29-04-16 0715hr	RRU6 07-05-16 1015hr
N-NO_X	iNTAN1WFIA	*0.01*	mg/L	0.01	1.8	1.3	1.3	2	0.87	2.5	<0.01	1.2	0.96	0.38	1.1	3.8
N-total	iNP1WTFIA	*0.01*	mg/L	0.3	1.8	1.5	1.3	2	0.88	2.6	0.09	1.4	1	0.41	1.2	3.9
Na	iMET1WCICP	*0.1*	mg/L	NP	91.4	53.9	86.4	87.1	104	87.2	51.6	53.3	64.7	60.1	58.9	132
Ni	iMET1WCMS	*0.001*	mg/L	0.011	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
OH	iALK1WATI	*1*	mg/L	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
P-total	iPP1WTFIA	*0.005*	mg/L	0.01	0.011	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	0.011
Pb	iMET1WCMS	*0.0001*	mg/L	0.034	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
pH (field)	WTW pH330i field meter	*0.1*	[H+]	6.0 - 8.0	7.4	7.3	7.0	7.2	7.2	7.7	7.9	7.0	6.9	7.2	7.0	7.4
pH (lab)	iPH1WASE	*0.1*	[H+]	6.0 - 8.0	7.9	7.8	7.7	7.9	7.8	8	8	7.7	7.6	7.9	7.7	7.8
Redox (field)	WTW pH330i field meter	*-1999*	mV	NP	-27.2	-19.3	-3.8	-15.6	-13.5	-46.1	-56.8	-1.1	2.6	-19.4	-3.3	-22.9
S	iMET1WCICP	*0.1*	mg/L	NP	28	28	25	24	25	22	14	12	14	13	12	22
S-SO_4	iMET1WCICP	*0.1*	mg/L	NP	84	50	73.6	72	75.3	66.3	43.3	34.8	40.5	40	36.6	67.1
Se	iMET1WCMS	*0.001*	mg/L	0.011	0.002	<0.001	<0.001	0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.003
TDS-calc	iSOL1WDCA	*5*	mg/L	NP	700	390	700	670	330	620	420	410	450	430	440	940
Temp (field)	TPS WP-82Y logger	*-5*	°C	NP	27.4	25.0	30.1	30.7	27.4	28.2	24.8	29.6	26.6	28.6	28.2	27.7
TSS	iSOL1WPGR	*1*	mg/L	NP	3	4	7	<1	34	2	4	4	<1	2	<1	19
U	iMET1WCMS	*0.0001*	mg/L	ID	0.0009	0.0004	0.0004	0.0004	0.001	0.0008	0.0002	0.0002	0.0001	0.0004	0.0003	0.0016
V	iMET1WCMS	*0.0001*	mg/L	ID	0.0017	0.0012	0.0008	0.0016	0.0015	0.0031	0.0019	0.0011	0.0003	0.0013	0.001	0.0027
Zn	iMET1WCMS	*0.001*	mg/L	0.008[H]	0.004	0.002	0.011	0.003	0.003	0.007	0.004	0.004	0.001	0.003	0.012	0.004

* ANZECC/ARMCANZ (2000) provide only a low reliability TV for iron (Fe);

[A] Default TV shown is for AsV, as no default TV is provided for total arsenic;

[B] For bioaccumulating chemicals, ANZECC/ARMCANZ (2000) recommend using the default 99% species protection level TV;

[H] Default TV should be modified for water hardness using algorithms provided in Table 3.4.3 of ANZECC/ARMCANZ (2000);

[N] Default TV shown is for ammonium nitrogen, as N-NH_4^+, for protection against eutrophication. Default TV for protection against toxic effects of ammonia, as N-NH_3, is 0.9 mg/L.

Appendix 4. Habitat data

Site	RRD1	RRD2	RRD3	RRD4	RRD5	RRD6	RRU1	RRU2	RRU3	RRU4	RRU5	RRU6
Date	30-04-16	30-04-16	30-04-16	29-04-16	29-04-16	30-04-16	05-05-16	28-04-16	28-04-16	28-04-16	29-04-16	07-05-16
Canopy cover (%)	0	25	5	15	35	5	2	20	2	5	50	5
Bedrock %	0	5	2	0	0	5	5	0	0	0	0	2
Boulders %	0	2	5	0	2	2	2	2	1	5	0	2
Cobbles %	10	3	5	5	10	3	10	10	19	15	5	35
Pebbles %	30	15	35	35	23	25	36	50	60	40	65	25
Gravel %	30	55	35	55	45	35	40	32	15	38	23	15
Sand %	5	20	13	5	15	5	5	3	3	2	5	0
Silt %	15	0	5	0	5	10	0	1	2	0	0	21
Clay %	10	0	0	0	0	15	2	2	0	0	2	0
Mineral %	45	41	41	36	49	5	5	49	53	12	10	20
Emergent veg %	10	10	20	35	20	20	5	25	0	60	43	40
Submergent veg %	0	30	15	5	15	30	25	15	0	10	20	5
Floating veg %	0	0	0	0	0	0	55	3	0	10	0	0
Algae %	5	2	10	5	10	3	5	2	15	5	10	3
Detritus %	40	10	10	15	2	38	0	2	5	2	5	30
Trailing veg %	0	5	2	2	2	2	0	3	0	0	5	0
LWD %	0	2	2	2	2	2	3	1	2	1	5	2
Other %	0	0	0	0	0	0	2	0	25	0	2	0
Max Pool Depth (m)	0.8	0.7	1	2	4	1.2	1.20	3	1	1	1.2	0.6
Pool Length (m)	7	12	25	150	45	20	100	60	3	120	40	40
Ave Pool Width (m)	3	6	5	20	25	30	20	10	5	20	10	12
Bed compaction*	2	3	3	2	3	1	3	2	2	2	3	3
Habitat diversity	4	7	7	7	7	7	7	8	5	7	8	6
Mean substrate size (phi)	-0.575	-1.750	-2.465	-2.900	-2.140	-0.025	-2.960	-3.405	-4.135	-3.945	-3.420	-2.515
Substrate diversity**	6	6	7	4	6	8	7	6	5	5	5	6

* Bed compaction categories range from 1 = loose, to 5 = armoured.

** Total number of substrate types present.

Appendix 5. Microinvertebrate data

Values are total abundance.

Phylum/Class/Order	Family	Lowest Taxon	RRU1	RRU2	RRU3	RRU4	RRU5	RRU6	RRD1	RRD2	RRD3	RRD4	RRD5	RRD6
PROTISTA														
CILIOPHORA	**Stentoridae**	*Stentor* sp.	0	0	0	4	*	0	0	0	0	0	0	0
RHIZOPODA	**Arcellidae**	*Arcella discoides* Ehrenberg, 1843	*	0	13	3	0	0	0	1	0	1	0	1
		Arcella hemisphaerica Perty 1852	0	0	25	0	0	0	0	2	0	0	0	0
		Arcella megastoma Penard, 1902	0	0	0	2	0	0	0	0	0	0	0	0
		Arcella [sm]	*	0	0	0	0	0	0	0	0	0	0	0
	Centropyxidae	*Centropyxis aculeata* (Ehrenberg, 1838)	0	0	0	0	1	0	0	0	0	0	0	0
		Centropyxis cf. *aculeata* (Ehrenberg, 1838) [v. sm]	0	0	0	1	1	0	0	0	0	0	0	0
		Centropyxis ecornis (Ehrenberg, 1841)	0	*	0	5	11	0	0	1	0	1	2	2
	Difflugiidae	*Difflugia globulosa* Dujardin, 1837	*	1	1	6	2	0	0	3	0	0	0	3
		Difflugia gramen Penard, 1902	0	0	0	0	0	0	0	0	0	0	0	2
		Difflugia sp. [sm, pyriform]	0	0	0	1	4	0	0	0	0	0	0	*
	Lesquereusiidae	*Lesquereusia spiralis* (Ehrenberg, 1840)	0	0	1	0	3	0	0	0	1	0	0	2
	Trigonopyxidae	*Cyclopyxis* sp.	0	0	0	1	0	0	0	0	0	0	0	0
ANIMALIA														
ROTIFERA														
Bdelloidea		indet. bdell. [lg, bidentate]	0	0	0	0	20	4	0	0	0	0	0	4
		indet. bdell. [sm, likely more than one sp.]	0	1	8	4	14	2	0	0	0	0	0	4
		indet. bdell. [tiny]	0	0	0	0	*	0	0	0	0	1	0	0
Monogononta	**Asplanchnidae**	*Asplanchnopus hyalinus* (Harring, 1913)	0	0	0	0	0	0	0	0	0	0	0	*
	Brachionidae	*Brachionus angularis* Gosse, 1851	*	0	0	0	0	0	0	0	0	0	0	0
		Keratella procurva (Thorpe, 1912)	0	0	0	0	0	0	0	0	0	*	0	0
		Plationus patulus (Müller, 1786)	0	1	0	0	0	0	0	0	0	0	0	2
		Platyias quadricornis (Ehrenberg, 1832)	0	*	0	0	0	0	0	0	0	0	0	0
	Dicranophoridae	*Dicranophoroides caudatus* (Ehrenberg, 1834)	0	0	0	0	1	0	0	1	0	0	0	0
	Euchlanidae	*Euchlanis dilatata* Ehrenberg, 1832	0	*	0	0	0	0	0	0	0	0	0	1
		Tripleuchlanis plicata (Levander, 1894)	0	0	0	2	1	0	0	0	0	0	0	*
	Flosculariidae	*Sinantherina* sp. [solitary]	*	*	0	0	0	0	0	0	0	0	0	0
	Gastropodidae	*Ascomorpha* sp.	0	0	1	0	0	0	0	0	0	1	0	3
	Lecanidae	*Lecane bulla* (Gosse, 1851)	0	0	1	7	2	0	0	0	0	0	0	4
		Lecane curvicornis (Murray, 1913)	0	0	0	0	9	0	0	0	0	0	0	0
		Lecane hamata (Stokes, 1896)	0	0	1	0	0	0	0	0	0	0	0	1

Phylum/Class/Order	Family	Lowest Taxon	RRU1	RRU2	RRU3	RRU4	RRU5	RRU6	RRD1	RRD2	RRD3	RRD4	RRD5	RRD6
		Lecane ludwigii (Eckstein, 1883)	0	0	0	0	0	0	0	0	0	1	0	0
		Lecane **n. sp.**	0	0	0	0	1	0	0	0	0	0	0	2
		Lecane stenroosi (Meissner, 1908)	2	0	0	0	0	1	0	0	0	1	0	0
		Lecane thalera(Harring & Myers, 1926)	0	0	0	11	9	0	0	0	0	1	0	1
		Lecane (s. str.) a	0	0	0	0	12	0	0	0	0	0	0	0
		Lecane (s. str.) b [v. sm]	0	0	0	0	1	0	0	0	0	0	0	0
		Lecane (*M.*) sp. a	0	0	0	1	4	0	0	0	0	0	0	0
		Lecane (*M.*) sp. b	0	0	0	0	3	0	0	0	0	0	0	0
		Lecane (*M.*) sp. c	0	0	0	0	1	1	0	0	0	0	0	0
	Lepadellidae	*Colurella* sp. [tiny]	0	0	0	0	2	0	0	0	0	0	0	0
		Lepadella cf. *rhomboides* (Gosse, 1886)	0	0	0	0	1	0	0	0	0	0	0	0
		Lepadella sp.	0	0	1	1	2	0	0	0	0	0	0	0
		Squatinella rostrum (Schmarda, 1846)	0	0	0	0	1	0	0	0	0	0	0	1
	Lindiidae	*Lindia* sp.	0	0	0	0	3	0	0	0	0	0	0	0
	Notommatidae	*Cephalodella gibba* (Ehrenberg, 1830)	0	0	1	0	0	0	0	0	0	0	0	0
		Cephalodella sp.	*	0	0	0	0	0	0	0	0	0	0	0
		notommatid, indet.	0	0	0	0	0	0	0	0	0	0	0	1
	Proalidae	*Proales* sp.	0	0	0	1	0	0	0	0	0	0	0	3
	Scaridiidae	*Scaridium* sp.	0	0	0	0	1	0	0	0	0	0	0	0
	Synchaetidae	*Polyarthra* sp.	5	145	6	0	0	0	0	0	0	0	0	39
		indet. contr. blob	*	0	3	2	0	0	0	0	0	0	0	0
		maybe rotifer	0	0	0	1	0	0	0	0	0	0	0	0
ARTHROPODA														
CLADOCERA	**Bosminidae**	*Bosmina meriodionalis* Sars, 1904	0	0	0	2	0	0	0	0	0	0	0	0
	Chydoridae	*Anthalona harti* Van Damme, Sinev & Dumont, 2011	0	0	0	0	0	0	0	1	0	0	0	0
		Chydorus sp.	0	0	0	1	0	0	0	0	0	0	0	0
		Dunhevedia crassa King, 1853	0	*	0	0	0	0	0	0	0	0	0	0
		Ephemeroporus barroisi (Richard, 1894)	0	0	0	2	0	0	0	1	2	0	0	0
		Karualona karua (King, 1853)	0	0	0	1	0	0	0	4	0	0	0	0
		indet. alonine	*	0	*	0	0	0	0	1	1	0	0	0
	Daphnidae	*Ceriodaphnia cornuta* Sars, 1885	*	0	0	0	0	0	0	0	0	0	0	0
		Ceriodaphnia sp.	0	*	0	0	0	0	0	0	0	0	0	0
	Ilyocryptidae	*Ilyocryptus* sp. [juv.]	0	0	0	0	0	1	0	0	0	0	0	0
	Moinidae	*Moina micrura*	0	*	0	0	0	0	0	0	0	0	0	0
	Sididae	*Diaphanosoma excisum* Sars, 1885	0	*	0	0	0	0	0	0	0	0	0	*
COPEPODA	**Calanoida**	*Eodiaptomus lumholtzi* (Sars, 1889)	0	0	0	0	0	0	0	0	0	0	0	1
		calanoid copepodite	0	0	0	0	0	0	0	0	0	0	0	1

Phylum/Class/Order	Family	Lowest Taxon	RRU1	RRU2	RRU3	RRU4	RRU5	RRU6	RRD1	RRD2	RRD3	RRD4	RRD5	RRD6
		calanoid nauplii	0	0	0	0	0	0	0	0	0	0	0	3
	Cyclopoida	*Mesocyclops darwini* Dussart & Fernando, 1988	0	0	0	1	0	0	0	0	1	0	0	*
		Mesocyclops sp. [other]	0	0	0	0	*		0	0	0	0	0	0
		Tropocyclops cf. *prasinus* (Fischer, 1860)	0	0	0	0	0	0	0	0	0	9	0	3
		indet. cyclopoid sp. [3-seg. P1-4]	0	0	0	0	0	0	0	2	0	0	0	0
		indet. cyclopoid lg	*	*	0	0	0	0	0	0	0	0	0	0
		indet. cyclopoid sm	*	2	1	0	0	0	0	8	0	0	0	0
		cyclopoid copepodites	11	2	35	14	5	1	2	76	0	21	0	26
		cyclopoid nauplii	184	56	106	93	97	2	0	13	0	168	0	85
OSTRACODA	**Cyprididae**	*Cypretta* sp.	*	*	0	1	0	0	0	3	0	0	0	*
		cf. *Cypridopsis* sp.	0	0	*	1	0	valves	0	0	0	*	0	0
		Heterocypris sp.	0	*	0	0	0	0	0	0	0	0	0	0
		Sarscypridopsis sp.	0	0	0	0	0	0	0	0	0	0	0	0
	Darwinulidae	*Vestalenula marmonieri*	0	*	0	1	3	valves	2	70	13	0	0	*
	Limnocytheridae	*Limnocythere* sp.	0	0	0	0	*	0	valves	2	2	0	0	*
	Notodromadidae	indet. juv.	0	0	0	0	2	0	1	3	1	0	0	3
		Taxa Richness	**16**	**19**	**18**	**27**	**33**	**7**	**3**	**17**	**7**	**12**	**1**	**33**

*found after initial count of ~200 cells

Appendix 6. Hyporheic invertebrate data

Values are log_{10} abundance categories, where 1= 1 individual, 2 = 2-10 individuals, 3 = 11-100, 4 = 101-1000, and so on. Hyporheic fauna classifications (Class) followed those of Boulton (2001), where: X = stygoxene, O = occasional hyporheic stygophile, P = possible hyporheic taxa, S = stygobite and U = Unclassified.

Phylum/Class/Order	Family	Lowest Taxon	Class	RRD1	RRD2	RRD3	RRD4	RRD5	RRD6	RRU1	RRU2	RRU3	RRU4	RRU5	RRU6
PLATYHELMINTHES															
TURBELLARIA		Turbellaria spp.	X	0	0	0	0	1	1	0	0	0	0	0	2
NEMATODA		Nematoda spp.	O	0	0	0	0	3	2	2	0	0	1	0	0
MOLLUSCA															
GASTROPODA															
Cerithimorpha	**Thiaridae**	*Melanoides* spp.	X	2	0	0	3	2	0	0	0	0	0	0	0
Hygrophila	**Planorbidae**	*Gyraulus* spp.	X	0	0	0	2	0	0	0	0	0	0	0	0
ANNELIDA															
OLIGOCHAETA		Oligochaeta spp. (imm./dam.)	U	0	0	2	0	2	0	0	0	2	2	0	0
Tubificida	**Naididae**	Naididae spp. (imm./dam.)	O	1	3	0	0	3	0	0	0	0	2	2	0
		Allonais pectinata	O	0	0	0	0	0	0	0	0	0	1	0	0
		Branchiura sowerbyi	O	0	2	0	0	0	0	0	0	0	3	0	0
		Pristina aequiseta	O	0	3	0	0	0	0	0	0	0	0	0	0
		Pristina leidyi	O	0	0	0	0	0	0	0	0	0	0	2	0
		Pristina longiseta	O	1	0	2	0	1	3	0	0	0	1	0	1
	Phreodrilidae	Phreodrilidae spp.	O	0	0	0	2	0	0	0	0	1	0	0	0
ARTHROPODA															
CRUSTACEA															
MALACOSTRACA															
Amphipoda		Amphipoda spp. (stygofauna)	S	3	2	3	0	0	0	1	0	2	0	2	3
	Eriopisidae	*Nedsia* spp.	S	3	2	1	1	0	0	0	0	2	1	0	3

Phylum/Class/Order	Family	Lowest Taxon	Class	RRD1	RRD2	RRD3	RRD4	RRD5	RRD6	RRU1	RRU2	RRU3	RRU4	RRU5	RRU6
Thermosbaenacea	**Halosbaenidae**	*Halosbaena tulki*	S	0	2	2	1	0	0	0	0	2	0	0	0
MAXILLIPODA															
Cyclopoida		cyclopoid copepodites	U	2	3	1	0	1	3	2	0	3	0	2	3
	Cyclopidae	*Halicyclops calm*	O	0	0	0	0	0	0	1	1	0	0	0	0
		Mesocyclops darwini	O	0	0	0	0	0	0	0	0	2	0	0	0
		Microcyclops varicans	O	1	0	0	0	0	2	0	0	0	0	0	2
OSTRACODA															
	Candonidae	*Candonopsis* cf. *tenuis*	S	0	0	0	0	0	0	0	0	0	0	0	1
	Cyprididae	*Cypridopsis* sp.	O	2	0	0	1	0	0	0	0	0	0	0	0
		Cyprinotus cingalensis	O	1	0	0	0	0	0	0	0	0	0	0	0
		Stenocypris major	X	0	0	0	1	0	0	0	0	0	0	0	0
	Darwinulidae	*Vestalenula marmonieri*	S	3	0	0	0	1	0	2	0	0	0	0	0
ARACHNIDA		Acarina spp.	P	2	3	0	2	2	3	2	0	2	2	1	2
HEXAPODA															
ENTOGNATHA															
Entomobryomorpha		Entomobryoidea spp.	O	2	1	0	0	3	1	0	1	2	2	2	3
Poduromorpha		Poduroidea spp.	O	1	0	0	2	0	0	0	0	0	0	0	0
Symphypleona		Symphypleona spp.	O	0	0	0	0	0	0	2	0	0	0	0	1
INSECTA															
Ephemeroptera	**Caenidae**	*Tasmanocoenis* sp. P/*arcuata*	X	0	0	0	0	0	0	0	0	1	0	0	0
Coleoptera		Coleoptera spp. (L)	U	0	2	0	0	0	0	0	0	0	2	0	2
	Carabidae	Carabidae sp.	X	0	0	0	0	0	0	0	0	0	1	0	0
	Dytiscidae	Bidessini sp. (L)	X	0	0	0	0	0	0	0	0	0	1	0	0
	Elmidae	*Austrolimnius* spp. (L)	X	2	0	2	0	0	0	0	0	0	0	0	0
	Hydraenidae	Hydraenidae sp. (L)	O	0	0	0	0	1	0	0	0	0	0	0	1
		Hydraena spp.	O	2	0	0	0	0	0	0	0	0	0	0	0
	Hydrophilidae	Hydrophilidae spp. (L)	X	0	0	1	0	0	0	0	0	0	0	1	0

Phylum/Class/Order	Family	Lowest Taxon	Class	RRD1	RRD2	RRD3	RRD4	RRD5	RRD6	RRU1	RRU2	RRU3	RRU4	RRU5	RRU6
		Chaetarthria nigerrima (L)	X	0	0	0	0	2	0	0	0	0	0	0	0
		Enochrus sp. (L)	X	0	0	0	0	1	0	0	0	0	0	0	0
		Helochares sp. (L)	X	0	0	0	0	0	0	1	0	0	0	0	0
	Ptiliidae	Ptiliidae sp.	X	0	0	1	0	0	0	0	0	0	0	0	0
	Scirtidae	Scirtidae spp. (L)	X	2	1	0	0	0	1	0	0	0	1	2	2
	Staphylinidae	Staphylinidae sp.	X	0	1	0	0	0	0	0	0	0	0	0	0
Diptera	**Ceratopogonidae**	Ceratopogonidae spp. (P)	X	1	2	0	0	2	0	3	0	0	2	1	2
		Ceratopogoninae spp.	X	3	3	3	2	4	3	0	3	3	4	2	4
		Dasyheleinae spp.	X	0	3	3	2	3	1	3	2	1	2	0	0
		Forcipomyiinae spp.	X	0	0	0	0	2	0	0	0	0	0	0	0
	Chironomidae	Chironomidae sp. (P)	X	0	1	0	0	0	0	0	0	0	0	0	0
	Chironominae														
	Chironomini	*Paratendipes* sp. K1	X	0	1	0	0	3	0	0	0	0	0	0	0
		Polypedilum sp. 1	X	0	0	0	0	0	0	0	0	0	2	0	0
	Tanytarsini	*Cladotanytarsus* sp. (WWTS4)	X	0	0	0	0	1	0	0	0	0	0	0	0
		Tanytarsus sp. (WWTS1)	X	1	1	0	0	1	0	2	0	1	1	0	0
		Paratanytarsus sp. (WWTS2)	X	1	2	0	0	2	0	2	0	0	0	0	0
	Orthocladiinae	Orthocladiinae sp. (WWO7)	X	0	2	0	0	0	0	0	0	0	0	0	0
		Orthocladiinae sp. (WWO8)	X	0	0	2	0	0	2	0	0	2	0	0	2
	Tanypodinae	*Paramerina* sp. (WWT1)	X	2	0	0	0	0	0	0	0	1	0	0	0
	Dolichopodidae	Dolichopodidae spp.	X	0	2	2	0	0	0	0	1	0	0	0	0
	Empididae	Empididae spp.	X	0	0	2	0	0	0	0	0	0	0	0	0
	Tabanidae	Tabanidae sp.	X	0	0	0	0	0	0	1	0	0	0	0	0
	Tipulidae	Tipulidae spp.	X	0	1	0	0	3	0	2	1	0	0	0	0
		Taxa richness		**21**	**22**	**14**	**11**	**22**	**11**	**14**	**6**	**15**	**18**	**10**	**16**

(imm./dam) = taxa were too immature / damaged to be accurately identified to a lower taxonomic level.

(P) = taxa were in pupal form.

(L) = taxa were in larval form.

NB: some chironomid taxa are followed by their unique morphotype code (in parentheses).

Appendix 7. Macroinvertebrate data

Values are $\log_{10}$ abundance categories, where 1= 1 individual, 2 = 2-10 individuals, 3 = 11-100, 4 = 101-1000, and so on.

Phylum/Class/Order	Family	Lowest Taxon	RRD1	RRD2	RRD3	RRD4	RRD5	RRD6	RRU1	RRU2	RRU3	RRU4	RRU5	RRU6
CNIDARIA														
HYDROZOA														
Anthoathecata	**Hydridae**	*Hydra* sp.	1	0	0	0	0	0	0	0	0	0	0	0
MOLLUSCA														
GASTROPODA		Gastropoda spp. (imm./dam.)	0	0	0	0	0	0	0	0	0	0	2	0
Cerithimorpha	**Thiaridae**	*Melanoides* spp.	3	0	3	3	2	3	4	4	2	2	3	4
Hygrophila	**Lymnaeidae**	*Bullastra vinosa*	2	2	0	0	3	3	2	2	1	0	0	0
	Planorbidae	*Amerianna* spp.	0	0	0	0	0	0	0	2	0	0	0	0
		Ferrissia petterdi	2	2	0	0	0	0	0	0	0	0	2	0
		Gyraulus spp.	3	3	0	3	2	3	4	3	0	0	2	2
BIVALVIA														
Unionoida	**Hyriidae**	*Velesunio* spp.	0	0	0	0	0	0	0	0	0	0	0	2
ANNELIDA														
OLIGOCHAETA		Oligochaeta spp.	3	3	3	3	3	0	3	3	3	3	4	2
ARTHROPODA														
CRUSTACEA														
MALACOSTRACA														
Amphipoda		Amphipoda spp. (stygofauna)	0	0	3	2	0	0	0	0	0	0	0	0
	Eriopisidae	*Nedsia* spp.	0	0	2	3	0	0	0	0	0	0	0	0
Decapoda	**Atyidae**	Atyidae spp. (imm./dam.)	2	0	2	0	0	0	0	0	0	0	2	2
		Caridina indistincta	3	3	3	2	3	3	3	4	3	2	3	1
CHELICERATA														
ARACHNIDA		Acarina spp.	3	3	0	2	2	0	4	3	3	0	3	2
HEXAPODA														
ENTOGNATHA														
Entomobryomorpha		Entomobryoidea spp.	2	2	0	0	0	0	2	0	0	0	0	0
Symphypleona		Symphypleona sp.	0	0	0	0	0	0	1	0	0	0	0	0
INSECTA														
Odonata														
Anisoptera		Anisoptera spp. (imm./dam.)	2	2	2	0	1	2	2	3	2	2	0	0
	Aeshnidae	*Hemianax papuensis*	0	0	0	0	0	1	0	0	0	0	0	0
	Libellulidae	*Crocothemis nigrifrons*	0	2	0	0	0	0	1	0	0	0	1	0

Phylum/Class/Order	Family	Lowest Taxon	RRD1	RRD2	RRD3	RRD4	RRD5	RRD6	RRU1	RRU2	RRU3	RRU4	RRU5	RRU6
		Diplacodes bipunctata	0	0	0	0	0	1	0	0	2	2	0	1
		Diplacodes haematodes	0	0	0	0	0	0	1	0	0	1	0	0
		Orthetrum caledonicum	2	0	0	1	0	1	1	0	0	0	0	0
		Rhodothemis lieftincki	0	0	0	0	1	0	0	2	2	3	2	0
		Rhyothemis graphiptera	0	0	1	2	1	0	0	0	0	0	0	0
		Zyxomma elgneri	0	0	1	0	0	0	0	1	2	0	1	0
	Lindeniidae	*Ictinogomphus dobsoni*	1	0	0	1	0	2	0	0	1	0	0	0
Zygoptera		Zygoptera spp. (imm./dam.)	1	2	1	2	0	2	2	2	0	3	0	3
	Coenagrionidae	*Argiocnemis rubescens*	2	2	0	0	0	0	2	0	2	0	1	0
		Ischnura aurora	0	2	0	0	2	2	3	2	0	2	0	2
		Ischnura heterosticta	0	0	0	0	0	0	0	0	0	2	0	0
		Pseudagrion aureofrons	0	0	0	0	0	0	2	1	0	1	0	0
		Pseudagrion microcephalum	0	0	0	0	0	1	0	0	0	2	0	0
	Isostictidae	*Eurysticta coolawanyah*	0	0	1	2	0	0	0	0	0	0	0	0
Ephemeroptera	**Baetidae**	Baetidae spp. (imm./dam.)	2	3	3	3	2	3	1	3	0	2	0	2
		Cloeon fluviatile	0	3	2	2	2	0	3	0	0	0	0	0
		Cloeon sp. Red Stripe	2	4	3	3	2	2	3	3	1	3	2	3
	Caenidae	Caenidae spp. (imm./dam.)	0	3	3	2	0	2	1	0	2	0	0	0
		Tasmanocoenis sp. M	0	0	2	0	0	0	0	0	0	0	0	0
		Tasmanocoenis sp. P/*arcuata*	2	3	2	2	0	2	1	0	0	0	1	0
Hemiptera	**Belostomatidae**	Belostomatidae spp. (imm./dam.)	0	2	0	0	0	2	3	2	0	2	2	2
		Diplonychus spp.	0	2	1	0	1	0	0	2	0	0	2	1
		Lethocerus distinctifemur	0	0	0	0	0	0	0	0	1	0	0	0
	Corixidae/Micronectidae	Corixidae/Micronectidae spp. (imm./dam.)	0	2	0	2	0	2	2	3	0	0	0	0
	Gelastocoridae	*Nerthra* spp. (imm./dam.)	0	0	0	1	0	0	1	0	0	0	0	0
	Gerridae	Gerridae spp. (imm./dam.)	0	2	0	0	0	0	2	2	0	0	1	0
		Limnogonus fossarum gilguy	0	2	0	0	2	0	2	1	0	2	0	0
	Hebridae	Hebridae spp. (imm./dam.)	1	1	0	0	2	2	0	2	0	0	1	2
		Hebrus axillaris	0	0	0	0	0	2	0	0	0	0	0	0

Phylum/Class/Order	Family	Lowest Taxon	RRD1	RRD2	RRD3	RRD4	RRD5	RRD6	RRU1	RRU2	RRU3	RRU4	RRU5	RRU6
		Merragata hackeri	0	0	0	0	0	0	0	2	0	0	2	0
	Hydrometridae	*Hydrometra papuana*	0	0	0	0	0	0	0	0	0	0	1	0
	Mesoveliidae	Mesoveliidae spp. (imm./dam.)	2	3	0	0	1	2	3	0	0	2	0	2
		Mesovelia spp. (imm./dam.)	0	0	0	2	0	0	0	0	0	0	0	0
		Mesovelia hackeri	0	1	0	0	0	2	0	0	0	0	0	0
		Mesovelia hungerfordi	0	0	0	2	0	0	0	0	0	0	0	0
		Mesovelia vittigera	0	2	0	2	0	0	2	0	0	0	1	0
	Micronectidae	*Micronecta* spp. (imm./dam.)	0	0	0	0	0	0	0	2	0	0	0	0
		Micronecta paragoga	0	0	0	0	0	2	0	0	0	0	0	0
	Nepidae	Nepidae spp. (imm./dam.)	1	0	0	0	0	0	0	0	0	0	0	0
		Laccotrephes tristis	0	0	1	0	0	0	0	1	0	0	0	0
		Ranatra diminuta	1	2	0	0	0	0	1	0	0	0	0	0
	Pleidae	*Paraplea* spp.	3	2	1	2	2	3	4	3	0	3	0	3
Coleoptera		Coleoptera spp. (L)	2	0	0	0	0	0	0	0	0	0	0	0
		Unknown spp. (L)	0	0	0	0	0	0	2	0	0	0	0	0
	Dytiscidae	*Allodessus bistrigatus*	0	0	0	0	0	2	0	0	0	0	0	0
		Bidessini spp. (L)	0	0	0	0	0	0	1	0	0	2	1	0
		Copelatus nigrolineatus	0	0	0	0	0	0	1	0	0	0	0	1
		Cybister tripunctatus	0	0	0	0	0	1	0	0	1	0	0	0
		Hydaticus consanguineus	0	2	0	0	0	0	0	0	0	0	0	0
		Hydaticus daemeli	0	0	0	0	0	0	0	1	0	0	0	0
		Hydroglyphus godeffroyi	0	0	0	0	0	2	0	1	0	0	0	0
		Hydroglyphus grammopterus	0	0	0	0	0	2	0	0	0	0	0	0
		Hydroglyphus leai	0	0	0	0	0	0	2	0	0	0	0	0
		Hydroglyphus orthogrammus	0	0	0	0	0	2	2	2	0	0	0	0
		Hydrovatus spp. (L)	2	0	0	0	0	0	4	0	2	0	1	0
		Hydrovatus opacus	2	0	0	0	0	0	2	0	2	0	0	0
		Hyphydrus lyratus	0	1	0	0	0	2	0	2	0	0	0	1
		Laccophilus sharpi	0	0	0	0	0	0	0	2	0	0	0	0
		Limbodessus compactus	2	1	0	0	0	2	2	0	0	1	0	0

Phylum/Class/Order	Family	Lowest Taxon	RRD1	RRD2	RRD3	RRD4	RRD5	RRD6	RRU1	RRU2	RRU3	RRU4	RRU5	RRU6
		Necterosoma darwini	0	0	0	0	0	0	0	0	0	0	0	1
		Necterosoma regulare	0	0	0	0	0	0	0	0	0	0	0	2
		Onychohydrus atratus	1	0	0	0	0	0	0	0	2	0	0	0
		Platynectes decempunctatus var. *decempunc.*	0	0	0	0	0	2	0	1	2	0	0	1
		Rhantaticus congestus	0	1	0	0	0	0	1	0	0	0	0	0
		Tiporus tambreyi	2	0	0	0	0	0	0	0	2	2	0	3
	Elmidae	*Austrolimnius* spp. (L)	2	0	2	0	0	0	0	0	0	0	0	0
	Haliplidae	*Haliplus pilbaraensis*	0	0	0	0	0	0	2	0	0	0	0	0
	Hydraenidae	*Hydraena* spp.	2	0	0	0	0	2	4	3	0	0	0	0
		Limnebius spp.	0	0	0	0	0	2	0	2	0	0	0	0
	Hydrochidae	*Hydrochus* spp.	3	2	0	2	0	3	3	1	2	1	0	3
	Hydrophilidae	Hydrophilidae spp. (L)	0	0	0	0	0	0	3	0	0	0	0	0
		Anacaena horni	2	2	0	0	0	0	0	0	0	0	0	0
		Berosus dallasae	0	0	0	0	0	2	0	1	0	0	0	2
		Enochrus deserticola	0	1	0	0	0	1	3	2	2	0	0	0
		Helochares spp. (L)	0	2	0	2	2	2	3	0	0	3	0	2
		Helochares tatei	0	0	0	0	1	1	1	0	0	0	0	0
		Laccobius sp.	0	0	0	0	0	0	0	0	0	1	0	0
		Paracymus spenceri	0	2	0	0	0	0	3	2	0	2	0	0
		Regimbartia attenuata	1	0	0	0	0	2	2	0	0	0	0	0
		Regimbartia attenuata (L)	0	0	0	0	0	0	0	1	0	0	0	0
		Sternolophus marginicollis	2	3	1	0	0	0	0	3	3	0	1	0
	Noteridae	*Neohydrocoptus subfasciatus* (L)	2	1	0	0	0	0	0	0	0	0	0	0
	Scirtidae	Scirtidae spp. (L)	0	0	0	0	2	0	1	0	1	0	1	0
Diptera	**Ceratopogonidae**	Ceratopogonidae spp. (P)	0	2	2	2	2	0	2	0	0	3	0	2
		Ceratopogoninae spp.	2	0	3	2	1	2	3	2	1	2	3	3
		Dasyheleinae spp.	2	3	3	2	3	1	4	3	0	3	3	2
		Forcipomyiinae spp.	0	1	0	0	0	0	3	0	0	0	0	0
	Chironomidae	Chironomidae spp. (P)	2	2	2	2	2	2	3	2	0	1	2	0
	Chironominae													

Phylum/Class/Order	Family	Lowest Taxon	RRD1	RRD2	RRD3	RRD4	RRD5	RRD6	RRU1	RRU2	RRU3	RRU4	RRU5	RRU6
	Chironomini	*Chironomus* sp. (WWC3)	0	2	0	0	3	0	0	2	3	3	2	0
		Cladopelma curtivalva	3	2	3	2	0	3	2	0	0	0	0	0
		Cryptochironomus griseidorsum	2	0	0	0	0	0	0	0	0	0	0	0
		Dicrotendipes sp. (WWC17)	0	0	0	2	0	0	0	0	0	0	0	0
		Dicrotendipes sp. 1	0	0	2	2	0	0	0	0	0	0	0	0
		Dicrotendipes sp. 2	3	0	3	0	0	1	3	3	2	0	0	0
		Kiefferulus intertinctus	0	0	0	2	2	0	0	2	3	0	0	0
		Parachironomus sp. K2	0	0	0	0	0	0	2	0	0	0	0	0
		Paratendipes sp. K1	3	2	0	0	0	0	0	0	0	0	0	0
		Polypedilum (Pentapedilum) leei	2	0	0	0	0	3	2	0	0	0	0	2
		Polypedilum sp. 1	3	3	0	2	2	2	0	3	2	3	3	3
		Polypedilum sp. 2	0	0	0	0	2	0	0	0	0	0	0	2
		Skusella subvittata	2	0	0	0	0	0	0	0	0	0	0	0
	Tanytarsini	*Cladotanytarsus* sp. (WWTS4)	3	2	3	3	0	1	2	3	0	0	0	3
		Paratanytarsus sp. (WWTS2)	0	0	2	0	0	0	0	0	0	2	3	2
		Tanytarsus sp. (WWTS1)	0	3	2	0	3	0	3	3	3	3	3	2
	Orthocladiinae	*Nanocladius* sp. (WWO6)	0	0	0	0	0	0	3	0	0	0	0	0
	Tanypodinae	*Ablabesmyia hilli*	0	0	0	2	2	0	0	2	0	2	0	0
		Fittkauimyia disparipes	0	0	0	0	0	0	0	0	2	0	0	0
		Larsia albiceps	4	3	3	3	3	3	3	4	2	3	3	3
		Paramerina sp. (WWT1)	3	3	2	2	2	0	3	3	3	2	0	3
		Procladius sp. (WWT5)	3	0	3	3	3	0	0	0	0	2	0	3
	Culicidae	Culicidae spp. (P)	0	0	0	0	0	0	3	1	0	0	0	0
		Anopheles spp.	0	2	0	0	2	0	3	3	0	2	2	2
		Culex spp.	0	2	0	0	0	0	4	2	0	0	0	2
	Dolichopodidae	Dolichopodidae sp.	1	0	0	0	0	0	0	0	0	0	0	0
	Ephydridae	Ephydridae spp.	0	0	0	0	0	0	0	0	0	0	0	2
	Sciomyzidae	Sciomyzidae spp.	0	0	0	0	0	0	2	0	0	0	0	0
	Stratiomyidae	Stratiomyidae spp.	2	0	0	0	0	2	3	0	0	1	0	0
		Stratiomyidae sp. (P)	0	0	0	0	1	0	0	0	0	0	0	0

Phylum/Class/Order	Family	Lowest Taxon	RRD1	RRD2	RRD3	RRD4	RRD5	RRD6	RRU1	RRU2	RRU3	RRU4	RRU5	RRU6
	Tabanidae	Tabanidae spp.	0	2	0	0	0	1	3	0	0	0	0	0
	Thaumaleidae	Thaumaleidae spp.	0	0	0	0	0	0	0	0	0	0	0	2
	Tipulidae	Tipulidae sp. (P)	0	0	0	0	0	0	1	0	0	0	0	0
Trichoptera	**Ecnomidae**	*Ecnomus* spp.	1	0	2	0	1	0	0	0	0	0	0	0
	Hydroptilidae	*Hellyethira* spp.	0	0	2	0	0	0	0	0	0	0	0	0
	Leptoceridae	Leptoceridae spp. (imm./dam.)	0	0	0	0	2	0	0	0	1	0	0	0
		Leptocerus souta	0	0	0	0	0	0	2	0	0	0	0	0
		Oecetis sp.	1	0	0	0	0	0	0	0	0	0	0	0
		Triplectides ciuskus seductus	0	0	2	0	0	0	0	0	0	0	0	0
Lepidoptera	**Crambidae**	*Acentropinae* spp.	0	2	0	0	0	0	0	1	0	0	0	0
		Parapoynx spp.	0	1	0	0	0	2	2	2	0	2	0	0
		Taxa richness	**54**	**56**	**38**	**39**	**38**	**52**	**72**	**56**	**34**	**40**	**34**	**42**

(imm./dam) = taxa were too immature / damaged to be accurately identified to a lower taxonomic level.

(P) = taxa were in pupal form.

(L) = taxa were in larval form.

NB: some chironomid taxa are followed by their unique morphotype code (in parentheses)

Appendix B: Geology, Land Systems and Pre-European Vegetation Mapping of the Survey Area

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410000 415000 420000 425000 430000

7600000

7595000

7590000

Legend

Mesa H Riparian Community Survey Area

Surface Geological Unit (Stewart et al. 2008)

QUATERNARY

- Qa
- Qrc

CENOZOIC

- Czlr

CRETACEOUS

- Kswn

PALEOPROTEROZOIC

- Lsy
- Lchk
- Lfhw
- Lchb

ARCHEAN

- Ashm
- Abfm
- Awfj
- Achm

Lchk Kswn Abfm Qrc Ashm Awfj Qrc Achm Czlr Abfm Lchb Czlr Qa Qrc Lfhw Qa Lchk Lchb Achm Czlr Lfhw Czlr Lfhw Ashm Awfj Czlr Qa Achm Qrc Lchk Qrc Ashm Qrc Lsy Achm Qrc

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Mesa H Riparian Community Assessment - June 2016

Figure B.1: Geological Units of the Mesa H Riparian Community Survey Area

Datum: GDA 1994 - Projection: MGA Zone 50

0 500 1,000 1,500 2,000 2,500 3,000 metres

N

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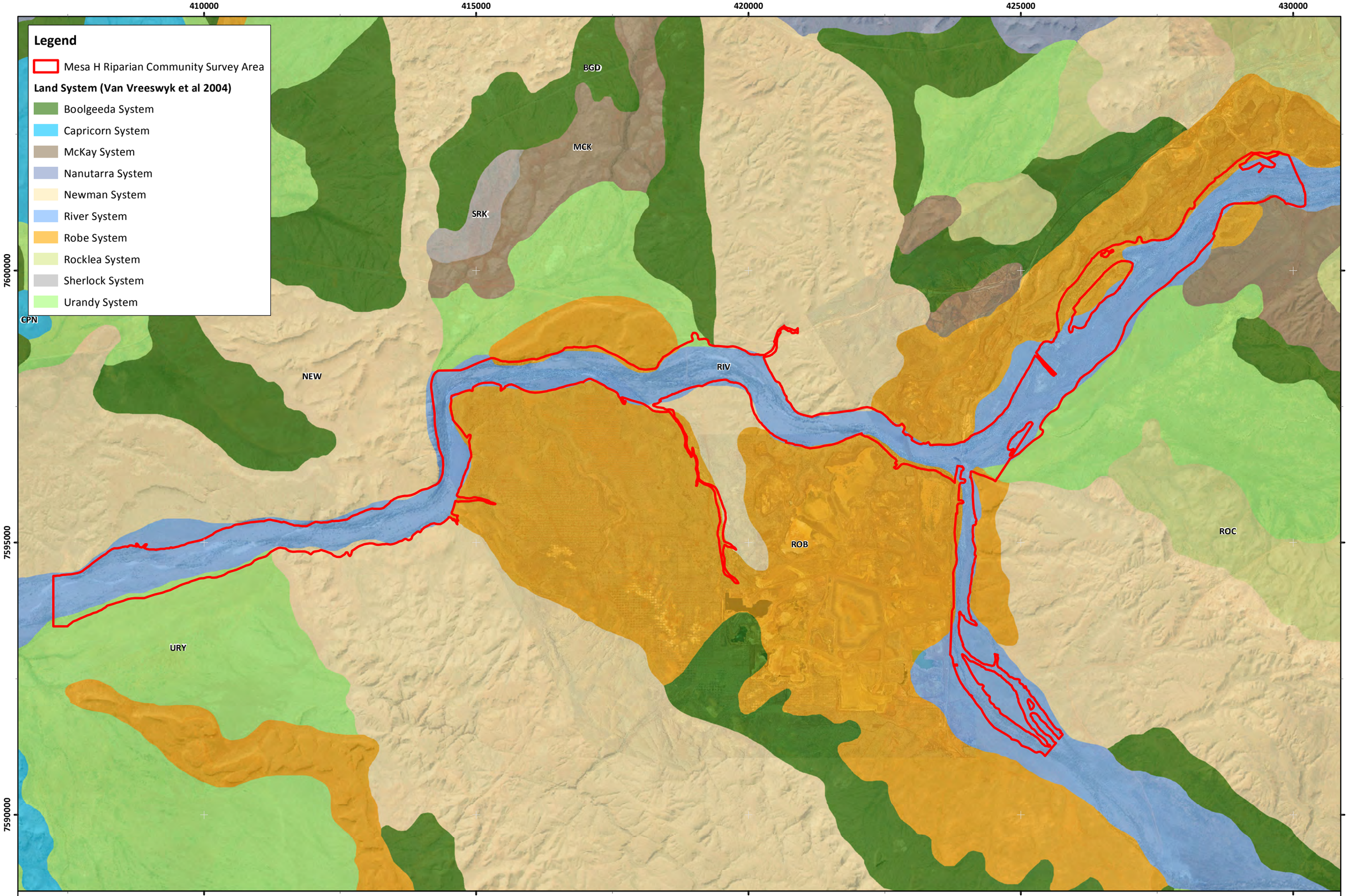
Author: D. Roocke | Drawn: W. An | Date: 05-04-2017 | Figure Ref: 14269-16-BIDR-1RevB_170406_FigB1_GeoUnits



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Mesa H Riparian Community Assessment - June 2016

Figure B.2: Land Systems of the Mesa H Riparian Community Survey Area

Datum: GDA 1994 - Projection: MGA Zone 50

0 500 1,000 1,500 2,000 2,500 3,000 metres

N

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Author: D. Roocke | Drawn: W. An | Date: 05-04-2017 | Figure Ref: 14269-16-BIDR-1RevB_170406_FigB2_LandSystems

410000 415000 420000 425000 430000

7600000 7595000 7590000

Legend

Mesa H Riparian Community Survey Area

Vegetation Association (Shepherd et al. 2002)

- 82 Hummock grasslands, low tree steppe; snappy gum over *Triodia wiseana*
- 173 Hummock grasslands, shrub steppe; kanji over soft spinifex & *Triodia wiseana* on basalt
- 603 Hummock grasslands, sparse shrub steppe; *Acacia bivenosa* over hard spinifex
- 605 Hummock grasslands, shrub steppe; *Acacia pachycarpa* & waterwood over soft spinifex
- 609 *Triodia* open hummock grassland - Mosaic: Hummock grasslands, open low tree steppe; bloodwood with sparse kanji shrubs over soft spinifex/Hummock grasslands, open low tree steppe; snappy gum over *Triodia wiseana* on a lateritic crust
- 620 Hummock grasslands, shrub steppe; snakewood over soft spinifex

609 603 173 82 620

Robe River Mining Co. Pty Ltd

Mesa H Riparian Community Assessment - June 2016

Figure B.3: Pre-European Vegetation of the Mesa H Riparian Community Survey Area

Datum: GDA 1994 - Projection: MGA Zone 50

0 500 1,000 1,500 2,000 2,500 3,000 metres

N

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Author: D. Roocke | Drawn: W. An | Date: 05-04-2017 | Figure Ref: 14269-16-BIDR-1RevB_170406_FigB3_PreEuroVeg

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Appendix C: Conservation Categories for Flora, Fauna and Ecological Communities, and Categories for Introduced Flora

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Table C.1: Categories and definitions for EPBC Act listed flora and fauna species listed under the *Environment Protection and Biodiversity Conservation Act 1999*.

Conservation category	Definition
Extinct	Taxa with no reasonable doubt that the last member of the species has died.
Extinct in the wild	Taxa known to survive only in cultivation, in captivity or as a naturalized population well outside its past range; or it has not been recorded in its known and/or expected habitat, at appropriated seasons, anywhere in its past range, despite exhaustive surveys over a time frame appropriate to its life cycle and form.
Critically endangered (CR)	Taxa facing an extremely high risk of extinction in the wild in the immediate future, as determined in accordance with the prescribed criteria.
Endangered (E)	Taxa are not critically endangered; and are facing a very high risk of extinction in the wild in the near future, as determined in accordance with the prescribed criteria.
Vulnerable (V)	Taxa are not critically endangered or endangered; and are facing a high risk of extinction in the wild in the medium-term future, as determined in accordance with the prescribed criteria.
Conservation dependent (CD)	Taxa are the focus of a specific conservation program the cessation of which would result in the species becoming vulnerable, endangered or critically endangered; or the following subparagraphs are satisfied: i) the taxa is a species of fish; ii) the taxa is the focus of a management plan that provides management actions necessary to stop the decline of, and support the recovery of, the taxa so that its chances of long term survival in nature are maximized; iii) the management plan is in force under a law of the Commonwealth or of a State or Territory; iv) Cessation of the management plan would adversely affect the conservation status of the taxa Fish includes all taxa of bony fish, sharks, rays, crustaceans, molluscs and other marine organisms, but does not include marine mammals/reptiles.

Three categories exist for listing threatened ecological communities under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).

Table C.2: Definitions and criteria for threatened ecological communities listed under the *Environment Protection and Biodiversity Conservation Act 1999*.

Categories of ecological communities	
Critically endangered	If, at that time, it is facing an extremely high risk of extinction in the wild in the immediate future, as determined in accordance with the prescribed criteria.
Endangered	If, at that time, it is not critically endangered and is facing a very high risk of extinction in the wild in the near future, as determined in accordance with the prescribed criteria.
Vulnerable	If, at that time, it is not critically endangered or endangered, and is facing a high risk of extinction in the wild in the medium-term future, as determined in accordance with the prescribed criteria.

Table C.3: Categories of threatened ecological communities (Department of Parks and Wildlife 2015b).

PD: Presumed Destroyed
An ecological community that has been adequately searched for but for which no representative occurrences have been located. The community has been found to be totally destroyed or so extensively modified throughout its range that no occurrence of it is likely to recover its species composition and/or structure in the foreseeable future. An ecological community will be listed as presumed totally destroyed if there are no recent records of the community being extant **and either** of the following applies (A or B): A) Records within the last 50 years have not been confirmed despite thorough searches of known or likely habitats **or** B) All occurrences recorded within the last 50 years have since been destroyed.
CR : Critically Endangered
An ecological community that has been adequately surveyed and found to have been subject to a major contraction in area and/or that was originally of limited distribution and is facing severe modification or destruction throughout its range in the immediate future, or is already severely degraded throughout its range but capable of being substantially restored or rehabilitated. An ecological community will be listed as **Critically Endangered** when it has been adequately surveyed and is found to be facing an extremely high risk of total destruction in the immediate future. This will be determined on the basis of the best available information, by it meeting **any one or more of** the following criteria (A, B or C): A) The estimated geographic range, and/or total area occupied, and/or number of discrete occurrences since European settlement have been reduced by at least 90% **and either or both** of the following apply (i or ii): i) geographic range, and/or total area occupied and/or number of discrete occurrences are continuing to decline such that total destruction of the community is imminent (within approximately 10 years); ii) modification throughout its range is continuing such that in the immediate future (within approximately 10 years) the community is unlikely to be capable of being substantially rehabilitated. B) Current distribution is limited, **and one or more** of the following apply (i, ii or iii): i) geographic range and/or number of discrete occurrences, and/or area occupied is highly restricted and the community is currently subject to known threatening processes which are likely to result in total destruction throughout its range in the immediate future (within approximately 10 years); ii) there are very few occurrences, each of which is small and/or isolated and extremely vulnerable to known threatening processes; iii) there may be many occurrences but total area is very small and each occurrence is small and/or isolated and extremely vulnerable to known threatening processes. C) The ecological community exists only as highly modified occurrences that may be capable of being rehabilitated if such work begins in the immediate future (within approximately 10 years).

En: Endangered

An ecological community that has been adequately surveyed and found to have been subject to a major contraction in area and/or was originally of limited distribution and is in danger of significant modification throughout its range or severe modification or destruction over most of its range in the near future.

An ecological community will be listed as **Endangered** when it has been adequately surveyed and is not Critically Endangered but is facing a very high risk of total destruction in the near future. This will be determined on the basis of the best available information by it meeting **any one or more** of the following criteria (A, B, or C):

A) The geographic range, and/or total area occupied, and/or number of discrete occurrences have been reduced by at least 70% since European settlement **and either or both** of the following apply (i or ii):

i) the estimated geographic range, and/or total area occupied and/or number of discrete occurrences are continuing to decline such that total destruction of the community is likely in the short term future (within approximately 20 years);

ii) modification throughout its range is continuing such that in the short term future (within approximately 20 years) the community is unlikely to be capable of being substantially restored or rehabilitated.

B) Current distribution is limited, **and one or more** of the following apply (i, ii or iii):

i) geographic range and/or number of discrete occurrences, and/or area occupied is highly restricted and the community is currently subject to known threatening processes which are likely to result in total destruction throughout its range in the short term future (within approximately 20 years);

ii) there are few occurrences, each of which is small and/or isolated and all or most occurrences are very vulnerable to known threatening processes;

iii) there may be many occurrences but total area is small and all or most occurrences are small and/or isolated and very vulnerable to known threatening processes.

C) The ecological community exists only as very modified occurrences that may be capable of being substantially restored or rehabilitated if such work begins in the short-term future (within approximately 20 years).

VU: Vulnerable

An ecological community that has been adequately surveyed and is found to be declining and/or has declined in distribution and/or condition and whose ultimate security has not yet been assured and/or a community that is still widespread but is believed likely to move into a category of higher threat in the near future if threatening processes continue or begin operating throughout its range.

An ecological community will be listed as **Vulnerable** when it has been adequately surveyed and is not Critically Endangered or Endangered but is facing a high risk of total destruction or significant modification in the medium to long-term future. This will be determined on the basis of the best available information by it meeting **any one or more of** the following criteria (A, B or C):

A) The ecological community exists largely as modified occurrences that are likely to be capable of being substantially restored or rehabilitated.

B) The ecological community may already be modified and would be vulnerable to threatening processes, is restricted in area and/or range and/or is only found at a few locations.

C) The ecological community may be still widespread but is believed likely to move into a category of higher threat in the medium to long term future because of existing or impending threatening processes.

Possible threatened ecological communities that do not meet survey criteria or that are not adequately defined are added to the Priority Ecological Community Lists under Priorities 1, 2 and 3. Ecological Communities that are adequately known, and are rare but not threatened or meet criteria for Near Threatened, or that have been recently removed from the threatened list, are placed in Priority 4. These ecological communities require regular monitoring. Conservation Dependent ecological communities are placed in Priority 5.

Table C.4: Definitions and criteria for priority ecological communities (Department of Parks and Wildlife 2015b).

P1: Priority One – Poorly-known ecological communities
Ecological communities that are known from very few occurrences with a very restricted distribution (generally ≤5 occurrences or a total area of ≤ 100ha). Occurrences are believed to be under threat either due to limited extent, or being on lands under immediate threat (e.g. within agricultural or pastoral lands, urban areas, active mineral leases) or for which current threats exist. May include communities with occurrences on protected lands. Communities may be included if they are comparatively well-known from one or more localities but do not meet adequacy of survey requirements, and/or are not well defined, and appear to be under immediate threat from known threatening processes across their range.
P2: Priority Two – Poorly-Known ecological communities
Communities that are known from few occurrences with a restricted distribution (generally ≤10 occurrences or a total area of ≤200ha). At least some occurrences are not believed to be under immediate threat of destruction or degradation. Communities may be included if they are comparatively well known from one or more localities but do not meet adequacy of survey requirements, and/or are not well defined, and appear to be under threat from known threatening processes.
P3: Priority Three – Poorly-Known ecological communities
(i) Communities that are known from several to many occurrences, a significant number or area of which are not under threat of habitat destruction or degradation or: (ii) communities known from a few widespread occurrences, which are either large or with significant remaining areas of habitat in which other occurrences may occur, much of it not under imminent threat, or; (iii) communities made up of large, and/or widespread occurrences, that may or may not be represented in the reserve system, but are under threat of modification across much of their range from processes such as grazing by domestic and/or feral stock, and inappropriate fire regimes. Communities may be included if they are comparatively well known from several localities but do not meet adequacy of survey requirements and/or are not well defined, and known threatening processes exist that could affect them.
P4: Priority Four
Ecological communities that are adequately known, rare but not threatened or meet criteria for Near Threatened, or that have been recently removed from the threatened list. These communities require regular monitoring. (i) Rare. Ecological communities known from few occurrences that are considered to have been adequately surveyed, or for which sufficient knowledge is available, and that are considered not currently threatened or in need of special protection, but could be if present circumstances change. These communities are usually represented on conservation lands. (ii) Near Threatened. Ecological communities that are considered to have been adequately surveyed and that do not qualify for Conservation Dependent, but that are close to qualifying for Vulnerable. (iii) Ecological communities that have been removed from the list of threatened communities during the past five years.
P5: Priority Five – Conservation dependent ecological communities
Ecological communities that are not threatened but are subject to a specific conservation program, the cessation of which would result in the community becoming threatened within five years.

Table C.5: Conservation codes for Western Australian flora and fauna under the *Wildlife Conservation Act 1950*.

Code	Conservation category	Definition
S1	Schedule 1 of the Wildlife Conservation (Specially Protected Fauna) Notice and Wildlife Conservation (Rare Flora) Notice under the Wildlife Conservation Act 1950.	Taxa that is rare or likely to become extinct, as critically endangered taxa.
S2	Schedule 2 of the Wildlife Conservation (Specially Protected Fauna) Notice and Wildlife Conservation (Rare Flora) Notice under the Wildlife Conservation Act 1950.	Taxa that is rare or likely to become extinct, as endangered taxa.
S3	Schedule 3 of the Wildlife Conservation (Specially Protected Fauna) Notice and Wildlife Conservation (Rare Flora) Notice under the Wildlife Conservation Act 1950.	Taxa that is rare or likely to become extinct, as vulnerable taxa.
S4	Schedule 4 of the Wildlife Conservation (Specially Protected Fauna) Notice and Wildlife Conservation (Rare Flora) Notice under the Wildlife Conservation Act 1950.	Taxa that is presumed to be extinct.
S5	Schedule 5 of the Wildlife Conservation (Specially Protected Fauna) Notice under the Wildlife Conservation Act 1950.	Birds that are subject to international agreements relating to the protection of migratory birds.
S6	Schedule 6 of the Wildlife Conservation (Specially Protected Fauna) Notice under the Wildlife Conservation Act 1950.	Fauna that are of special conservation need being species dependent on ongoing conservation intervention.
S7	Schedule 7 of the Wildlife Conservation (Specially Protected Fauna) Notice under the Wildlife Conservation Act 1950.	Declared to be fauna that is in need of special protection, otherwise than for the reasons mentioned.

Note: Schedules 5, 6, and 7 are only related to conservation significant fauna.

Threatened fauna and flora (Schedule 1) are further ranked by the Department according to their level of threat using IUCN Red List criteria:

- CR: Critically Endangered - considered to be facing an extremely high risk of extinction in the wild.
- EN: Endangered - considered to be facing a very high risk of extinction in the wild.
- VU: Vulnerable - considered to be facing a high risk of extinction in the wild.

Taxa that have not yet been adequately surveyed to be listed under Schedule 1 or 2 are added to the Priority Flora and Priority Fauna Lists under Priorities 1, 2 or 3. These three categories are ranked in order of priority for survey and evaluation of conservation status so that consideration can be given to their declaration as threatened flora or fauna. Taxa that are adequately known, are rare but not threatened, or meet criteria for Near Threatened, or that have been recently removed from the threatened list for other than taxonomic reasons, are placed in Priority 4. These taxa require regular monitoring. Conservation Dependent species are placed in Priority 5.

Table C.6: Priority species under Western Australian *Wildlife Conservation Act 1950*.

P1: Priority One – Poorly known taxa
Taxa that are known from one or a few collections or sight records (generally five or less) which are potentially at risk. All occurrences are either: very small; or on lands not managed for conservation, e.g. agricultural or pastoral lands, urban areas, road and rail reserves, gravel reserves, and active mineral leases; or otherwise under threat of habitat destruction or degradation. Taxa may be included if they are comparatively well known from one or more localities but do not meet adequacy of survey requirements and appear to be under immediate threat from known threatening processes. Such taxa are in urgent need of further survey.
P2: Priority Two – Poorly known taxa
Taxa that are known from one or a few collections (generally five or less), some of which are on lands managed primarily for nature conservation, e.g. national parks, conservation parks, nature reserves, and other lands with secure tenure being managed for conservation. Taxa may be included if they are comparatively well known from one or more localities but do not meet adequacy of survey requirements and appear to be under threat from known threatening processes. Such taxa are in urgent need of further survey.
P3: Priority Three – Poorly known taxa
Taxa that are known from several localities and does not appear under imminent threat, or from few but widespread localities with either large population size or significant remaining areas of apparently suitable habitat, much of it not under imminent threat. Taxa may be included if they are comparatively well known from several localities but do not meet adequacy of survey requirements and known threatening processes exist that could affect them. Such taxa are in urgent need of further survey.
P4: Priority Four: Rare, near threatened and other taxa in need of monitoring
(a) Rare. Taxa that are considered to have been adequately surveyed, or for which sufficient knowledge is available, and that are considered not currently threatened or in need of special protection, but could be if present circumstances change. These taxa are usually represented on conservation lands. (b) Near Threatened. Taxa that are considered to have been adequately surveyed and that do not qualify for Conservation Dependent, but that are close to qualifying for Vulnerable. (c) Taxa that have been removed from the list of threatened species during the past five years for reasons other than taxonomy.
P5: Priority Five: Conservation dependent taxa
Taxa that are not threatened but are subject to a specific conservation program, the cessation of which would result in the taxa becoming threatened within five years.

The management of introduced flora species in Western Australia is regulated through the *Biosecurity and Agriculture Management Act 2007* (BAM Act). A list of declared pests, including 'pest' plants is provided under the BAM Act, which has been updated to incorporate a number of other Acts that are administered by DAFWA (2015). Declared pests can fall into two categories: one that relates to the prevention of introducing the species or eradicating it; and the other relates to managing the species and whether it can be kept (i.e. for scientific purposes, education or other purpose).

The threat and risk posed to site-specific biodiversity values, influences to rehabilitation success, primary production, infrastructure assets or human health will differ depending on the unique characteristics of each site and the associated land management practice or operation. Therefore site or project specific weed assessments and priorities should be reviewed for each project.

As per introduced flora species, the BAM Act seeks to establish a modern biosecurity regulatory scheme to prevent serious animal pests from entering the State and becoming established, and to minimise the spread and impact of any that are already present within the State. Declared animal pests fall into three categories as Gazetted under the BAM Act (DAFWA 2015). These categories are outlined in Table C.7.

Table C.7: Declared pests categories as gazetted under the *Biosecurity and Agriculture Management Act 2007* (Department of Agriculture and Food 2016).

Category	Description
C1 (Exclusion)	Pests will be assigned to this category if they are not established in Western Australia and control measures are to be taken, including border checks, in order to prevent them entering and establishing in the State.
C2 (Eradication)	Pests will be assigned to this category if they are present in Western Australia in low enough numbers or in sufficiently limited areas that their eradication is still a possibility.
C3 (Management)	Pests will be assigned to this category if they are established in Western Australia but it is feasible, or desirable, to manage them in order to limit their damage. Control measures can prevent a C3 pest from increasing in population size or density or moving from an area in which it is established into an area which currently is free of that pest.

Table C.8: IUCN Red List Conservation Categories of Threatened Species.

Category	Description
Critically Endangered (CR)	A taxon is Critically Endangered when the best available evidence indicates that it is considered to be facing an extremely high risk of extinction in the wild.
Endangered (EN)	A taxon is Endangered when the best available evidence indicates that it is considered to be facing a very high risk of extinction in the wild.
Vulnerable (VU)	A taxon is Vulnerable when the best available evidence indicates that it is considered to be facing a high risk of extinction in the wild.
Near Threatened (NT)	A taxon is Near Threatened when it has been evaluated against the criteria but does not qualify for Critically Endangered, Endangered or Vulnerable now, but is close to qualifying for or is likely to qualify for a threatened category in the near future.
Least Concern (LC)	A taxon is Least Concern when it has been evaluated against the criteria and does not qualify for Critically Endangered, Endangered, Vulnerable or Near Threatened. Widespread and abundant taxa are included in this category.

Appendix D: Database Search Results

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Government of Western Australia
Department of Parks and Wildlife

Your Ref: **14269-15**
Our Ref: **40-0915FL**
Enquiries: Jessica Donaldson
Phone: (08) 9219 8760
Email: flora.data@dpaw.wa.gov.au

Astron Environmental Services
129 Royal Street
East Perth WA 6004

Attention: Natalie Cadd

Dear Natalie Cadd,

REQUEST FOR THREATENED AND PRIORITY FLORA INFORMATION

I refer to your request of 14 September 2015 for Threatened (Declared Rare) and Priority Flora information in the Pannawonica area. The search was conducted within the area of the coordinates you submitted with an additional 20km buffer.

A search was undertaken for this area of **(1)** the Department's *Threatened (Declared Rare) and Priority Flora* database (for results, see "TPFL" – coordinates are GDA94), **(2)** the *Western Australian Herbarium Specimen* database for Threatened and Priority flora species opportunistically collected in the area of interest (for results, see "WAHERB"- coordinates are GDA94 – see condition number 4 in the attached 'Conditions in Respect of Supply') and **(3)**, the Department's *Threatened and Priority Flora List* [this list is searched using 'place names'. This list, which may also be used as a species target list, contains species that are declared rare (Conservation Code R or X for those presumed to be extinct), poorly known (Conservation Codes 1, 2 or 3), or require monitoring (Conservation Code 4) – for results, *if any*, see "TP List"]. The results are attached electronically to this email.

Attached also are the conditions under which this information has been supplied. Your attention is specifically drawn to the ninth point, which refers to the requirement to undertake field investigations for the accurate determination of Threatened and Priority flora occurrence at a site. *The information supplied should be regarded as an indication only of the Threatened and Priority flora that may be present and may be used as a target list in any surveys undertaken.*

The information provided does not preclude you from obtaining and complying with, where necessary, land clearing approvals from other agencies.

An invoice for $ 300 (plus GST) to supply this information will be forwarded.

It would be appreciated if any populations of Threatened and Priority flora you encounter in the area could be reported to this Department to ensure their ongoing management.

If you require any further details, or wish to discuss Threatened and Priority flora management, please contact Dr Ken Atkins, Manager, Species and Communities Branch, on (08) 9334 0455.

Yours faithfully

Jessica Donaldson
.....
THREATENED FLORA DATABASE OFFICER
for the Director General

29 September 2015

Species and Communities Branch
17 Dick Perry Avenue, Technology Park, Kensington
Phone: (08) 9334 0455 Fax: (08) 9334 0278 Teletype: (08) 9334 0546
Postal Address: Locked Bag 104, Bentley Delivery Centre, Western Australia 6983
www.dpaw.wa.gov.au

Government of **Western Australia**
Department of **Parks and Wildlife**

THREATENED AND PRIORITY FLORA INFORMATION

Conditions with Respect to the Supply of Information

- The data supplied may not be provided to any other organisations, nor be used for any purpose other than for the project for which it has been originally provided for; without the prior consent of the Executive Director, Department of Parks and Wildlife.
- Specific locality information for threatened flora is regarded as confidential, and should be treated as such by receiving organisations. Specific locality information for threatened flora may not be used in reports without the written permission of the Executive Director, Department of Parks and Wildlife. Reports may only show generalised locations at a low resolution or, where necessary, show specific locations without identifying species. Species and Communities Branch is to be contacted for guidance on the presentation of threatened flora information.
- The Department of Parks and Wildlife respects the privacy of private landowners who may have threatened and priority flora on their property. Threatened and priority flora locations identified in the data as being on private property should be treated in confidence, and contact with property owners must only be made through the Department of Parks and Wildlife.
- The development of the Perth Herbarium database was not originally intended for electronic mapping (eg. GIS ArcView). The latitude and longitude coordinates for each entry are not verified prior to being data based. It is only in recent times that collections have been submitted with GPS coordinates. Therefore, be aware when using this data in ArcView that some records may not plot to the locality description given with each collection.
- Acknowledgment of the Department of Parks and Wildlife as the source of data is to be made in any published material and cited as Parks and Wildlife (2015) Threatened and Priority Flora Database Search for [search area] accessed on the [date of search]. Prepared by the Species and Communities Branch for [Requesters name and company] for [purpose of search].
- Copies of all such publications are to be forwarded to the Department of Parks and Wildlife, Attention; the Manager, Species and Communities Branch.

Disclaimers with Respect to the Supply of Information

- Receiving organisations should note that while every effort has been made to prevent errors and omissions in the data, they may be present. The Department of Parks and Wildlife accepts no responsibility for this.
- Receiving organisations must also recognise that the database is subject to continual updating and amendment, and such considerations should be taken into account by the user.
- It should be noted that the supplied data does not necessarily represent a comprehensive listing of the threatened flora of the area in question. Its comprehensiveness is dependent on the amount of surveys carried out within a specified area. The receiving organisation should consider engaging a botanist, if required, to undertake a survey of the area under consideration.

Species and Communities Branch
17 Dick Perry Avenue, Technology Park, Kensington
Phone: (08) 9334 0455 Fax: (08) 9334 0278 Teletype: (08) 9334 0546
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www.dpaw.wa.gov.au

Department of Parks and Wildlife

ABBREVIATIONS USED IN THREATENED AND PRIORITY FLORA DATABASE

VESTING

AAP	Aboriginal Planning Authority
AGR	Chief Executive, Dep. of Agriculture
ALT	Aboriginal Land Trust
APB	Agricultural Protection Board of WA
BGP	Botanical Gardens & Parks Authority
BSA	Boy Scouts Association
CC	Conservation Commission – NPNCA - LFC
CGT	Crown Grant in Trust
COM	Commonwealth of Australia
CRO	Crown Freehold-Govt Ownership
CRW	Crown
DAG	Dep. of Agriculture
DOW	Dep. of Water
DPI	Dep. of Planning
EXD	Exec Direc CALM
FES	Fire and Emergency Services Aust.
HOW	Dep. of Housing/State Housing Commission
ILD	Industrial Lands Develop. Auth
LAC	LandCorp
LGA	Shire/LGA
MAG	Minister for Agriculture
MCB	Metropolitan Cemeteries Board
MED	Ministry of Education
MHE	Minister for Health
MIN	Minister for Mines
MPL	Ministry for Planning
MPR	Minister for Prisons
MRD	Main Roads WA
MTR	Minister for Transport
MWA	Minister for Water Resources
MWO	Minister for Works
NAT	Natural Trust of Australia WA
NON	Not Vested
PLB	Pastoral Lands Board
PRI	Private/Freehold
RAI	Public Transport Authority
REL	Religious Organisation
SPC	State Planning Commission
SYN	Synergy (ex Western Power)
SWA	State of Western Australia
TEL	Telstra
UNK	Unknown
WAT	Water Corporation
WEL	Minister Community Welfare
WRC	Water & Rivers Commission
XPL	Ex-Pastoral Lease

PURPOSES

ABR	Aboriginal Reserve
ACC	Access Track
AER	Aerodrome
AIR	Airport
ARS	Agricultural Research Station
BAP	Baptist Union of WA
CAM	Camping
CAR	Caravan park
CEM	Cemetery
CFA	Conservation of Fauna
CFF	Conservation Of Flora & Fauna
CFL	Conservation of Flora
CHU	Church
CMN	Communications
COM	Common
CON	Conservation Park
CPK	Car Park
CRM	Conservation & Resource Management
DEF	Defence
DRA	Drain
EDE	Educational Endowment
EDU	Educational purposes
UWA	
ENE	Enjoyment of Natural Environ.
EPL	Ex-pastoral Lease (Sect 33(2) CALM Act)
EPS	Explosives
EXC	Excepted from sale
EXL	Exploration Lease
EXP	Experimental Farm
FIR	Firing Range
FOR	State Forest
FP	Foreshore Purposes
GE	General Lease
GHA	Grain Handling
GOL	Golf
GRA	Gravel Pit
GVT	Government Requirements
HAR	Harbour Purposes
HEP	Heritage Purposes
HER	Heritage trail
HOS	Hospital
KEN	Kennels
LGA	LGA/Shire Requirements
LPR	Landscape Protection
MIN	Mining lease
MUN	Municipal Purposes
NPK	National Park
NRE	Nature Reserve
OTH	Other
PAR	Parkland (& Recreation)
PAS	Pastoral lease
PCR	Proposed for Conservation
PFF	Protection of Flora & Fauna
PFL	Protection of Flora
PIC	Picnic ground
PLA	Plantation
PMC	Protection of Meteorite Crater
POS	Public Open Space
PPA	Public parkland
PRS	Prison site
PUR	Purchase Lease
PUT	Public Utility
QUA	Quarry
RAC	Racecourse
RAD	Radio Station
REC	Recreation
REH	Rehabilitation/Re-establish Native Plants
RRE	Railway Reserve
RUB	Rubbish
SAL	Saleyards
SAN	Sand
SCH	School-site
SET	Settlers requirements
SHO	Showgrounds
SNN	Sanitary
SOI	Soil Conservation
STO	Stopping place
STK	Stock Route
TIM	Timber
TOU	Tourism
TOW	Town-site
TRA	Training Ground
TRI	Trig station
UCL	Unallocated Crown Land
UNK	Unknown
VER	Road Verge
VPF	Vermin Proof Fence
WAT	Water
WLS	Wildlife Sanctuary
WOO	Firewood

ABBREVIATIONS USED IN THE WESTERN AUSTRALIAN HERBARIUM DATABASE

Geocode Method - The method that was used to record the latitude and longitude.

Auto - Indicates that the coordinate data in the record was created automatically (i.e. by software), usually by creating a coordinate from information provided in the Nearest Named Place or Locality textual description fields.

GAP - Acronym for "Generalised Arbitrary Point" as used in HISPID. GAP indicates that the coordinate data was obtained manually from the Nearest Named Place or Locality textual description fields.

GPS - Acronym for "Global Positioning System". GPS indicates that the coordinate data in the record was obtained from a GPS unit by the collector of the specimen.

MAN - Shorthand for manual. MAN indicates that the coordinate data was created by hand using some method not allowed for by one of the other manual Geocode Method values, in particular, TOPO, GAP, or GPS.

TOPO - Shorthand for topographic map. TOPO indicates that the coordinate data was obtained by plotting textual locality details against a topographic map.

None - Indicates that no coordinate data has been supplied by the collector.

Unknown - Indicates that there is no known method for determining the coordinate data. Should be used if the collector provided no indication of how they sampled the specimen's coordinate data.

PREC (Precision) - precision ratings for coordinates.

Precision 1: Absolutely precise (to nearest 100m or nearest second) and must be GPS determined. For example 35°26'42"S 123°40'26"E

Precision 2: Falling within a diameter of 3km (ca 2 minutes) or if no GPS mentioned in collecting notes. (The location must be able to be pinpointed on a 1:250 000 map, a spot locality. For example 35°26'42"S 123°40'26"E

Precision 3: Falling within a diameter of 10km (ca 7 minutes) or for degrees and minutes, where seconds have not been given. For example 35°26'_"S 123°40'_"E

Precision 4: Falling within a diameter of ca 50km (30 minutes). For example 35°26'_"S 123°40'_"E

Precision 5: Where a location is a prescribed large geographical area within a state or only the state is given. Diameter is greater than 50km. For example 35°_'_"S 123°_'_"E

Precision 6: used when localities are New Holland, Eastern Australia or Not given. Fields will be left blank.

Department of Parks and Wildlife

CONSERVATION CODES

For Western Australian Flora and Fauna

T Threatened species

Listed as Specially Protected under the *Wildlife Conservation Act 1950,* published under Schedule 1 of the Wildlife Conservation (Specially Protected Fauna) Notice for Threatened Fauna and Wildlife Conservation (Rare Flora) Notice for Threatened Flora (which may also be referred to as Declared Rare Flora).

- Fauna that is rare or likely to become extinct are declared to be fauna that is in need of special protection
- Flora that are extant and considered likely to become extinct, or rare and therefore in need of special protection, are declared to be rare flora

Species* which have been adequately searched for and are deemed to be, in the wild, either rare, at risk of extinction, or otherwise in need of special protection, and have been gazetted as such.
The assessment of the conservation status of these species is based on their national extent.

X Presumed extinct species

Listed as Specially Protected under the *Wildlife Conservation Act 1950,* published under Schedule 2 of the Wildlife Conservation (Specially Protected Fauna) Notice for Presumed Extinct Fauna and Wildlife Conservation (Rare Flora) Notice for Presumed Extinct Flora (which may also be referred to as Declared Rare Flora).

Species which have been adequately searched for and there is no reasonable doubt that the last individual has died, and have been gazetted as such.

IA Migratory birds protected under an international agreement

Listed as Specially Protected under the *Wildlife Conservation Act 1950,* listed under Schedule 3 of the Wildlife Conservation (Specially Protected Fauna) Notice.

Birds that are subject to an agreement between the government of Australia and the governments of Japan (JAMBA), China (CAMBA) and The Republic of Korea (ROKAMBA), relating to the protection of migratory birds.

S Other specially protected fauna

Listed as Specially Protected under the *Wildlife Conservation Act 1950.* Fauna declared to be in need of special protection, otherwise than for the reasons mentioned for Schedules 1, 2 or 3, are published under Schedule 4 of the Wildlife Conservation (Specially Protected Fauna) Notice.

Threatened Fauna and Flora are ranked according to their level of threat using IUCN Red List categories and criteria. *For example:* Carnaby's Cockatoo (*Calyptorynchus latirostris*) is listed as 'Specially Protected' under the *Wildlife Conservation Act 1950,* published under Schedule 1, and referred to as a 'Threatened' species with a ranking of 'Endangered'.

CR Critically Endangered - considered to be facing an extremely high risk of extinction in the wild.

EN Endangered - considered to be facing a very high risk of extinction in the wild.

VU Vulnerable - considered to be facing a high risk of extinction in the wild.

A list of the current rankings can be downloaded from the Parks and Wildlife Threatened Species and Communities webpage at http://dpaw.wa.gov.au/plants-and-animals/threatened-species-and-communities/

P Priority species

Species that maybe threatened or near threatened but are data deficient, have not yet been adequately surveyed to be listed under the Schedules of the Wildlife Conservation (Specially Protected Fauna) Notice or the Wildlife Conservation (Rare Flora) Notice, are added to the Priority Fauna or Priority Flora Lists under Priorities 1, 2 or 3. These three categories are ranked in order of priority for survey and evaluation of conservation status so that consideration can be given to their declaration as threatened flora or fauna. Species that are adequately known, are rare but not threatened, or meet criteria for near threatened, or that have been recently removed from the threatened list for other than taxonomic reasons, are placed in Priority 4. These species require regular monitoring. Conservation dependent species that are subject to a specific conservation program are placed in Priority 5.

Assessment of Priority codes is based on the Western Australian distribution of the species, unless the distribution in WA is part of a contiguous population extending into adjacent States, as defined by the known spread of locations.

1: Priority One: Poorly-known species

Species that are known from one or a few locations (generally five or less) which are potentially at risk. All occurrences are either: very small; or on lands not managed for conservation, e.g. agricultural or pastoral lands, urban areas, road and rail reserves, gravel reserves and active mineral leases; or otherwise under threat of habitat destruction or degradation. Species may be included if they are comparatively well known from one or more locations but do not meet adequacy of survey requirements and appear to be under immediate threat from known threatening processes. Such species are in urgent need of further survey.

2: Priority Two: Poorly-known species

Species that are known from one or a few locations (generally five or less), some of which are on lands managed primarily for nature conservation, e.g. national parks, conservation parks, nature reserves and other lands with secure tenure being managed for conservation. Species may be included if they are comparatively well known from one or more locations but do not meet adequacy of survey requirements and appear to be under threat from known threatening processes. Such species are in urgent need of further survey.

3: Priority Three: Poorly-known species

Species that are known from several locations, and the species does not appear to be under imminent threat, or from few but widespread locations with either large population size or significant remaining areas of apparently suitable habitat, much of it not under imminent threat. Species may be included if they are comparatively well known from several locations but do not meet adequacy of survey requirements and known threatening processes exist that could affect them. Such species are in need of further survey.

4: Priority Four: Rare, Near Threatened and other species in need of monitoring

(a) Rare. Species that are considered to have been adequately surveyed, or for which sufficient knowledge is available, and that are considered not currently threatened or in need of special protection, but could be if present circumstances change. These species are usually represented on conservation lands.
(b) Near Threatened. Species that are considered to have been adequately surveyed and that do not qualify for Conservation Dependent, but that are close to qualifying for Vulnerable.
(c) Species that have been removed from the list of threatened species during the past five years for reasons other than taxonomy.

5: Priority Five: Conservation Dependent species

Species that are not threatened but are subject to a specific conservation program, the cessation of which would result in the species becoming threatened within five years.

*Species includes all taxa (plural of taxon - a classificatory group of any taxonomic rank, e.g. a family, genus, species or any infraspecific category i.e. subspecies, variety or forma).

DEPARTMENT OF ENVIRONMENT AND CONSERVATION

THREATENED AND PRIORITY ECOLOGICAL COMMUNITIES INFORMATION

CONDITIONS IN RESPECT OF SUPPLY OF INFORMATION

1. All requests for data are to be made in writing to the Director General, Department of Environment and Conservation Attention: Species and Communities Branch

2. The data supplied may not be supplied to other organisations, nor be used for any purpose other than for the project for which they have been provided, without the prior written consent of the data custodian (Val English), Species and Communities Branch.

3. Specific locality information for threatened and priority ecological communities (TECs/PECs) is regarded as confidential, and should be treated as such by receiving organisations. Specific locality information for TECs/PECs may not be used in public reports without the written permission of the Director General, Department of Environment and Conservation. Publicly available reports may only show generalised locations (ie buffer locations). The TEC database manager is to be contacted for guidance on the presentation of TEC/PEC information.

4. Note that the Department of Environment and Conservation respects the privacy of private landowners who may have threatened and priority ecological communities on their property. Locations of TECs/PECs identified in the data as being on private property should be treated in confidence, and contact with property owners made through the Department of Environment and Conservation.

5. Receiving organisations should note that while every effort has been made to prevent errors and omissions in the data provided, they may be present. The Department of Environment and Conservation accepts no responsibility for this.

6. Receiving organisations must also recognise that the Threatened Ecological Communities database is subject to continual updating and amendment, and such considerations should be taken into account by the user.

7. It should be noted that the supplied data do not necessarily represent a comprehensive listing of the threatened and priority ecological communities of the area in question. Its comprehensiveness is dependant on the amount of survey carried out within the specified area. Private property has been relatively little surveyed. The receiving organisation should employ a consultant, if there is any likelihood of the presence of any threatened or priority ecological community, to undertake a survey of the area under consideration.

8. Acknowledgment of the Department of Environment and Conservation as source of the data is to be made in any published material. Copies of all such publications are to be forwarded to the Department of Environment and Conservation, Attention: Manager, Species and Communities Branch.

NatureMap
Mapping Western Australia's biodiversity

NatureMap Species Report

Created By Guest user on 25/07/2016

Kingdom Plantae
Current Names Only Yes
Core Datasets Only Yes
Method 'By Circle'
Centre 116° 11' 50" E,21° 44' 11" S
Buffer 40km
Group By Family

Family	Species	Records
Acanthaceae	1	1
Aizoaceae	3	7
Amaranthaceae	26	73
Apiaceae	1	1
Araliaceae	3	6
Arecaceae	1	4
Asphodelaceae	1	1
Asteraceae	20	39
Boraginaceae	7	11
Brassicaceae	1	1
Campanulaceae	2	4
Capparaceae	1	4
Caryophyllaceae	4	15
Celastraceae	2	2
Chenopodiaceae	9	13
Cleomaceae	1	5
Combretaceae	3	5
Convolvulaceae	6	10
Cucurbitaceae	3	8
Cyperaceae	23	51
Dilleniaceae	2	2
Droseraceae	1	1
Euphorbiaceae	15	35
Fabaceae	86	256
Frankeniaceae	1	1
Gentianaceae	1	2
Goodeniaceae	14	31
Haloragaceae	3	6
Hydrocharitaceae	5	15
Lamiaceae	4	8
Lauraceae	1	2
Lentibulariaceae	1	1
Loranthaceae	4	5
Lythraceae	4	13
Malvaceae	58	174
Marsileaceae	3	3
Menispermaceae	1	2
Molluginaceae	3	7
Moraceae	2	4
Myrtaceae	15	36
Nyctaginaceae	5	12
Oleaceae	1	4
Onagraceae	1	3
Oxalidaceae	1	1
Papaveraceae	1	1
Pedaliaceae	1	1
Phrymaceae	2	2
Phyllanthaceae	5	8
Plantaginaceae	1	1
Poaceae	74	183
Portulacaceae	6	12
Potamogetonaceae	3	7
Proteaceae	7	9
Pteridaceae	4	10
Rubiaceae	5	6
Ruppiaceae	1	1
Sapindaceae	1	1
Scrophulariaceae	5	8
Solanaceae	16	38
Stylidiaceae	2	2
Surianaceae	1	1
Thymelaeaceae	1	1
Violaceae	1	2
Zygophyllaceae	8	24
TOTAL	**495**	**1203**

Name ID	Species Name	Naturalised	Conservation Code	[1]Endemic To Query Area

	Name ID	Species Name	Naturalised	Conservation Code	[1]Endemic To Query Area
Acanthaceae					
1.	12088	*Rostellularia adscendens var. clementii*			
Aizoaceae					
2.	44241	*Trianthema glossostigmum*			
3.	44305	*Trianthema pilosum*			
4.	44362	*Trianthema triquetrum*			
Amaranthaceae					
5.	2647	*Alternanthera angustifolia*			
6.	2651	*Alternanthera nana (Hairy Joyweed)*			
7.	2653	*Alternanthera pungens (Khaki Weed)*	Y		
8.	31076	*Amaranthus cochleitepalus*			
9.	2660	*Amaranthus cuspidifolius*			
10.	2663	*Amaranthus interruptus (Native Amaranth)*			
11.	2666	*Amaranthus mitchellii (Boggabri Weed)*			
12.		*Amaranthus sp.*			
13.	20018	*Amaranthus undulatus*			
14.	18361	*Gomphrena affinis subsp. pilbarensis*			
15.	2680	*Gomphrena cunninghamii*			
16.	2690	*Ptilotus aervoides*			
17.	2694	*Ptilotus appendiculatus*			
18.	2696	*Ptilotus astrolasius*			
19.	2698	*Ptilotus auriculifolius*			
20.	2699	*Ptilotus axillaris (Mat Mulla Mulla)*			
21.	2704	*Ptilotus calostachyus (Weeping Mulla Mulla)*			
22.	2711	*Ptilotus clementii (Tassel Top)*			
23.	2725	*Ptilotus fusiformis*			
24.	2728	*Ptilotus gomphrenoides*			
25.	2734	*Ptilotus incanus*			
26.	2738	*Ptilotus latifolius (Tangled Mulla Mulla)*			
27.	41001	*Ptilotus nobilis subsp. nobilis (Yellow Tails)*			
28.	2747	*Ptilotus obovatus (Cotton Bush)*			
29.		*Ptilotus sp.*			
30.	2766	*Ptilotus villosiflorus*			
Apiaceae					
31.	6218	*Daucus glochidiatus (Australian Carrot)*			
Araliaceae					
32.	6202	*Astrotricha hamptonii (Ironplant)*			
33.	6278	*Trachymene oleracea*			
34.	19043	*Trachymene oleracea subsp. oleracea*			
Arecaceae					
35.	1042	*Phoenix dactylifera (Date Palm)*	Y		
Asphodelaceae					
36.	1364	*Asphodelus fistulosus (Onion Weed)*	Y		
Asteraceae					
37.	7822	*Angianthus acrohyalinus (Hook-leaf Angianthus)*			
38.	7866	*Blumea tenella*			
39.	14090	*Calocephalus beardii*			
40.	7893	*Calocephalus knappii*			
41.	7899	*Calotis breviradiata*			
42.	7906	*Calotis plumulifera*			
43.	19762	*Centipeda minima subsp. macrocephala*			
44.	35558	*Flaveria trinervia (Speedy Weed)*	Y		
45.	29594	*Helichrysum luteoalbum (Jersey Cudweed)*			
46.	13494	*Pentalepis trichodesmoides*			
47.	42160	*Pentalepis trichodesmoides subsp. trichodesmoides*			
48.	17817	*Pluchea dunlopii*			
49.	17816	*Pluchea ferdinandi-muelleri*			
50.	43944	*Pluchea longiseta*			
51.	8168	*Pluchea rubelliflora*			
52.	8192	*Pterocaulon sphacelatum (Apple Bush)*			
53.	8193	*Pterocaulon sphaeranthoides*			
54.	13310	*Rhodanthe margarethae*			
55.	8238	*Streptoglossa liatroides*			
56.	8240	*Streptoglossa odora*			
Boraginaceae					
57.	6706	*Heliotropium cunninghamii*			

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58.	6712	*Heliotropium heteranthum*			
59.	6713	*Heliotropium ovalifolium*			
60.	17309	*Heliotropium pachyphyllum*			
61.		*Heliotropium sp.*			
62.	17031	*Heliotropium transforme*			
63.	11750	*Trichodesma zeylanicum var. zeylanicum*			
Brassicaceae					
64.	3037	*Lepidium phlebopetalum (Veined Peppercress)*			
Campanulaceae					
65.	37480	*Lobelia arnhemiaca*			
66.	36880	*Lobelia heterophylla subsp. pilbarensis*			
Capparaceae					
67.	11670	*Capparis spinosa var. nummularia (Coastal Caper)*			
Caryophyllaceae					
68.	2898	*Polycarpaea corymbosa*			
69.	12075	*Polycarpaea corymbosa var. corymbosa*			
70.	2901	*Polycarpaea holtzei*			
71.	2903	*Polycarpaea longiflora*			
Celastraceae					
72.	4731	*Stackhousia intermedia*			
73.	18405	*Stackhousia sp. swollen gynophore (W.R. Barker 2041)*			
Chenopodiaceae					
74.	11632	*Dysphania glomulifera subsp. eremaea*			
75.	2544	*Maireana georgei (Satiny Bluebush)*			
76.	2551	*Maireana melanocoma (Pussy Bluebush)*			
77.	2604	*Sclerolaena costata*			
78.	2607	*Sclerolaena densiflora*			
79.	2611	*Sclerolaena eriacantha (Tall Bindii)*			
80.	2638	*Suaeda arbusculoides*			
81.	31616	*Tecticornia auriculata*			
82.	33220	*Tecticornia pterygosperma subsp. denticulata*			
Cleomaceae					
83.	2988	*Cleome viscosa (Tickweed, Tjinduwadhu)*			
Combretaceae					
84.	5300	*Terminalia canescens (Joolal)*			
85.	45698	*Terminalia circumalata*			
86.	5313	*Terminalia supranitifolia*		P3	
Convolvulaceae					
87.	6608	*Bonamia pannosa*			
88.	44782	*Bonamia pilbarensis*			
89.	6633	*Ipomoea muelleri (Poison Morning Glory, Yumbu)*			
90.	11312	*Ipomoea pes-caprae subsp. brasiliensis*			
91.	6637	*Ipomoea polymorpha*			
92.		*Polymeria sp.*			
Cucurbitaceae					
93.	7369	*Citrullus colocynthis*	Y		
94.	41721	*Cucumis variabilis*			
95.	7381	*Trichosanthes cucumerina*			
Cyperaceae					
96.	750	*Bulbostylis barbata*			
97.	774	*Cyperus bifax (Downs Nutgrass)*			
98.	786	*Cyperus cunninghamii*			
99.	12811	*Cyperus cunninghamii subsp. cunninghamii*			
100.	788	*Cyperus dactylotes*			
101.	789	*Cyperus difformis (Rice Sedge)*			
102.	12808	*Cyperus hesperius*			
103.	798	*Cyperus iria*			
104.	799	*Cyperus ixiocarpus*			
105.	12807	*Cyperus microcephalus subsp. microcephalus*			
106.	810	*Cyperus rotundus (Nut Grass)*	Y		
107.	814	*Cyperus squarrosus*			
108.	818	*Cyperus vaginatus (Stiffleaf Sedge)*			
109.	823	*Eleocharis atropurpurea*			
110.	826	*Eleocharis dulcis (Chinese Water Chestnut)*			
111.	827	*Eleocharis geniculata*			

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112.	831	*Eleocharis sphacelata (Tall Spikerush, Djabren)*			
113.	851	*Fimbristylis dichotoma (Eight Day Grass)*			
114.	862	*Fimbristylis microcarya*			
115.	12159	*Fimbristylis simulans*			
116.	963	*Schoenoplectus laevis*			
117.	964	*Schoenoplectus lateriflorus*			
118.	16257	*Schoenoplectus subulatus*			
Dilleniaceae					
119.	5135	*Hibbertia hypericoides (Yellow Buttercups)*			
120.	5146	*Hibbertia montana*		P4	
Droseraceae					
121.	43544	*Drosera finlaysoniana*			
Euphorbiaceae					
122.	17422	*Adriana tomentosa var. tomentosa*			
123.	4617	*Euphorbia australis (Namana)*			
124.	42843	*Euphorbia australis var. glabra*		P2	
125.	35303	*Euphorbia australis var. subtomentosa*			
126.	4620	*Euphorbia boophthona (Gascoyne Spurge)*			
127.	9048	*Euphorbia careyi*			
128.	4629	*Euphorbia hirta (Asthma Plant)*	Y		
129.		*Euphorbia sp.*			
130.	4647	*Euphorbia tannensis*			
131.	12097	*Euphorbia tannensis subsp. eremophila (Desert Spurge)*			
132.	42879	*Euphorbia trigonosperma*			
133.	13281	*Euphorbia vaccaria*			
134.	42877	*Euphorbia vaccaria var. erucoides*			
135.	42876	*Euphorbia vaccaria var. vaccaria*			
136.	4650	*Euphorbia wheeleri*			
Fabaceae					
137.	3209	*Acacia ampliceps*			
138.	44586	*Acacia ampliceps x sclerosperma subsp. sclerosperma*			
139.	3214	*Acacia ancistrocarpa (Fitzroy Wattle)*			
140.	37260	*Acacia aptaneura*			
141.	3223	*Acacia arida*			
142.	3228	*Acacia atkinsiana*			
143.	3241	*Acacia bivenosa*			
144.	3260	*Acacia citrinoviridis*			
145.	17013	*Acacia colei var. colei*			
146.	17014	*Acacia colei var. ileocarpa*			
147.	3300	*Acacia dictyophleba (Sandhill Wattle, Ngarkalya)*			
148.	16174	*Acacia elachantha*			
149.	3360	*Acacia hamersleyensis*			
150.	3377	*Acacia inaequilatera (Baderi)*			
151.	3419	*Acacia ligulata (Umbrella Bush, Watarka)*			
152.	3471	*Acacia orthocarpa (Needleleaf Wattle)*			
153.	3500	*Acacia pruinocarpa (Gidgee)*			
154.	3501	*Acacia ptychophylla*			
155.	3506	*Acacia pyrifolia (Ranji Bush, Kandji)*			
156.	29016	*Acacia pyrifolia var. morrisonii*			
157.	29015	*Acacia pyrifolia var. pyrifolia*			
158.	3519	*Acacia rhodophloia*			
159.	13078	*Acacia sclerosperma subsp. sclerosperma*			
160.	29135	*Acacia sericophylla*			
161.		*Acacia sp.*			
162.	3553	*Acacia spondylophylla*			
163.	13070	*Acacia synchronicia*			
164.	3577	*Acacia tetragonophylla (Kurara, Wakalpuka)*			
165.	3579	*Acacia trachycarpa (Minni Ritchi, Balgali)*			
166.	23521	*Acacia trudgeniana*			
167.	3585	*Acacia tumida (Pindan Wattle, Walgali)*			
168.	20319	*Acacia tumida var. pilbarensis*			
169.	3598	*Acacia wanyu*			
170.	3606	*Acacia xiphophylla*			
171.	3680	*Aeschynomene indica (Budda Pea)*			
172.	17147	*Alysicarpus muelleri*			
173.	11055	*Cajanus cinereus*			
174.	3783	*Crotalaria medicaginea*			
175.	11231	*Crotalaria novae-hollandiae subsp. novae-hollandiae*			

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176.	17439	*Cullen lachnostachys*			
177.	17118	*Cullen leucanthum*			
178.	17119	*Cullen leucochaites*			
179.	17120	*Cullen pogonocarpum*			
180.	3871	*Erythrina vespertilio (Yulbah)*			
181.	3971	*Indigofera boviperda*			
182.	17113	*Indigofera boviperda subsp. boviperda*			
183.	45436	*Indigofera chamaeclada subsp. pubens*			
184.	3973	*Indigofera colutea (Sticky Indigo)*			
185.	45473	*Indigofera fractiflexa subsp. fractiflexa*			
186.	3980	*Indigofera linifolia*			
187.	3982	*Indigofera monophylla*			
188.	3985	*Indigofera rugosa*			
189.	20317	*Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)*		P3	
190.	3987	*Indigofera trita*			
191.	3989	*Isotropis atropurpurea (Poison Sage)*			
192.	4061	*Lotus cruentus (Redflower Lotus)*			
193.	4105	*Mirbelia viminalis*			
194.	3675	*Petalostylis labicheoides (Slender Petalostylis)*			
195.	20862	*Rhynchosia bungarensis*		P4	
196.	4191	*Rhynchosia minima (Rhynchosia)*			
197.	12280	*Senna artemisioides subsp. oligophylla*			
198.	12305	*Senna glutinosa subsp. chatelainiana*			
199.	12307	*Senna glutinosa subsp. glutinosa*			
200.	12309	*Senna glutinosa subsp. pruinosa*			
201.	12308	*Senna glutinosa subsp. x luerssenii*			
202.	12312	*Senna notabilis*			
203.		*Senna sp.*			
204.	12319	*Senna venusta*			
205.	4198	*Sesbania formosa (White Dragon Tree)*			
206.	13596	*Swainsona complanata*			
207.	12356	*Swainsona formosa*			
208.	4234	*Swainsona maccullochiana (Ashburton Pea)*			
209.	4280	*Tephrosia rosea (Flinders River Poison, Bungoo'dah)*			
210.	41825	*Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)*			
211.		*Tephrosia sp.*			
212.	15947	*Tephrosia sp. B Kimberley Flora (C.A. Gardner 7300)*			
213.	17768	*Tephrosia sp. Bungaroo Creek (M.E. Trudgen 11601)*			
214.	41811	*Tephrosia sp. Fortescue (A.A. Mitchell 606)*			
215.	42442	*Tephrosia sp. NW Eremaean (S. van Leeuwen et al. PBS 0356)*			
216.	40060	*Tephrosia sp. clay soils (S. van Leeuwen et al. PBS 0273)*			
217.	4285	*Tephrosia supina*			
218.	4286	*Tephrosia uniovulata*			
219.	4287	*Tephrosia virens*			
220.		*Vigna benthamii*			
221.	4323	*Vigna lanceolata (Maloga Vigna, Wega)*			
222.	11576	*Vigna lanceolata var. lanceolata*			
Frankeniaceae					
223.	5188	*Frankenia ambita*			
Gentianaceae					
224.	41646	*Schenkia clementii*			
Goodeniaceae					
225.	7424	*Dampiera candicans*			
226.	7490	*Goodenia armitiana*			
227.	7509	*Goodenia forrestii*			
228.	7521	*Goodenia lamprosperma*			
229.	7526	*Goodenia microptera*			
230.	12552	*Goodenia muelleriana*			
231.	7530	*Goodenia nuda*		P4	
232.	7544	*Goodenia ramelii*			
233.		*Goodenia sp.*			
234.	10982	*Goodenia stobbsiana*			
235.	7556	*Goodenia tenuiloba*			
236.	7644	*Scaevola spinescens (Currant Bush, Maroon)*			
237.	7654	*Velleia connata (Cup Velleia)*			
238.	7658	*Velleia discophora (Cabbage Poison)*			
Haloragaceae					
239.	6174	*Haloragis gossei*			

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240.	23464	*Haloragis gossei var. inflata*			
241.	6201	*Myriophyllum verrucosum (Red Water Milfoil)*			
Hydrocharitaceae					
242.	17955	*Najas graminea var. graminea*			
243.	138	*Najas marina (Prickly Water Nymph)*			
244.	139	*Najas tenuifolia (Water Nymph)*			
245.	17868	*Vallisneria nana*			
246.		*Vallisneria sp.*			
Lamiaceae					
247.	6830	*Basilicum polystachyon*			
248.	13692	*Clerodendrum floribundum var. angustifolium*			
249.	13691	*Clerodendrum floribundum var. ovatum*			
250.	6907	*Ocimum basilicum (Basil)*	Y		
Lauraceae					
251.	2949	*Cassytha capillaris*			
Lentibulariaceae					
252.	7125	*Utricularia australis*			
Loranthaceae					
253.	13700	*Amyema bifurcata*			
254.	2383	*Amyema preissii (Wireleaf Mistletoe)*			
255.	2385	*Amyema sanguinea*			
256.	2396	*Lysiana casuarinae*			
Lythraceae					
257.	5276	*Ammannia auriculata*			
258.	5277	*Ammannia baccifera*			
259.	5285	*Rotala diandra*			
260.	5286	*Rotala mexicana*			
Malvaceae					
261.	4891	*Abutilon fraseri (Lantern Bush)*			
262.	16919	*Abutilon hannii*			
263.	4895	*Abutilon lepidum*			
264.	4898	*Abutilon macrum*			
265.	4901	*Abutilon otocarpum (Desert Chinese Lantern)*			
266.	4902	*Abutilon oxycarpum (Flannel Weed)*			
267.		*Abutilon sp.*			
268.	42920	*Abutilon sp. Dioicum (A.A. Mitchell PRP 1618)*			
269.		*Abutilon sp. Dioicum (A.A.Mitchell PRP 1618)*			
270.	14113	*Abutilon sp. Pilbara (W.R. Barker 2025)*			
271.	13659	*Corchorus laniflorus*			
272.	18408	*Corchorus lasiocarpus subsp. parvus*			
273.	4862	*Corchorus parviflorus*			
274.	4864	*Corchorus sidoides (Flannel Weed)*			
275.	18415	*Corchorus sidoides subsp. sidoides*			
276.	18414	*Corchorus sidoides subsp. vermicularis*			
277.		*Corchorus sp.*			
278.	20242	*Corchorus sp. Hamersley Range hilltops (S. van Leeuwen 3826)*			
279.	17661	*Corchorus tectus*			
280.	4865	*Corchorus tridens*			
281.	4910	*Gossypium australe (Native Cotton)*			
282.	4918	*Gossypium robinsonii (Wild Cotton)*			
283.		*Gynatrix pulchella*			
284.	29317	*Hibiscus austrinus var. austrinus*			
285.	4922	*Hibiscus brachychlaenus*			
286.	4925	*Hibiscus coatesii*			
287.	4930	*Hibiscus goldsworthii*			
288.	4933	*Hibiscus leptocladus*			
289.	4941	*Hibiscus solanifolius*			
290.	11651	*Hibiscus sturtii var. campylochlamys*			
291.	11385	*Hibiscus sturtii var. grandiflorus*			
292.	11477	*Hibiscus sturtii var. platychlamys*			
293.	5024	*Keraudrenia nephrosperma*			
294.	5051	*Melhania oblongifolia*			
295.		*Melhania sp.*			
296.	5053	*Melochia pyramidata*	Y		
297.	31758	*Sida arsiniata*			
298.	4971	*Sida cardiophylla*			
299.	4972	*Sida clementii*			

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300.	4976	*Sida echinocarpa*			
301.	4977	*Sida fibulifera (Silver Sida)*			
302.	4988	*Sida rohlenae*			
303.	18149	*Sida rohlenae subsp. rohlenae*			
304.		*Sida sp.*			
305.	31859	*Sida sp. Articulation below (A.A. Mitchell PRP 1605)*			
306.	33698	*Sida sp. Pilbara (A.A. Mitchell PRP 1543)*			
307.		*Sida sp. Pilbara (A.A.Mitchell PRP1543)*			
308.	31852	*Sida sp. Supplejack Station (T.S. Henshall 2345)*			
309.	16617	*Sida sp. spiciform panicles (E. Leyland s.n. 14/8/90)*			
310.	16948	*Sida sp. verrucose glands (F.H. Mollemans 2423)*			
311.	4989	*Sida spinosa (Spiny Sida)*			
312.	4875	*Triumfetta chaetocarpa (Urchins)*			
313.	14694	*Triumfetta clementii*			
314.	4878	*Triumfetta johnstonii*			
315.	14942	*Triumfetta maconochieana*			
316.		*Triumfetta sp.*			
317.	17529	*Triumfetta tenuiseta*			
318.	5106	*Waltheria indica*			
Marsileaceae					
319.	74	*Marsilea drummondii (Common Nardoo)*			
320.	76	*Marsilea hirsuta (Nardoo)*			
321.		*Marsilea sp.*			
Menispermaceae					
322.	2942	*Tinospora smilacina (Snakevine, Oondala)*			
Molluginaceae					
323.	2835	*Glinus lotoides (Hairy Carpet Weed)*			
324.	2836	*Glinus oppositifolius*			
325.	29851	*Mollugo molluginea*			
Moraceae					
326.	31578	*Ficus aculeata var. indecora (Ranji)*			
327.	19648	*Ficus brachypoda*			
Myrtaceae					
328.	16783	*Corymbia candida*			
329.	16782	*Corymbia candida subsp. candida*			
330.	16780	*Corymbia candida subsp. dipsodes*			
331.	17077	*Corymbia ferriticola*			
332.	17093	*Corymbia hamersleyana*			
333.		*Corymbia terminalis*			
334.	17084	*Corymbia zygophylla*			
335.	5580	*Eucalyptus camaldulensis (River Gum, Yabalinyba)*			
336.	35345	*Eucalyptus camaldulensis subsp. obtusa (Blunt-budded River Red Gum)*			
337.	35343	*Eucalyptus camaldulensis subsp. refulgens*			
338.	18088	*Eucalyptus leucophloia subsp. leucophloia*			
339.	5875	*Melaleuca argentea (Silver Cadjeput, Bandaran)*			
340.	5879	*Melaleuca bracteata (River Teatree)*			
341.	5915	*Melaleuca glomerata*			
342.	6081	*Verticordia forrestii (Forrest's Featherflower)*			
Nyctaginaceae					
343.	2769	*Boerhavia burbidgeana*			
344.	2770	*Boerhavia coccinea (Tar Vine, Wituka)*			
345.	2772	*Boerhavia gardneri*			
346.	2774	*Boerhavia repleta*			
347.	2775	*Boerhavia schomburgkiana*			
Oleaceae					
348.	12059	*Jasminum didymum subsp. lineare (Desert Jasmine)*			
Onagraceae					
349.	6136	*Ludwigia perennis*			
Oxalidaceae					
350.	4349	*Oxalis corniculata (Yellow Wood Sorrel)*	Y		
Papaveraceae					
351.	17797	*Argemone ochroleuca subsp. ochroleuca*	Y		
Pedaliaceae					
352.	43521	*Josephinia sp. Style-topped fruit (M. Maier BES MM 1017)*			Y

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Phrymaceae					
353.	7060	*Glossostigma diandrum*			
354.	12486	*Peplidium aithocheilum*			
Phyllanthaceae					
355.	12013	*Flueggea virosa subsp. melanthesoides (Dogwood, Guwal)*			
356.	9056	*Phyllanthus baccatus*			
357.	17626	*Phyllanthus erwinii*			
358.	4680	*Phyllanthus maderaspatensis*			
359.		*Phyllanthus sp.*			
Plantaginaceae					
360.	7098	*Stemodia grossa (Marsh Stemodia, Mindjaara)*			
Poaceae					
361.	172	*Acrachne racemosa*			
362.	204	*Aristida burbidgeae*			
363.	207	*Aristida contorta (Bunched Kerosene Grass)*			
364.	210	*Aristida holathera*			
365.	12063	*Aristida holathera var. holathera*			
366.	213	*Aristida ingrata*			
367.	215	*Aristida latifolia (Feathertop Wiregrass)*			
368.	217	*Aristida nitidula (Flat-awned Threeawn)*			
369.		*Aristida sp.*			
370.	239	*Bothriochloa bladhii (Forest Bluegrass)*			
371.	16355	*Bothriochloa decipiens var. cloncurrensis*		P1	
372.	241	*Brachyachne convergens (Spider Grass)*			
373.	258	*Cenchrus ciliaris (Buffel Grass)*	Y		
374.	259	*Cenchrus echinatus (Burrgrass)*	Y		
375.	29721	*Cenchrus setiger (Birdwood Grass)*	Y		
376.	266	*Chloris barbata (Purpletop Chloris)*	Y		
377.	270	*Chloris pumilio*			
378.	279	*Cymbopogon ambiguus (Scentgrass)*			
379.		*Cymbopogon sp.*			
380.	283	*Cynodon dactylon (Couch)*	Y		
381.	290	*Dactyloctenium radulans (Button Grass)*			
382.	303	*Dichanthium fecundum (Curly Bluegrass)*			
383.	13741	*Dichanthium sericeum subsp. humilius*			
384.	310	*Digitaria brownii (Cotton Panic Grass)*			
385.	313	*Digitaria ctenantha (Comb Finger Grass)*			
386.	328	*Echinochloa colona (Awnless Barnyard Grass)*	Y		
387.	355	*Elytrophorus spicatus (Spikegrass)*			
388.	357	*Enneapogon caerulescens (Limestone Grass)*			
389.		*Enneapogon sp.*			
390.	375	*Eragrostis cumingii (Cuming's Love Grass)*			
391.	378	*Eragrostis dielsii (Mallee Lovegrass)*			
392.	380	*Eragrostis eriopoda (Woollybutt Grass, Wangurnu)*			
393.	16731	*Eragrostis exigua*			
394.	381	*Eragrostis falcata (Sickle Lovegrass)*			
395.	388	*Eragrostis leptocarpa (Drooping Lovegrass)*			
396.	38505	*Eragrostis surreyana*		P3	
397.	398	*Eragrostis tenellula (Delicate Lovegrass)*			
398.	399	*Eragrostis xerophila (Knotty-butt Neverfail)*			
399.	400	*Eriachne aristidea*			
400.	403	*Eriachne benthamii (Swamp Wanderrie)*			
401.	407	*Eriachne festucacea (Plains Wandarrie Grass)*			
402.	411	*Eriachne helmsii (Buck Wanderrie Grass)*			
403.	413	*Eriachne mucronata (Mountain Wanderrie Grass)*			
404.	16485	*Eriachne pulchella subsp. dominii*			
405.	16486	*Eriachne pulchella subsp. pulchella*			
406.	421	*Eriachne tenuiculmis*			
407.	426	*Eriochloa pseudoacrotricha (Perennial Cupgrass)*			
408.	11011	*Eulalia aurea*			
409.	443	*Heteropogon contortus (Bunch Speargrass)*			
410.	464	*Iseilema membranaceum (Small Flinders Grass)*			
411.	471	*Leptochloa digitata (Whorled Cane Grass)*			
412.	19061	*Leptochloa fusca*			
413.	505	*Panicum laevinode*			
414.	518	*Paspalidium clementii (Clements Paspalidium)*			
415.	519	*Paspalidium constrictum (Knottybutt Grass)*			
416.	523	*Paspalidium rarum (Rare Paspalidium)*			
417.	525	*Paspalidium tabulatum*			

	Name ID	Species Name	Naturalised	Conservation Code	[1]Endemic To Query Area
418.	606	*Setaria dielsii (Diels' Pigeon Grass)*			
419.	629	*Sporobolus australasicus (Fairy Grass)*			
420.	17819	*Themeda sp. Mt Barricade (M.E. Trudgen 2471)*			
421.	673	*Themeda triandra*			
422.	679	*Triodia angusta*			
423.	13131	*Triodia epactia*			
424.	17877	*Triodia melvillei*			
425.		*Triodia sp.*			
426.	45373	*Triodia sp. Pannawonica (B.M. Anderson & M.D. Barrett BMA 89)*		P1	Y
427.	43220	*Triodia sp. Peedamulla (A.A. Mitchell PRP 1636)*			
428.	35843	*Triodia sp. Robe River (M.E. Trudgen et al. MET 12367)*		P3	
429.	704	*Triodia wiseana (Limestone Spinifex)*			
430.	717	*Urochloa piligera*			
431.	729	*Xerochloa barbata (Rice Grass)*			
432.	730	*Xerochloa imberbis (Rice Grass)*			
433.	732	*Yakirra australiensis*			
434.	11894	*Yakirra australiensis var. australiensis*			
Portulacaceae					
435.	2864	*Calandrinia ptychosperma*			
436.	2878	*Portulaca conspicua*			
437.	2882	*Portulaca intraterranea*			
438.	2884	*Portulaca oleracea (Purslane, Wakati)*			
439.	2886	*Portulaca pilosa (Djanggara)*	Y		
440.		*Portulaca sp.*			
Potamogetonaceae					
441.		*Potamogeton sp.*			
442.	20426	*Potamogeton tepperi*			
443.	113	*Potamogeton tricarinatus (Floating Pondweed)*			
Proteaceae					
444.	19570	*Grevillea pyramidalis subsp. leucadendron*			
445.	2121	*Grevillea wickhamii (Wickham's Grevillea)*			
446.	13440	*Grevillea wickhamii subsp. aprica*			
447.	19478	*Grevillea wickhamii subsp. hispidula*			
448.	19074	*Grevillea wickhamii subsp. macrodonta*			
449.	2138	*Hakea chordophylla*			
450.	19137	*Hakea lorea subsp. lorea*			
Pteridaceae					
451.	30	*Ceratopteris thalictroides*			
452.	32	*Cheilanthes brownii*			
453.	37	*Cheilanthes lasiophylla (Woolly Cloak Fern)*			
454.	12818	*Cheilanthes sieberi subsp. sieberi*			
Rubiaceae					
455.	7338	*Oldenlandia crouchiana*			
456.	7339	*Oldenlandia galioides*			
457.		*Oldenlandia sp.*			
458.	12964	*Pomax rupestris*			
459.	13339	*Synaptantha tillaeacea var. tillaeacea*			
Ruppiaceae					
460.		*Ruppia sp.*			
Sapindaceae					
461.	4759	*Dodonaea coriacea*			
Scrophulariaceae					
462.	7192	*Eremophila cuneifolia (Pinyuru, T'iranju)*			
463.	15052	*Eremophila forrestii subsp. forrestii*			
464.	16696	*Eremophila fraseri subsp. fraseri*			
465.	7234	*Eremophila longifolia (Berrigan, Tulypurpa)*			
466.	23997	*Eremophila tietkensii*			
Solanaceae					
467.	6971	*Nicotiana benthamiana (Tjuntiwari)*			
468.	11331	*Nicotiana occidentalis subsp. obliqua*			
469.	11856	*Nicotiana occidentalis subsp. occidentalis*			
470.		*Nicotiana sp.*			
471.	20652	*Physalis angulata*	Y		
472.	6989	*Solanum ashbyae*			
473.	6995	*Solanum centrale (Desert Raisin, Kampurarpa)*			
474.	6998	*Solanum cleistogamum*			

	Name ID	Species Name	Naturalised	Conservation Code	[1]Endemic To Query Area
475.	7002	*Solanum diversiflorum*			
476.	7009	*Solanum gabrielae*			
477.	7014	*Solanum horridum*			
478.	7018	*Solanum lasiophyllum (Flannel Bush, Mindjulu)*			
479.	7022	*Solanum nigrum (Black Berry Nightshade)*	Y		
480.	7029	*Solanum phlomoides*			
481.		*Solanum sp.*			
482.	7036	*Solanum sturtianum (Thargomindah Nightshade)*			
Stylidiaceae					
483.	7729	*Stylidium fluminense*			
484.	18123	*Stylidium weeliwolli*		P2	
Surianaceae					
485.	3182	*Stylobasium spathulatum (Pebble Bush)*			
Thymelaeaceae					
486.	5230	*Pimelea ammocharis*			
Violaceae					
487.	5215	*Hybanthus aurantiacus*			
Zygophyllaceae					
488.	4368	*Tribulopis angustifolia*			
489.	4374	*Tribulus astrocarpus*			
490.	4377	*Tribulus hirsutus*			
491.	4379	*Tribulus macrocarpus*			
492.	4380	*Tribulus occidentalis (Perennial Caltrop)*			
493.	4381	*Tribulus platypterus (Cork Hopbush)*			
494.		*Tribulus sp.*			
495.	4383	*Tribulus terrestris (Caltrop)*	Y		

Conservation Codes
T - Rare or likely to become extinct
X - Presumed extinct
IA - Protected under international agreement
S - Other specially protected fauna
1 - Priority 1
2 - Priority 2
3 - Priority 3
4 - Priority 4
5 - Priority 5

[1] For NatureMap's purposes, species flagged as endemic are those whose records are wholely contained within the search area. Note that only those records complying with the search criterion are included in the calculation. For example, if you limit records to those from a specific datasource, only records from that datasource are used to determine if a species is restricted to the query area.

Australian Government

Department of the Environment

EPBC Act Protected Matters Report

This report provides general guidance on matters of national environmental significance and other matters protected by the EPBC Act in the area you have selected.

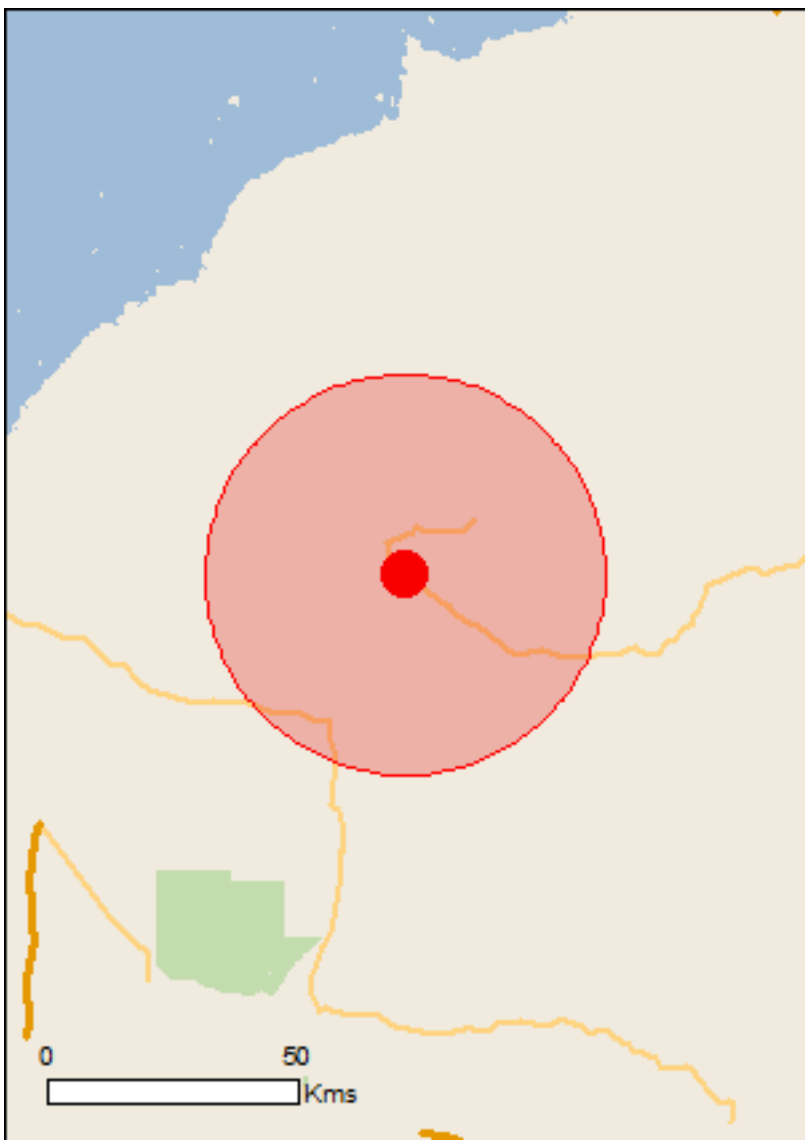
Information on the coverage of this report and qualifications on data supporting this report are contained in the caveat at the end of the report.

Information is available about Environment Assessments and the EPBC Act including significance guidelines, forms and application process details.

Report created: 25/07/16 16:03:50

Summary
Details
- Matters of NES
- Other Matters Protected by the EPBC Act
- Extra Information

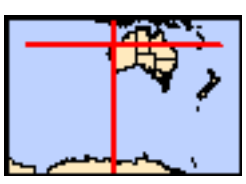
Caveat
Acknowledgements



This map may contain data which are ©Commonwealth of Australia (Geoscience Australia), ©PSMA 2010

Coordinates

Buffer: 40.0Km



Summary

Matters of National Environmental Significance

This part of the report summarises the matters of national environmental significance that may occur in, or may relate to, the area you nominated. Further information is available in the detail part of the report, which can be accessed by scrolling or following the links below. If you are proposing to undertake an activity that may have a significant impact on one or more matters of national environmental significance then you should consider the Administrative Guidelines on Significance.

World Heritage Properties:	None
National Heritage Places:	None
Wetlands of International Importance:	None
Great Barrier Reef Marine Park:	None
Commonwealth Marine Area:	None
Listed Threatened Ecological Communities:	None
Listed Threatened Species:	8
Listed Migratory Species:	7

Other Matters Protected by the EPBC Act

This part of the report summarises other matters protected under the Act that may relate to the area you nominated. Approval may be required for a proposed activity that significantly affects the environment on Commonwealth land, when the action is outside the Commonwealth land, or the environment anywhere when the action is taken on Commonwealth land. Approval may also be required for the Commonwealth or Commonwealth agencies proposing to take an action that is likely to have a significant impact on the environment anywhere.

The EPBC Act protects the environment on Commonwealth land, the environment from the actions taken on Commonwealth land, and the environment from actions taken by Commonwealth agencies. As heritage values of a place are part of the 'environment', these aspects of the EPBC Act protect the Commonwealth Heritage values of a Commonwealth Heritage place. Information on the new heritage laws can be found at http://www.environment.gov.au/heritage

A permit may be required for activities in or on a Commonwealth area that may affect a member of a listed threatened species or ecological community, a member of a listed migratory species, whales and other cetaceans, or a member of a listed marine species.

Commonwealth Land:	None
Commonwealth Heritage Places:	None
Listed Marine Species:	12
Whales and Other Cetaceans:	None
Critical Habitats:	None
Commonwealth Reserves Terrestrial:	None
Commonwealth Reserves Marine:	None

Extra Information

This part of the report provides information that may also be relevant to the area you have nominated.

State and Territory Reserves:	None
Regional Forest Agreements:	None
Invasive Species:	10
Nationally Important Wetlands:	None
Key Ecological Features (Marine)	None

Details

Matters of National Environmental Significance

Listed Threatened Species		[Resource Information]
Name	Status	Type of Presence
Birds		
Pezoporus occidentalis Night Parrot [59350]	Endangered	Species or species habitat may occur within area
Rostratula australis Australian Painted Snipe [77037]	Endangered	Species or species habitat may occur within area
Mammals		
Dasyurus hallucatus Northern Quoll, Digul [331]	Endangered	Species or species habitat known to occur within area
Macroderma gigas Ghost Bat [174]	Vulnerable	Species or species habitat likely to occur within area
Macrotis lagotis Greater Bilby [282]	Vulnerable	Species or species habitat likely to occur within area
Rhinonicteris aurantia (Pilbara form) Pilbara Leaf-nosed Bat [82790]	Vulnerable	Roosting known to occur within area
Plants		
Lepidium catapycnon Hamersley Lepidium, Hamersley Catapycnon [9397]	Vulnerable	Species or species habitat likely to occur within area
Reptiles		
Liasis olivaceus barroni Olive Python (Pilbara subspecies) [66699]	Vulnerable	Species or species habitat known to occur within area

Listed Migratory Species		[Resource Information]
* Species is listed under a different scientific name on the EPBC Act - Threatened Species list.		
Name	Threatened	Type of Presence
Migratory Marine Birds		
Apus pacificus Fork-tailed Swift [678]		Species or species habitat likely to occur within area
Migratory Terrestrial Species		
Hirundo rustica Barn Swallow [662]		Species or species habitat may occur within area

Name	Threatened	Type of Presence
[Motacilla cinerea](#)		
Grey Wagtail [642]		Species or species habitat may occur within area
[Motacilla flava](#)		
Yellow Wagtail [644]		Species or species habitat may occur within area
Migratory Wetlands Species		
[Charadrius veredus](#)		
Oriental Plover, Oriental Dotterel [882]		Species or species habitat may occur within area
[Glareola maldivarum](#)		
Oriental Pratincole [840]		Species or species habitat may occur within area
[Pandion haliaetus](#)		
Osprey [952]		Species or species habitat known to occur within area

Other Matters Protected by the EPBC Act

Listed Marine Species [Resource Information]

* Species is listed under a different scientific name on the EPBC Act - Threatened Species list.

Name	Threatened	Type of Presence
Birds		
[Apus pacificus](#)		
Fork-tailed Swift [678]		Species or species habitat likely to occur within area
[Ardea alba](#)		
Great Egret, White Egret [59541]		Species or species habitat known to occur within area
[Ardea ibis](#)		
Cattle Egret [59542]		Species or species habitat may occur within area
[Charadrius veredus](#)		
Oriental Plover, Oriental Dotterel [882]		Species or species habitat may occur within area
[Glareola maldivarum](#)		
Oriental Pratincole [840]		Species or species habitat may occur within area
[Haliaeetus leucogaster](#)		
White-bellied Sea-Eagle [943]		Species or species habitat likely to occur within area
[Hirundo rustica](#)		
Barn Swallow [662]		Species or species habitat may occur within area
[Merops ornatus](#)		
Rainbow Bee-eater [670]		Species or species habitat may occur within area
[Motacilla cinerea](#)		
Grey Wagtail [642]		Species or species habitat may occur within area
[Motacilla flava](#)		
Yellow Wagtail [644]		Species or species habitat may occur within area

Name	Threatened	Type of Presence
Pandion haliaetus		
Osprey [952]		Species or species habitat known to occur within area
Rostratula benghalensis (sensu lato)		
Painted Snipe [889]	Endangered*	Species or species habitat may occur within area

Extra Information

Invasive Species [Resource Information]

Weeds reported here are the 20 species of national significance (WoNS), along with other introduced plants that are considered by the States and Territories to pose a particularly significant threat to biodiversity. The following feral animals are reported: Goat, Red Fox, Cat, Rabbit, Pig, Water Buffalo and Cane Toad. Maps from Landscape Health Project, National Land and Water Resouces Audit, 2001.

Name	Status	Type of Presence
Birds		
Columba livia		
Rock Pigeon, Rock Dove, Domestic Pigeon [803]		Species or species habitat likely to occur within area
Mammals		
Capra hircus		
Goat [2]		Species or species habitat likely to occur within area
Equus asinus		
Donkey, Ass [4]		Species or species habitat likely to occur within area
Felis catus		
Cat, House Cat, Domestic Cat [19]		Species or species habitat likely to occur within area
Mus musculus		
House Mouse [120]		Species or species habitat likely to occur within area
Oryctolagus cuniculus		
Rabbit, European Rabbit [128]		Species or species habitat likely to occur within area
Vulpes vulpes		
Red Fox, Fox [18]		Species or species habitat likely to occur within area
Plants		
Cenchrus ciliaris		
Buffel-grass, Black Buffel-grass [20213]		Species or species habitat likely to occur within area
Parkinsonia aculeata		
Parkinsonia, Jerusalem Thorn, Jelly Bean Tree, Horse Bean [12301]		Species or species habitat likely to occur within area
Prosopis spp.		
Mesquite, Algaroba [68407]		Species or species

Name	Status	Type of Presence
		habitat likely to occur within area

Caveat

The information presented in this report has been provided by a range of data sources as acknowledged at the end of the report.

This report is designed to assist in identifying the locations of places which may be relevant in determining obligations under the Environment Protection and Biodiversity Conservation Act 1999. It holds mapped locations of World and National Heritage properties, Wetlands of International and National Importance, Commonwealth and State/Territory reserves, listed threatened, migratory and marine species and listed threatened ecological communities. Mapping of Commonwealth land is not complete at this stage. Maps have been collated from a range of sources at various resolutions.

Not all species listed under the EPBC Act have been mapped (see below) and therefore a report is a general guide only. Where available data supports mapping, the type of presence that can be determined from the data is indicated in general terms. People using this information in making a referral may need to consider the qualifications below and may need to seek and consider other information sources.

For threatened ecological communities where the distribution is well known, maps are derived from recovery plans, State vegetation maps, remote sensing imagery and other sources. Where threatened ecological community distributions are less well known, existing vegetation maps and point location data are used to produce indicative distribution maps.

For species where the distributions are well known, maps are digitised from sources such as recovery plans and detailed habitat studies. Where appropriate, core breeding, foraging and roosting areas are indicated under 'type of presence'. For species whose distributions are less well known, point locations are collated from government wildlife authorities, museums, and non-government organisations; bioclimatic distribution models are generated and these validated by experts. In some cases, the distribution maps are based solely on expert knowledge.

Only selected species covered by the following provisions of the EPBC Act have been mapped:

- migratory and
- marine

The following species and ecological communities have not been mapped and do not appear in reports produced from this database:

- threatened species listed as extinct or considered as vagrants
- some species and ecological communities that have only recently been listed
- some terrestrial species that overfly the Commonwealth marine area
- migratory species that are very widespread, vagrant, or only occur in small numbers

The following groups have been mapped, but may not cover the complete distribution of the species:

- non-threatened seabirds which have only been mapped for recorded breeding sites
- seals which have only been mapped for breeding sites near the Australian continent

Such breeding sites may be important for the protection of the Commonwealth Marine environment.

Coordinates

-21.73639 116.19722

Acknowledgements

This database has been compiled from a range of data sources. The department acknowledges the following custodians who have contributed valuable data and advice:

-Office of Environment and Heritage, New South Wales
-Department of Environment and Primary Industries, Victoria
-Department of Primary Industries, Parks, Water and Environment, Tasmania
-Department of Environment, Water and Natural Resources, South Australia
-Parks and Wildlife Commission NT, Northern Territory Government
-Department of Environmental and Heritage Protection, Queensland
-Department of Parks and Wildlife, Western Australia
-Environment and Planning Directorate, ACT
-Birdlife Australia
-Australian Bird and Bat Banding Scheme
-Australian National Wildlife Collection
-Natural history museums of Australia
-Museum Victoria
-Australian Museum
-South Australian Museum
-Queensland Museum
-Online Zoological Collections of Australian Museums
-Queensland Herbarium
-National Herbarium of NSW
-Royal Botanic Gardens and National Herbarium of Victoria
-Tasmanian Herbarium
-State Herbarium of South Australia
-Northern Territory Herbarium
-Western Australian Herbarium
-Australian National Herbarium, Atherton and Canberra
-University of New England
-Ocean Biogeographic Information System
-Australian Government, Department of Defence
Forestry Corporation, NSW
-Geoscience Australia
-CSIRO
-Other groups and individuals

The Department is extremely grateful to the many organisations and individuals who provided expert advice and information on numerous draft distributions.

Please feel free to provide feedback via the Contact Us page.

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NatureMap
Mapping Western Australia's biodiversity

NatureMap Species Report

Created By Guest user on 22/09/2015

Current Names Only Yes
Core Datasets Only Yes
Method 'By Circle'
Centre 116°12' 02" E,21°44' 47" S
Buffer 40km
Group By Family

Family	Species	Records
Acanthaceae	1	1
Acanthizidae	5	33
Acariformes	7	470
Accipitridae	10	108
Actinopodidae	1	1
Aegothelidae	1	2
Aeolosomatidae	1	3
Aeshnidae	1	2
Agamidae	12	217
Aizoaceae	3	7
Alaudidae	1	1
Amaranthaceae	26	52
Ameiridae	4	14
Ameroseiidae	1	1
Amphipoda	1	2
Amphisopodidae	1	3
Anatidae	6	34
Ancylidae	1	3
Anhingidae	2	2
Apiaceae	1	1
Araliaceae	3	6
Araneidae	1	1
Arcellidae	3	3
Ardeidae	6	32
Arecaceae	1	4
Arrenuridae	10	22
Artamidae	5	40
Ascidae	3	15
Asphodelaceae	1	1
Asteraceae	19	32
Atrochidae	1	1
Aturidae	4	5
Atyidae	1	4
Baetidae	3	7
Bathynellidae	1	1
Bdelloidea	2	14
Belostomatidae	2	4
Bogidiellidae	2	7
Boidae	5	15
Boraginaceae	5	6
Bovidae	1	15
Brachionidae	6	6
Brassicaceae	1	1
Bufonidae	1	4
Burhinidae	1	3
Caenidae	5	13
Camelidae	1	1
Campanulaceae	2	4
Campephagidae	3	80
Candonidae	29	80
Canidae	4	11
Canthocamptidae	1	4
Capparaceae	1	4
Caprimulgidae	1	5
Carangidae	1	1
Carphodactylidae	5	14
Caryophyllaceae	3	10
Casuariidae	1	22
Celastraceae	1	1
Centropodidae	1	5
Centropyxidae	1	1
Ceratopogonidae	14	36
Charadriidae	2	2
Chenopodiaceae	7	10
Chironomidae	51	120
Chrysomelidae	1	1
Chthoniidae	3	9
Chydoridae	7	9
Cinclosomatidae	1	1
Cirolanidae	4	7
Cleomaceae	1	5
Clupeidae	1	1
Coenagrionidae	8	19
Columbidae	8	192
Combretaceae	2	4
Conochilidae	1	1
Convolvulaceae	5	8

Copepoda	3	20
Corinnidae	1	1
Corixidae	6	9
Corvidae	3	70
Cracticidae	4	53
Cuculidae	2	12
Cucurbitaceae	3	7
Culicidae	6	10
Cyclopidae	16	55
Cyperaceae	22	42
Cyprididae	9	12
Cypridopsidae	1	1
Daphniidae	1	1
Darwinulidae	4	6
Dasyuridae	10	281
Diaptomidae	1	4
Diatom Family	65	116
Dicaeidae	1	2
Dicruridae	5	155
Difflugiidae	3	3
Diosaccidae	1	5
Diplodactylidae	12	158
Diplopoda	1	1
Dolichopodidae	2	5
Droseraceae	1	1
Dytiscidae	23	49
Ecnomidae	1	7
Ectinosomatidae	2	9
Elapidae	15	80
Elmidae	4	4
Elopidae	1	2
Emballonuridae	2	50
Enchytraeidae	2	4
Ephydridae	1	3
Equidae	1	1
Estrilidae	5	224
Euchlanidae	3	9
Euglyphiidae	1	3
Euphorbiaceae	12	24
Fabaceae	77	221
Falconidae	5	60
Felidae	1	11
Floscullariacea	1	1
Flosculariidae	1	1
Frankeniaceae	1	1
Gekkonidae	6	121
Gelastocoridae	1	1
Gentianaceae	1	1
Gerridae	5	8
Glareolidae	1	1
Gomphidae	1	5
Goodeniaceae	13	23
Hadziidae	4	19
Halcyonidae	4	49
Haliplidae	3	3
Haloragaceae	2	3
Hebridae	2	3
Hemicorduliidae	3	4
Hersiliidae	1	2
Hipposideridae	1	2
Hirudinea	1	1
Hirundinidae	4	7
Hubbardiidae	5	280
Hydrachnidae	2	4
Hydraenidae	5	9
Hydridae	1	3
Hydrobiidae	1	3
Hydrocharitaceae	3	6
Hydrochidae	6	14
Hydrodromidae	1	3
Hydrophilidae	15	22
Hydropsychidae	1	2
Hydroptilidae	2	8
Hydryphantidae	1	4
Hygrobatidae	4	7
Hylidae	2	38
Hyriidae	1	3
Ilyocryptidae	1	1
Isopoda	1	3
Isostictidae	1	4
Lamiaceae	4	7
Lamponidae	9	25
Lauraceae	1	1
Lecanidae	17	33
Lentibulariaceae	1	1
Lepadellidae	6	10
Leporidae	1	1
Leptoceridae	8	16
Lesquereusidae	1	3
Libellulidae	5	11
Limnesiidae	3	15
Limnichidae	1	2
Limnocytheridae	2	11
Lindeniidae	1	3
Loranthaceae	3	3
Lutjanidae	1	1
Lycosidae	2	4
Lymnaeidae	1	6
Lythraceae	4	8
Macropodidae	4	60
Maluridae	5	63
Malvaceae	46	112
Marsileaceae	2	2
Megadermatidae	1	14
Meliphagidae	8	236

Melitidae	1	2
Menispermaceae	1	2
Meropidae	1	83
Mesoveliidae	2	3
Microcerberidae	1	1
Mideopsidae	5	8
Molluginaceae	3	5
Molossidae	2	5
Moraceae	2	4
Motacillidae	1	1
Mugilidae	2	3
Muridae	8	301
Myobatrachidae	2	70
Myrtaceae	13	22
Mytilinidae	1	2
NO FAMILY	1	7
Naididae	11	28
Nematoda	8	13
Nemertini	1	1
Nemesiidae	1	14
Neoniphargidae	1	1
Nepidae	2	3
Nereidae	1	2
Noteridae	1	1
Notommatidae	5	5
Notonectidae	1	1
Nyctaginaceae	5	9
Ochteridae	1	2
Oleaceae	1	4
Olibrinidae	1	3
Oligochaeta	1	1
Olpiidae	1	1
Onagraceae	1	2
Oonopidae	2	2
Ostracoda	1	7
Otididae	1	19
Oxidae	4	10
Pachycephalidae	3	88
Papaveraceae	1	1
Parabathynellidae	3	12
Paramelitidae	3	13
Parasitiformes	1	1
Parastenocarididae	2	3
Pardalotidae	3	29
Pedaliaceae	1	1
Pelecanidae	1	3
Peritrichidae	1	1
Petroicidae	2	13
Pezidae	2	3
Phalacrocoracidae	4	17
Phalangeridae	1	3
Phasianidae	1	2
Philodinidae	1	4
Philopotamidae	1	2
Pholcidae	1	1
Phreodrilidae	5	16
Phrymaceae	2	2
Phyllanthaceae	5	6
Pionidae	1	2
Planorbidae	4	10
Plantaginaceae	1	1
Pleidae	3	6
Poaceae	62	138
Podargidae	1	1
Podicipedidae	3	18
Polycentropodidae	1	1
Pomatostomidae	3	13
Portulacaceae	5	9
Potamogetonaceae	1	3
Prodidomidae	2	2
Proteaceae	6	8
Psittacidae	9	281
Pteridaceae	4	9
Ptilonorhynchidae	2	7
Pygopodidae	10	53
Pyralidae	4	6
Rallidae	4	8
Recurvirostridae	1	3
Ridgewayiidae	1	16
Rubiaceae	3	4
Salticidae	2	2
Sapindaceae	1	1
Scaridiidae	1	1
Scatophagidae	1	1
Scincidae	42	504
Sciomyzidae	1	2
Scirtidae	2	3
Scolopacidae	3	7
Scolopendridae	5	27
Scorpaenidae	1	1
Scrophulariaceae	4	5
Scutigeridae	1	7
Sididae	1	2
Sillaginidae	1	1
Simuliidae	1	2
Solanaceae	14	25
Sparassidae	1	1
Spongillidae	1	1
Staphylinidae	1	1
Stratiomyidae	1	6
Strigidae	3	7
Stylidiaceae	2	2
Surianaceae	1	1
Syarinidae	2	11
Sylviidae	4	35

Synchaetidae	1	2
Tabanidae	1	5
Tachyglossidae	1	3
Terapontidae	2	4
Testudinellidae	3	4
Tetraodontidae	1	1
Thermosbaenacea	1	2
Thermosbaenacidae	2	16
Thiaridae	2	3
Threskiornithidae	2	11
Thymelaeaceae	1	1
Tipulidae	5	5
Trichocercidae	4	4
Trichotriidae	1	2
Trochanteriidae	1	3
Trochanteriidae?	1	4
Turbellaria	2	5
Turnicidae	1	11
Tytonidae	1	1
Unionicolidae	12	32
Urodacidae	1	1
Varanidae	13	67
Veliidae	1	2
Vespertilionidae	5	53
Violaceae	1	2
Zygophyllaceae	6	19
TOTAL	**1376**	**7383**

	Name ID	Species Name	Naturalised	Conservation Code	[1]Endemic To Query Area
Acanthaceae					
1.	12088	*Rostellularia adscendens var. clementii*			
Acanthizidae					
2.	24260	*Acanthiza apicalis (Broad-tailed Thornbill, Inland Thornbill)*			
3.	24265	*Acanthiza uropygialis (Chestnut-rumped Thornbill)*			
4.	25530	*Gerygone fusca (Western Gerygone)*			
5.	24271	*Gerygone fusca subsp. fusca (Western Gerygone)*			
6.	30948	*Smicrornis brevirostris (Weebill)*			
Acariformes					
7.		*Acariformes sp.*			
8.		*Acarina sp.*			
9.		*Oribatida group 1 (PSS)*			
10.		*Oribatida group 4 (PSS)*			
11.		*Oribatida group 5 (PSS)*			
12.		*Oribatida sp. 4 (PSW)*			
13.		*Trombidioidea sp.*			
Accipitridae					
14.	25535	*Accipiter cirrocephalus (Collared Sparrowhawk)*			
15.	25536	*Accipiter fasciatus (Brown Goshawk)*			
16.	24283	*Accipiter fasciatus subsp. didimus (Brown Goshawk)*			
17.	24285	*Aquila audax (Wedge-tailed Eagle)*			
18.	25538	*Aquila morphnoides (Little Eagle)*			
19.	24289	*Circus assimilis (Spotted Harrier)*			
20.	25540	*Elanus caeruleus (Black-shouldered Kite)*			
21.	24293	*Haliaeetus leucogaster (White-bellied Sea-Eagle)*		IA	
22.	24295	*Haliastur sphenurus (Whistling Kite)*			
23.	25542	*Milvus migrans (Black Kite)*			
Actinopodidae					
24.		*Missulena rutraspina*			
Aegothelidae					
25.	25544	*Aegotheles cristatus (Australian Owlet-nightjar)*			
Aeolosomatidae					
26.		*Aeolosoma sp. 1 (PSS)*			
Aeshnidae					
27.		*Hemianax papuensis*			
Agamidae					
28.	30833	*Amphibolurus longirostris (Long-nosed Dragon)*			
29.	25458	*Ctenophorus caudicinctus (Ring-tailed Dragon)*			
30.	24865	*Ctenophorus caudicinctus subsp. caudicinctus (Ring-tailed Dragon)*			
31.	24872	*Ctenophorus femoralis (Dune Dragon)*			
32.	25459	*Ctenophorus isolepis (Crested Dragon, Military Dragon)*			
33.	24874	*Ctenophorus isolepis subsp. citrinus (Crested Dragon, Military Dragon)*			
34.	24876	*Ctenophorus isolepis subsp. isolepis (Crested Dragon, Military Dragon)*			
35.	24882	*Ctenophorus nuchalis (Central Netted Dragon)*			
36.	24886	*Ctenophorus reticulatus (Western Netted Dragon)*			
37.	25510	*Pogona minor (Dwarf Bearded Dragon)*			
38.	24907	*Pogona minor subsp. minor (Dwarf Bearded Dragon)*			
Aizoaceae					
39.	44241	*Trianthema glossostigmum*			
40.	44305	*Trianthema pilosum*			
41.	44362	*Trianthema triquetrum*			
Alaudidae					
42.	25545	*Mirafra javanica (Horsfield's Bushlark, Singing Bushlark)*			
Amaranthaceae					
43.	2647	*Alternanthera angustifolia*			
44.	2648	*Alternanthera denticulata (Lesser Joyweed)*			
45.	2651	*Alternanthera nana (Hairy Joyweed)*			
46.	2653	*Alternanthera pungens (Khaki Weed)*	Y		
47.	31076	*Amaranthus cochleitepalus*			
48.	2660	*Amaranthus cuspidifolius*			
49.	2663	*Amaranthus interruptus (Native Amaranth)*			
50.	2666	*Amaranthus mitchellii (Boggabri Weed)*			

	Name ID	Species Name	Naturalised	Conservation Code	[1]Endemic To Query Area
51.	20018	*Amaranthus undulatus*			
52.	18361	*Gomphrena affinis subsp. pilbarensis*			
53.	2680	*Gomphrena cunninghamii*			
54.	2690	*Ptilotus aervoides*			
55.	2694	*Ptilotus appendiculatus*			
56.	2696	*Ptilotus astrolasius*			
57.	2698	*Ptilotus auriculifolius*			
58.	2699	*Ptilotus axillaris (Mat Mulla Mulla)*			
59.	2704	*Ptilotus calostachyus (Weeping Mulla Mulla)*			
60.	2711	*Ptilotus clementii (Tassel Top)*			
61.	2725	*Ptilotus fusiformis*			
62.	2728	*Ptilotus gomphrenoides*			
63.	2734	*Ptilotus incanus*			
64.	2738	*Ptilotus latifolius (Tangled Mulla Mulla)*			
65.	41001	*Ptilotus nobilis subsp. nobilis (Yellow Tails)*			
66.	2747	*Ptilotus obovatus (Cotton Bush)*			
67.	11396	*Ptilotus obovatus var. obovatus*			
68.	2766	*Ptilotus villosiflorus*			
Ameiridae					
69.		*Inermipes sp. 2 (PSS)*			Y
70.		*Stygonitocrella sp.*			
71.		*Stygonitocrella trispinosa*			
72.		*Stygonitocrella unispinosa*			
Ameroseiidae					
73.		*Amerosius pulmosus*			Y
Amphipoda					
74.		*Amphipoda sp.*			
Amphisopodidae					
75.		*Pilbarophreatoicus platyarthricus*			
Anatidae					
76.	24312	*Anas gracilis (Grey Teal)*			
77.	24316	*Anas superciliosa (Pacific Black Duck)*			
78.	24318	*Aythya australis (Hardhead)*			
79.	24321	*Chenonetta jubata (Australian Wood Duck, Wood Duck)*			
80.	24322	*Cygnus atratus (Black Swan)*			
81.	24325	*Dendrocygna eytoni (Plumed Whistling Duck)*			
Ancylidae					
82.		*Ferrissia sp.*			
Anhingidae					
83.	25553	*Anhinga melanogaster (Darter)*			
84.	24332	*Anhinga melanogaster subsp. novaehollandiae (Darter)*			
Apiaceae					
85.	6218	*Daucus glochidiatus (Australian Carrot)*			
Araliaceae					
86.	6202	*Astrotricha hamptonii (Ironplant)*			
87.	6278	*Trachymene oleracea*			
88.	19043	*Trachymene oleracea subsp. oleracea*			
Araneidae					
89.		*Backobourkia collina*			
Arcellidae					
90.		*Arcella gibbosa (ex P2)*			
91.		*Arcella sp.*			
92.		*Arcella sp. P1*			
Ardeidae					
93.	25557	*Ardea garzetta (Little Egret)*			
94.	25559	*Ardea intermedia (Intermediate Egret)*			
95.	41324	*Ardea modesta (Eastern Great Egret)*		IA	
96.	24340	*Ardea novaehollandiae (White-faced Heron)*			
97.	24341	*Ardea pacifica (White-necked Heron)*			
98.	25564	*Nycticorax caledonicus (Rufous Night Heron)*			
Arecaceae					
99.	1042	*Phoenix dactylifera (Date Palm)*	Y		
Arrenuridae					

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100.		*Arrenurus ensifer*			
101.		*Arrenurus harveyi*			
102.		*Arrenurus liliaceus*			
103.		*Arrenurus purpureus*			
104.		*Arrenurus rouxi*			
105.		*Arrenurus sp.*			
106.		*Arrenurus sp. 9 (nr pseudaffinis) (PSW)*			
107.		*Arrenurus sp. nov. 2 (PSS)*			
108.		*Arrenurus tripartitus*			
109.		*Arrenurus vanderpalae*			
Artamidae					
110.	25566	*Artamus cinereus (Black-faced Woodswallow)*			
111.	24352	*Artamus cinereus subsp. melanops (Black-faced Woodswallow)*			
112.	25567	*Artamus leucorynchus (White-breasted Woodswallow)*			
113.	24355	*Artamus minor (Little Woodswallow)*			
114.	24356	*Artamus personatus (Masked Woodswallow)*			
Ascidae					
115.		*Protogamasellus dispar*			Y
116.		*Protogamasellus massula*			Y
117.		*Protogamasellus mica*			
Asphodelaceae					
118.	1364	*Asphodelus fistulosus (Onion Weed)*	Y		
Asteraceae					
119.	7822	*Angianthus acrohyalinus (Hook-leaf Angianthus)*			
120.	7866	*Blumea tenella*			
121.	14090	*Calocephalus beardii*			
122.	7893	*Calocephalus knappii*			
123.	7906	*Calotis plumulifera*			
124.	19762	*Centipeda minima subsp. macrocephala*			
125.	35558	*Flaveria trinervia (Speedy Weed)*	Y		
126.	29594	*Helichrysum luteoalbum (Jersey Cudweed)*			
127.	12635	*Olearia fluvialis*			
128.	13494	*Pentalepis trichodesmoides*			
129.	42160	*Pentalepis trichodesmoides subsp. trichodesmoides*			
130.	17817	*Pluchea dunlopii*			
131.	17816	*Pluchea ferdinandi-muelleri*			
132.	43944	*Pluchea longiseta*			
133.	8168	*Pluchea rubelliflora*			
134.	8192	*Pterocaulon sphacelatum (Apple Bush)*			
135.	8193	*Pterocaulon sphaeranthoides*			
136.	13310	*Rhodanthe margarethae*			
137.	8240	*Streptoglossa odora*			
Atrochidae					
138.		*Cupelopagis? n. sp.*			
Aturidae					
139.		*Austraturus sp. P2 (PSW)*			
140.		*Axonopsella nr truza (PSW)*			
141.		*Axonopsella sp.*			
142.		*Axonopsella sp. P2 (PSW)*			
Atyidae					
143.		*Caridina indistincta*			
Baetidae					
144.		*Baetid genus 1 WA sp. 1 (KIM_UWA)*			
145.		*Baetidae sp.*			
146.		*Cloeon sp.*			
Bathynellidae					
147.		*Bathynellidae sp.*			
Bdelloidea					
148.		*Bdelloidea sp.*			
149.		*Bdelloidea sp. 2:2*			
Belostomatidae					
150.		*Diplonychus eques*			
151.		*Lethocerus distinctifemur*			
Bogidiellidae					

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152.		*Bogidiellidae sp.*			
153.		*Bogidiellidae sp. 1 (PSS)*			
Boidae					
154.	25318	*Antaresia perthensis (Pygmy Python)*			
155.	25241	*Antaresia stimsoni subsp. stimsoni (Stimson's Python)*			
156.	25320	*Aspidites melanocephalus (Black-headed Python)*			
157.	25236	*Aspidites ramsayi (Woma)*		S	
158.	25238	*Liasis olivaceus subsp. barroni (Pilbara Olive Python)*		T	
Boraginaceae					
159.	6706	*Heliotropium cunninghamii*			
160.	6712	*Heliotropium heteranthum*			
161.	6713	*Heliotropium ovalifolium*			
162.	17031	*Heliotropium transforme*			
163.	11750	*Trichodesma zeylanicum var. zeylanicum*			
Bovidae					
164.	24251	*Bos taurus (European Cattle)*	Y		
Brachionidae					
165.		*Brachionus cf. nilsoni (CB)*			
166.		*Brachionus dichotomus*			
167.		*Brachionus sericus*			
168.		*Keratella procurva*			
169.		*Plationus patulus*			
170.		*Platyias quadricornis*			
Brassicaceae					
171.	3037	*Lepidium phlebopetalum (Veined Peppercress)*			
Bufonidae					
172.	42306	*Platyplectrum spenceri (Centralian Burrowing Frog)*			
Burhinidae					
173.	24359	*Burhinus grallarius (Bush Stone-curlew)*			
Caenidae					
174.		*Tasmanocoenis arcuata*			
175.		*Tasmanocoenis sp. E (PSW)*			
176.		*Tasmanocoenis sp. M (PSW)*			
177.		*Tasmanocoenis sp. P (PSW)*			
178.		*Wundacaenis dostini*			
Camelidae					
179.	24254	*Camelus dromedarius (Dromedary, Camel)*	Y		
Campanulaceae					
180.	37480	*Lobelia arnhemiaca*			
181.	36880	*Lobelia heterophylla subsp. pilbarensis*			
Campephagidae					
182.	25568	*Coracina novaehollandiae (Black-faced Cuckoo-shrike)*			
183.	24363	*Coracina novaehollandiae subsp. subpallida (Black-faced Cuckoo-shrike)*			
184.	24367	*Lalage tricolor (White-winged Triller)*			
Candonidae					
185.		*'Kencandona' 'verrucosa' (PSS)*			Y
186.		*Areacandona 'astrepte' (PSS)*			
187.		*Areacandona 'cylindrata' (PSS)*			
188.		*Areacandona 'fortescueiensis' (PSS)*			
189.		*Areacandona 'lepte' (PSS)*			
190.		*Areacandona 'triangulum' (PSS)*			
191.		*Areacandona cf. 'lepte' (PSS)*			
192.		*Areacandona sp.*			
193.		*Areacandona sp. 4' (PSS)*			Y
194.		*Candonid Genus 4 sp. 1 (PSS)*			Y
195.		*Candonopsis tenuis*			
196.		*Deminutiocandona 'aenigma' (PSS)*			
197.		*Deminutiocandona cf. 'atope' (PSS)*			
198.		*Humphreyscandona 'akaina' (PSS)*			
199.		*Humphreyscandona cf. 'capillus' (PSS)*			
200.		*Humphreyscandona cf. imperfecta (PSS)*			
201.		*Humphreyscandona cf. woutersi (PSS)*			
202.		*Humphreyscandona fovea*			
203.		*Humphreyscandona imperfecta*			

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204.		*Humphreyscandona pilbarae*			
205.		*Humphreyscandona sp. 2 (PSS)*			
206.		*Humphreyscandona waldockae*			
207.		*Humphreyscandona woutersi*			
208.		*Meridiescandona sp. 2' (PSS)*			
209.		*Origocandona 'posteriorecta' (PSS)*			
210.		*Origocandona sp. 2' (PSS)*			
211.		*Pilbaracandona 'rosa' (PSS)*			
212.		*Pilbaracandona 'temporaria' (PSS)*			
213.		*Pilbaracandona cf. 'rosa' (PSS)*			Y
Canidae					
214.	25454	*Canis lupus (Dog, Dingo)*	Y		
215.	24039	*Canis lupus subsp. dingo (Dingo)*	Y		
216.	30883	*Canis lupus subsp. familiaris (Dog)*	Y		
217.	24040	*Vulpes vulpes (Red Fox)*	Y		
Canthocamptidae					
218.		*Elaphoidella humphreysi*			
Capparaceae					
219.	11670	*Capparis spinosa var. nummularia (Coastal Caper)*			
Caprimulgidae					
220.	24368	*Eurostopodus argus (Spotted Nightjar)*			
Carangidae					
221.		*Caranx papuensis*			
Carphodactylidae					
222.	24969	*Nephrurus levis subsp. pilbarensis*			
223.	25498	*Nephrurus wheeleri*			
224.	24972	*Nephrurus wheeleri subsp. cinctus*			
225.	24973	*Nephrurus wheeleri subsp. wheeleri*			
Caryophyllaceae					
226.	12075	*Polycarpaea corymbosa var. corymbosa*			
227.	2901	*Polycarpaea holtzei*			
228.	2903	*Polycarpaea longiflora*			
Casuariidae					
229.	24470	*Dromaius novaehollandiae (Emu)*			
Celastraceae					
230.	18405	*Stackhousia sp. swollen gynophore (W.R. Barker 2041)*			
Centropodidae					
231.	25600	*Centropus phasianinus (Pheasant Coucal)*			
Centropyxidae					
232.		*Centropyxis sp.*			
Ceratopogonidae					
233.		*Alluaudomyia sp.*			
234.		*Atrichopogon sp. P1 (PSW)*			
235.		*Bezzia sp. 2 (SAP)*			
236.		*Bezzia sp. P1 (PSW)*			
237.		*Bezzia sp. P2 (PSW)*			
238.		*Culicoides sp.*			
239.		*Culicoides sp. P1 (PSW)*			
240.		*Dasyheleinae sp. P1 (PSW)*			
241.		*Dasyheleinae sp. P2 (PSW)*			
242.		*Lanatomyia sp.*			
243.		*Monohelea sp. P1 (PSW)*			
244.		*Nilobezzia sp.*			
245.		*Nilobezzia sp. P1 (PSW)*			
246.		*Nilobezzia sp. P2 (PSW)*			
Charadriidae					
247.	24373	*Charadrius melanops (Black-fronted Dotterel)*			
248.	24386	*Vanellus tricolor (Banded Lapwing)*			
Chenopodiaceae					
249.	11632	*Dysphania glomulifera subsp. eremaea*			
250.	2544	*Maireana georgei (Satiny Bluebush)*			
251.	2551	*Maireana melanocoma (Pussy Bluebush)*			
252.	2604	*Sclerolaena costata*			

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253.	2607	*Sclerolaena densiflora*			
254.	2611	*Sclerolaena eriacantha (Tall Bindii)*			
255.	33220	*Tecticornia pterygosperma subsp. denticulata*			
Chironomidae					
256.		*Ablabesmyia hilli*			
257.		*Ablabesmyia notabilis*			
258.		*Chironomini genus K2 sp. 1*			
259.		*Chironomus aff. alternans (V24) (CB)*			
260.		*Cladopelma curtivalva*			
261.		*Cladotanytarsus aff K4 (PSW)*			
262.		*Clinotanypus crux*			
263.		*Coelopynia pruinosa*			
264.		*Cryptochironomus griseidorsum*			
265.		*Dicrotendipes 'CA1' Pilbara type 3 (= 'K4', P3)) (PSW)*			
266.		*Dicrotendipes 'CA1' Pilbara type 1 (was lindae) (PSW)*			
267.		*Dicrotendipes conjunctus*			
268.		*Dicrotendipes jobetus*			
269.		*Fittkauimyia disparipes*			
270.		*Harrisius sp.*			
271.		*Kiefferulus intertinctus*			
272.		*Kiefferulus tumidus*			
273.		*Larsia albiceps*			
274.		*Microchironomus 'K1' (PSW)*			
275.		*Nanocladius sp. 1 (VCD7)*			
276.		*Orthocladiinae SO3 sp.*			
277.		*Orthocladiinae sp. G (SAP)*			
278.		*Parachironomus 'K1' (PSW)*			
279.		*Parachironomus 'K2' (PSW)*			
280.		*Parachironomus sp. 1 (VSCL35) (SAP)*			
281.		*Paramerina sp.A (parva?) (SAP)*			
282.		*Paratanytarsus sp. P3 (PSW)*			
283.		*Paratendipes sp. 'K1' (PSW)*			
284.		*Pentaneurini sp. P1 (PSW)*			
285.		*Polypedilum leei*			
286.		*Polypedilum nr. convexum (PSW)*			
287.		*Polypedilum nubifer*			
288.		*Polypedilum sp. S1 (PSW)*			
289.		*Polypedilum watsoni*			
290.		*Procladius Pilbara sp. 1 (PSW)*			
291.		*Procladius paludicola*			
292.		*Rheotanytarsus christinae*			
293.		*Rheotanytarsus juliae*			
294.		*Rheotanytarsus trivittatus*			
295.		*Skusella subvittata*			
296.		*Stenochironomus cf watsoni*			
297.		*Tanytarsus 'K12' (PSW)*			
298.		*Tanytarsus fuscithorax/semibarbitarsus*			
299.		*Tanytarsus sp. D (SAP)*			
300.		*Tanytarsus sp. H (SAP)*			
301.		*Tanytarsus sp. P1 (PSW)*			
302.		*Tanytarsus sp. P2 (PSW)*			
303.		*Tanytarsus sp. P5 (PSW)*			
304.		*Tanytarsus sp. P7 (PSW)*			
305.		*Tanytarsus sp. P9 (PSW)*			
306.		*Thienemanniella sp. P1 (PSW)*			
Chrysomelidae					
307.		*Chrysomelidae sp.*			
Chthoniidae					
308.		*Lagynochthonius asema*			Y
309.		*Tyrannochthonius aridus*			
310.		*Tyrannochthonius basme*			Y
Chydoridae					
311.		*Alona rigidicaudis*			
312.		*Armatalona macrocopa*			
313.		*Chydorus eurynotus*			
314.		*Dunhevedia crassa*			
315.		*Ephemeroporus barroisi s.l.*			
316.		*Karualona karua*			

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317.		*Pseudomonospilus diporus*			
Cinclosomatidae					
318.	24390	*Psophodes occidentalis (Western Wedgebill, Chiming Wedgebill)*			
Cirolanidae					
319.		*Haptolana sp.*			
320.		*Haptolana sp. nov. 1 (PSS)*			
321.		*Speocirolana sp.*			
322.		*Speocirolana? sp. nov. 1 (PSS)*			
Cleomaceae					
323.	2988	*Cleome viscosa (Tickweed, Tjinduwadhu)*			
Clupeidae					
324.		*Nematalosa erebi*			
Coenagrionidae					
325.		*Agriocnemis kunjina*			
326.		*Argiocnemis rubescens*			
327.		*Austroagrion pindrina/Ischnura heterosticta*			
328.		*Coenagrionidae sp.*			
329.		*Ischnura aurora aurora*			
330.		*Ischnura heterosticta heterosticta*			
331.		*Pseudagrion aureofrons*			
332.		*Pseudagrion microcephalum*			
Columbidae					
333.	24399	*Columba livia (Domestic Pigeon)*	Y		
334.	24401	*Geopelia cuneata (Diamond Dove)*			
335.	25585	*Geopelia striata (Zebra Dove)*			
336.	24403	*Geopelia striata subsp. placida (Peaceful Dove)*			
337.	24404	*Geophaps plumifera (Spinifex Pigeon)*			
338.	24407	*Ocyphaps lophotes (Crested Pigeon)*			
339.	24409	*Phaps chalcoptera (Common Bronzewing)*			
340.	24411	*Phaps histrionica (Flock Bronzewing, Flock Pigeon)*			
Combretaceae					
341.	5300	*Terminalia canescens (Joolal)*			
342.	5313	*Terminalia supranitifolia*		P3	
Conochilidae					
343.		*Conochilus natans*			
Convolvulaceae					
344.	6608	*Bonamia pannosa*			
345.	44782	*Bonamia pilbarensis*			
346.	6633	*Ipomoea muelleri (Poison Morning Glory, Yumbu)*			
347.	11312	*Ipomoea pes-caprae subsp. brasiliensis*			
348.	6637	*Ipomoea polymorpha*			
Copepoda					
349.		*Calanoida sp.*			
350.		*Harpacticoida sp*			
351.		*Harpacticoida sp. 2 (SAP)*			
Corinnidae					
352.		*Supunna picta?*			Y
Corixidae					
353.		*Micronecta adelaidae (ex P4)*			
354.		*Micronecta annae illiesi*			
355.		*Micronecta annae s.l.*			
356.		*Micronecta nsp. P1 (PSW)*			
357.		*Micronecta nsp. P3 (PSW)*			
358.		*Micronecta sp.*			
Corvidae					
359.	24416	*Corvus bennetti (Little Crow)*			
360.	25593	*Corvus orru (Torresian Crow)*			
361.	24418	*Corvus orru subsp. cecilae (Western Crow)*			
Cracticidae					
362.	24420	*Cracticus nigrogularis (Pied Butcherbird)*			
363.	25595	*Cracticus tibicen (Australian Magpie)*			
364.	24422	*Cracticus tibicen subsp. dorsalis (White-backed Magpie)*			
365.	24424	*Cracticus torquatus subsp. torquatus (Grey Butcherbird)*			

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Cuculidae					
366.	42307	*Cacomantis pallidus (Pallid Cuckoo)*			
367.	24431	*Chrysococcyx basalis (Horsfield's Bronze Cuckoo)*			
Cucurbitaceae					
368.	7369	*Citrullus colocynthis*	Y		
369.	41721	*Cucumis variabilis*			
370.	7381	*Trichosanthes cucumerina*			
Culicidae					
371.		*Anopheles annulipes s.l.*			
372.		*Culex (Culex) bitaeniorhynchus*			
373.		*Culex ?palpalis (SAP)*			
374.		*Culex nr. crinicauda (PSW)*			
375.		*Culex sp.*			
376.		*Culex starkae*			
Cyclopidae					
377.		*Apocyclops dengizicus*			
378.		*Australoeucyclops karaytugi*			
379.		*Diacyclops humphreysi s. str X unispinosus*			
380.		*Ectocyclops rubrescens*			
381.		*Eucyclops australiensis*			
382.		*Eucyclops nr australiensis*			
383.		*Halicyclops (Rochacyclops) calm*			
384.		*Halicyclops (Rochacyclops) roachi*			
385.		*Mesocyclops brooksi*			
386.		*Mesocyclops darwini*			
387.		*Mesocyclops notius*			
388.		*Microcyclops varicans*			
389.		*Orbuscyclops westaustraliensis*			
390.		*Paracyclops sp. 5 (SAP)*			
391.		*Paracyclops sp. 6 (PSW)*			
392.		*Paracyclops sp. 8 (PSW)*			
Cyperaceae					
393.	750	*Bulbostylis barbata*			
394.	774	*Cyperus bifax (Downs Nutgrass)*			
395.	786	*Cyperus cunninghamii*			
396.	12811	*Cyperus cunninghamii subsp. cunninghamii*			
397.	788	*Cyperus dactylotes*			
398.	789	*Cyperus difformis (Rice Sedge)*			
399.	12808	*Cyperus hesperius*			
400.	798	*Cyperus iria*			
401.	799	*Cyperus ixiocarpus*			
402.	810	*Cyperus rotundus (Nut Grass)*	Y		
403.	814	*Cyperus squarrosus*			
404.	818	*Cyperus vaginatus (Stiffleaf Sedge)*			
405.	823	*Eleocharis atropurpurea*			
406.	826	*Eleocharis dulcis (Chinese Water Chestnut)*			
407.	827	*Eleocharis geniculata*			
408.	831	*Eleocharis sphacelata (Tall Spikerush, Djabren)*			
409.	851	*Fimbristylis dichotoma (Eight Day Grass)*			
410.	862	*Fimbristylis microcarya*			
411.	12159	*Fimbristylis simulans*			
412.	963	*Schoenoplectus laevis*			
413.	964	*Schoenoplectus lateriflorus*			
414.	16257	*Schoenoplectus subulatus*			
Cypididae					
415.		*Cypretta seurati*			
416.		*Cypretta sp PSW074*			
417.		*Cypretta sp. BOS080*			
418.		*Cypretta sp. PSW018 (PSW)*			
419.		*Ilyodromus sp BOS25*			
420.		*Ilyodromus sp.*			
421.		*Ilyodromus sp. PB*			
422.		*Isocypris williamsi (ex Ilyodromus sp. 413)*			
423.		*Stenocypris major*			
Cypridopsidae					
424.		*Cypridopsis sp.*			

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Daphniidae					
425.		*Simocephalus heilongjiangensis*			
Darwinulidae					
426.		*Darwinula stevensoni*			
427.		*Penthesilenula brasiliensis*			
428.		*Vestalenula marmonieri*			
429.		*Vestalenula matildae*			
Dasyuridae					
430.	30903	*Dasycercus blythi (Brush-tailed Mulgara, Ampurta)*		P4	
431.	24091	*Dasykaluta rosamondae (Little Red Kaluta)*			
432.	24093	*Dasyurus hallucatus (Northern Quoll)*		T	
433.	24094	*Ningaui ridei (Wongai Ningaui)*			
434.	24095	*Ningaui timealeyi (Pilbara Ningaui)*			
435.	24101	*Planigale ingrami (Long-tailed Planigale)*			
436.	24102	*Planigale maculata (Common Planigale)*			
437.	24106	*Pseudantechinus woolleyae (Woolley's Pseudantechinus)*			
438.	24116	*Sminthopsis macroura (Stripe-faced Dunnart)*			
439.	24120	*Sminthopsis youngsoni (Lesser Hairy-footed Dunnart)*			
Diaptomidae					
440.		*Eudiaptomus lumholtzi*			
Diatom Family					
441.		*Achnanthes exigua Grun.*			
442.		*Achnanthes exilis Kütz.*			
443.		*Achnanthidium minutissima (Kütz.) Czarnecki*			
444.		*Achnanthidium minutissima var. affinis (grun.) lange-bertalot*			
445.		*Amphora coffeaeformis (Ag.) Kütz.*			
446.		*Amphora pediculus (Kütz.) Grun.*			
447.		*Amphora veneta Kütz.*			
448.		*Anomoeoneis sphaerophora (Ehr.) Pfitzer*			
449.		*Anomoeoneis styriaca (Grun.) Hust.*			
450.		*Caloneis bacillum (Grun.) Cl.*			
451.		*Caloneis molaris (Grun.) Krammer*			
452.		*Caloneis silicula (Ehr.) Cl.*			
453.		*Craticula cuspidata (Grun. ex. Van Heurck) Mann*			
454.		*Cylotella menghiniana Kütz.*			
455.		*Cymbella affinis Kütz.*			
456.		*Cymbella aspera (Ehr.) Cl.*			
457.		*Cymbella cistula (Ehr.) Kirchner*			
458.		*Cymbella cymbiformis Ag.*			
459.		*Cymbella delicatula Kütz.*			
460.		*Cymbella falaisensis (Grun.) Krammer & Lange-Bertalot*			
461.		*Cymbella helvetica Kütz.*			Y
462.		*Cymbella microcephala Grun.*			
463.		*Cymbella silesiaca Bleisch*			
464.		*Diploneis elliptica (Kütz.) Cl.*			
465.		*Diploneis pseudovalis Hust.*			
466.		*Encyonema minutum (Hilse ex Rabh.) Mann*			
467.		*Epithemia smithii Carruthers*			
468.		*Eunotia bilunaris (Ehr.) Mills.*			
469.		*Fragilaria capucina Desm.*			
470.		*Fragilaria tenera (W. Sm.) Lange-Bertalot*			
471.		*Fragilaria ulna (Nitz.) Lange Bertalot*			
472.		*Gomphonema clevei Fricke*			
473.		*Gomphonema parvulum (Kütz.) Kütz.*			
474.		*Hantzschia amphioxys (Ehr.) Grun.*			
475.		*Hantzschia marina (Donk.) Cl.*			
476.		*Luticola mutica (Kütz.) Mann*			
477.		*Mastogloia elliptica (Ag.) Cl.*			
478.		*Mastogloia elliptica var. danseii (thwaites) grun.*			
479.		*Mastogloia smithii Thwaites*			
480.		*Navicula bryophila Petersen*			
481.		*Navicula cincta (Ehr.) Ralfs.*			
482.		*Navicula cryptocephala Kütz.*			
483.		*Navicula cryptonella Lange-Bertalot*			
484.		*Navicula erifuga Lange-Bertalot*			
485.		*Navicula kotschyi Grun.*			Y
486.		*Navicula leptostriata Jørgensen*			
487.		*Navicula subrhynchocephala Hust.*			

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488.		*Navicula tripunctata (O.F. Muller) Bory*			Y
489.		*Navicula veneta Kütz.*			
490.		*Nitzschia amphibia Grun.*			
491.		*Nitzschia angustata Grun.*			
492.		*Nitzschia dissipata (Kütz.) Grun.*			
493.		*Nitzschia filiformis (W. Sm.) Van Heurck*			
494.		*Nitzschia frustulum (Kütz.) Grun.*			
495.		*Nitzschia microcephala Grun.*			
496.		*Nitzschia obtusa W. Sm*			
497.		*Nitzschia palea (Kütz.) W. Sm.*			
498.		*Nitzschia sigma (Kütz.) W. Sm.*			
499.		*Pinnularia divergens W. Sm.*			
500.		*Pinnularia gibba Ehr.*			
501.		*Pinnularia subcapitata Greg.*			
502.		*Pinnularia subrostrata (A. Cl.) Cl.-Euler*			
503.		*Pleurosigma delicatulum W. Sm.*			
504.		*Rhopalodia gibberula (Ehr.) O. Müll.*			
505.		*Sellephora pupula (Kütz) Mereschkowsky*			
Dicaeidae					
506.	25607	*Dicaeum hirundinaceum (Mistletoebird)*			
Dicruridae					
507.	24443	*Grallina cyanoleuca (Magpie-lark)*			
508.	25613	*Rhipidura fuliginosa (Grey Fantail)*			
509.	24452	*Rhipidura fuliginosa subsp. preissi (Grey Fantail)*			
510.	25614	*Rhipidura leucophrys (Willie Wagtail)*			
511.	24454	*Rhipidura leucophrys subsp. leucophrys (Willie Wagtail)*			
Difflugiidae					
512.		*Difflugia ampulla*			
513.		*Difflugia sp. P1*			
514.		*Difflugia sp. P2*			
Diosaccidae					
515.		*Schizopera roberiverensis*			
Diplodactylidae					
516.	24919	*Crenadactylus ocellatus subsp. horni (Clawless Gecko)*			
517.	24926	*Diplodactylus conspicillatus (Fat-tailed Gecko)*			
518.	41404	*Diplodactylus galaxias (Northern Pilbara Beak-faced Gecko)*			
519.	24937	*Diplodactylus mitchelli*			
520.	24944	*Diplodactylus savagei (Southern Pilbara Beak-faced Gecko)*			
521.	30933	*Lucasium stenodactylum*			
522.	30934	*Lucasium wombeyi*			
523.	24976	*Oedura marmorata (Marbled Velvet Gecko)*			
524.	24982	*Rhynchoedura ornata (Western Beaked Gecko)*			
525.	25517	*Strophurus ciliaris*			
526.	24927	*Strophurus elderi*			
527.	24949	*Strophurus wellingtonae*			
Diplopoda					
528.		*Diplopoda sp.*			
Dolichopodidae					
529.		*Dolichopodidae sp.*			
530.		*Dolichopodidae sp. A (SAP)*			
Droseraceae					
531.	43544	*Drosera finlaysoniana*			
Dytiscidae					
532.		*Allodessus bistrigatus*			
533.		*Antiporus bakewelli*			
534.		*Bidessini sp.*			
535.		*Boongurrus occidentalis*			
536.		*Copelatus nigrolineatus*			
537.		*Cybister tripunctatus*			
538.		*Hydaticus consanguineus*			
539.		*Hydroglyphus grammopterus (=trilineatus)*			
540.		*Hydroglyphus leai*			
541.		*Hydroglyphus orthogrammus*			
542.		*Hydrovatus sp.*			
543.		*Hydrovatus weiri*			
544.		*Hyphydrus elegans*			

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545.		*Hyphydrus lyratus*			
546.		*Laccophilus sharpi*			
547.		*Limbodessus compactus*			
548.		*Necterosoma regulare*			
549.		*Onychohydrus atratus*			
550.		*Platynectes decempunctatus var decempunctatus*			
551.		*Sternopriscus pilbarensis*			
552.		*Tiporus lachlani*			
553.		*Tiporus sp.*			
554.		*Tiporus tambreyi*			
Ecnomidae					
555.		*Ecnomus pilbarensis*			
Ectinosomatidae					
556.		*Pseudectinosoma galassiae*			
557.		*Pseudectinosoma sp.*			Y
Elapidae					
558.	25332	*Acanthophis wellsi (Pilbara Death Adder)*			
559.	25331	*Brachyurophis approximans (North-western Shovel-nosed Snake)*			
560.	25468	*Demansia psammophis (Yellow-faced Whipsnake)*			
561.	25295	*Demansia psammophis subsp. cupreiceps (Yellow-faced Whipsnake)*			
562.	25247	*Demansia psammophis subsp. psammophis (Yellow-faced Whipsnake)*			
563.	25297	*Demansia rufescens (Rufous Whipsnake)*			
564.	25301	*Furina ornata (Moon Snake)*			
565.	25254	*Parasuta monachus*			
566.	25261	*Pseudechis australis (Mulga Snake)*			
567.	42416	*Pseudonaja mengdeni (Western Brown Snake)*			
568.	25263	*Pseudonaja modesta (Ringed Brown Snake)*			
569.	25264	*Pseudonaja nuchalis (Gwardar, Northern Brown Snake)*			
570.	25305	*Simoselaps anomalus (Desert Banded Snake)*			
571.	25269	*Suta fasciata (Rosen's Snake)*			
572.	25307	*Suta punctata (Spotted Snake)*			
Elmidae					
573.		*Austrolimnius WA sp. 2 (= adult sp WA 2) (PSW)*			
574.		*Austrolimnius WA sp. 3 (larvae only) (PSW)*			
575.		*Elmidae sp. 1*			Y
576.		*Elmidae sp. 2*			Y
Elopidae					
577.		*Elops hawaiensis*			
Emballonuridae					
578.	24174	*Saccolaimus flaviventris (Yellow-bellied Sheathtail-bat)*			
579.	24175	*Taphozous georgianus (Common Sheathtail-bat)*			
Enchytraeidae					
580.		*Enchytraeus Pilbara sp. 1 (PSS)*			
581.		*Enchytraeus Pilbara sp. 2 (PSS)*			
Ephydridae					
582.		*Ephydridae sp. 2 (SAP)*			
Equidae					
583.	24257	*Equus asinus (Donkey)*	Y		
Estrilidae					
584.	24631	*Emblema pictum (Painted Finch)*			
585.	25685	*Neochmia ruficauda (Star Finch)*			
586.	24639	*Neochmia ruficauda subsp. clarescens (Star Finch)*			
587.	30870	*Taeniopygia guttata (Zebra Finch)*			
588.	30871	*Taeniopygia guttata subsp. castanotis (Zebra Finch)*			
Euchlanidae					
589.		*Euchlanis dilatata*			
590.		*Euchlanis incisa*			
591.		*Euchlanis oropha*			
Euglyphiidae					
592.		*Euglypha sp.*			
Euphorbiaceae					
593.	17422	*Adriana tomentosa var. tomentosa*			
594.	4617	*Euphorbia australis (Namana)*			
595.	35303	*Euphorbia australis var. subtomentosa*			

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596.	4620	*Euphorbia boophthona (Gascoyne Spurge)*			
597.	9048	*Euphorbia careyi*			
598.	4629	*Euphorbia hirta (Asthma Plant)*	Y		
599.	4647	*Euphorbia tannensis*			
600.	12097	*Euphorbia tannensis subsp. eremophila (Desert Spurge)*			
601.	42879	*Euphorbia trigonosperma*			
602.	42877	*Euphorbia vaccaria var. erucoides*			
603.	42876	*Euphorbia vaccaria var. vaccaria*			
604.	4650	*Euphorbia wheeleri*			
Fabaceae					
605.	3209	*Acacia ampliceps*			
606.	44586	*Acacia ampliceps x sclerosperma subsp. sclerosperma*			
607.	3214	*Acacia ancistrocarpa (Fitzroy Wattle)*			
608.	37260	*Acacia aptaneura*			
609.	3223	*Acacia arida*			
610.	3228	*Acacia atkinsiana*			
611.	3241	*Acacia bivenosa*			
612.	3260	*Acacia citrinoviridis*			
613.	17013	*Acacia colei var. colei*			
614.	17014	*Acacia colei var. ileocarpa*			
615.	3300	*Acacia dictyophleba (Sandhill Wattle, Ngarkalya)*			
616.	16174	*Acacia elachantha*			
617.	3360	*Acacia hamersleyensis*			
618.	3377	*Acacia inaequilatera (Baderi)*			
619.	3419	*Acacia ligulata (Umbrella Bush, Watarka)*			
620.	3471	*Acacia orthocarpa (Needleleaf Wattle)*			
621.	3501	*Acacia ptychophylla*			
622.	29016	*Acacia pyrifolia var. morrisonii*			
623.	29015	*Acacia pyrifolia var. pyrifolia*			
624.	13078	*Acacia sclerosperma subsp. sclerosperma*			
625.	29135	*Acacia sericophylla*			
626.	3553	*Acacia spondylophylla*			
627.	13070	*Acacia synchronicia*			
628.	3577	*Acacia tetragonophylla (Kurara, Wakalpuka)*			
629.	3579	*Acacia trachycarpa (Minni Ritchi, Balgali)*			
630.	23521	*Acacia trudgeniana*			
631.	20319	*Acacia tumida var. pilbarensis*			
632.	3598	*Acacia wanyu*			
633.	3606	*Acacia xiphophylla*			
634.	3680	*Aeschynomene indica (Budda Pea)*			
635.	17147	*Alysicarpus muelleri*			
636.	11055	*Cajanus cinereus*			
637.	11150	*Cajanus pubescens*			
638.	3783	*Crotalaria medicaginea*			
639.	11231	*Crotalaria novae-hollandiae subsp. novae-hollandiae*			
640.	17439	*Cullen lachnostachys*			
641.	17118	*Cullen leucanthum*			
642.	17119	*Cullen leucochaites*			
643.	17120	*Cullen pogonocarpum*			
644.	3871	*Erythrina vespertilio (Yulbah)*			
645.	17113	*Indigofera boviperda subsp. boviperda*			
646.	3973	*Indigofera colutea (Sticky Indigo)*			
647.	3974	*Indigofera georgei (Bovine Indigo)*			
648.	3980	*Indigofera linifolia*			
649.	3982	*Indigofera monophylla*			
650.	3985	*Indigofera rugosa*			
651.	20317	*Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)*		P3	
652.	41782	*Indigofera sp. Fractiflexa (S. van Leeuwen 3773)*			
653.	3987	*Indigofera trita*			
654.	3989	*Isotropis atropurpurea (Poison Sage)*			
655.	4061	*Lotus cruentus (Redflower Lotus)*			
656.	3675	*Petalostylis labicheoides (Slender Petalostylis)*			
657.	20862	*Rhynchosia bungarensis*		P4	
658.	4191	*Rhynchosia minima (Rhynchosia)*			
659.	12280	*Senna artemisioides subsp. oligophylla*			
660.	12305	*Senna glutinosa subsp. chatelainiana*			
661.	12307	*Senna glutinosa subsp. glutinosa*			
662.	12309	*Senna glutinosa subsp. pruinosa*			
663.	12308	*Senna glutinosa subsp. x luerssenii*			
664.	12312	*Senna notabilis*			

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665.	12319	*Senna venusta*			
666.	4198	*Sesbania formosa (White Dragon Tree)*			
667.	13596	*Swainsona complanata*			
668.	12356	*Swainsona formosa*			
669.	4234	*Swainsona maccullochiana (Ashburton Pea)*			
670.	4280	*Tephrosia rosea (Flinders River Poison, Bungoo'dah)*			
671.	41825	*Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)*			
672.	15947	*Tephrosia sp. B Kimberley Flora (C.A. Gardner 7300)*			
673.	17768	*Tephrosia sp. Bungaroo Creek (M.E. Trudgen 11601)*			
674.	41811	*Tephrosia sp. Fortescue (A.A. Mitchell 606)*			
675.	42442	*Tephrosia sp. NW Eremaean (S. van Leeuwen et al. PBS 0356)*			
676.	40060	*Tephrosia sp. clay soils (S. van Leeuwen et al. PBS 0273)*			
677.	4285	*Tephrosia supina*			
678.	4286	*Tephrosia uniovulata*			
679.	4287	*Tephrosia virens*			
680.	4323	*Vigna lanceolata (Maloga Vigna, Wega)*			
681.	11576	*Vigna lanceolata var. lanceolata*			
Falconidae					
682.	25621	*Falco berigora (Brown Falcon)*			
683.	24471	*Falco berigora subsp. berigora (Brown Falcon)*			
684.	25622	*Falco cenchroides (Australian Kestrel)*			
685.	24472	*Falco cenchroides subsp. cenchroides (Australian Kestrel)*			
686.	25623	*Falco longipennis (Australian Hobby)*			
Felidae					
687.	24041	*Felis catus (Cat)*	Y		
Flosculariacea					
688.		*Flosculariacea sp.*			
Flosculariidae					
689.		*Lacinularia cf. elliptica*			Y
Frankeniaceae					
690.	5188	*Frankenia ambita*			
Gekkonidae					
691.	24956	*Gehyra pilbara*			
692.	24958	*Gehyra punctata*			
693.	24959	*Gehyra variegata*			
694.	25232	*Hemidactylus frenatus (Asian House Gecko)*	Y		
695.	24961	*Heteronotia binoei (Bynoe's Gecko)*			
696.	24962	*Heteronotia spelea (Desert Cave Gecko)*			
Gelastocoridae					
697.		*Nerthra luteovaria*			
Gentianaceae					
698.	41646	*Schenkia clementii*			
Gerridae					
699.		*Gerridae sp.*			
700.		*Limnogonus fossarum gilguy*			
701.		*Limnogonus luctuosus*			
702.		*Limnogonus sp.*			
703.		*Rhagadotarsus anomalus*			
Glareolidae					
704.	24481	*Glareola maldivarum (Oriental Pratincole)*		IA	
Gomphidae					
705.		*Austroepigomphus (Xerogomphus) gordoni*			
Goodeniaceae					
706.	7424	*Dampiera candicans*			
707.	7490	*Goodenia armitiana*			
708.	7509	*Goodenia forrestii*			
709.	7521	*Goodenia lamprosperma*			
710.	7526	*Goodenia microptera*			
711.	12552	*Goodenia muelleriana*			
712.	7530	*Goodenia nuda*		P4	
713.	7544	*Goodenia ramelii*			
714.	10982	*Goodenia stobbsiana*			
715.	7556	*Goodenia tenuiloba*			
716.	7644	*Scaevola spinescens (Currant Bush, Maroon)*			

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717.	7654	*Velleia connata (Cup Velleia)*			
718.	7658	*Velleia discophora (Cabbage Poison)*			
Hadziidae					
719.	33954	*Nedsia hurlberti (amphipod)*		T	
720.		*Nedsia nr sp. 24 (PSS)*			
721.	33957	*Nedsia sculptilis (amphipod)*		T	
722.		*Nedsia sp. 4 (PSS)*			
Halcyonidae					
723.	25547	*Dacelo leachii (Blue-winged Kookaburra)*			
724.	24304	*Dacelo leachii subsp. leachii (Blue-winged Kookaburra)*			
725.	42351	*Todiramphus pyrrhopygius (Red-backed Kingfisher)*			
726.	25549	*Todiramphus sanctus (Sacred Kingfisher)*			
Haliplidae					
727.		*Haliplus halsei*			
728.		*Haliplus pilbarensis*			
729.		*Haliplus pinderi*			
Haloragaceae					
730.	23464	*Haloragis gossei var. inflata*			
731.	6201	*Myriophyllum verrucosum (Red Water Milfoil)*			
Hebridae					
732.		*Hebrus axillaris*			
733.		*Merragata hackeri*			
Hemicorduliidae					
734.		*Hemicordulia intermedia*			
735.		*Hemicordulia koomina*			
736.		*Hemicordulia sp.*			
Hersiliidae					
737.		*Tamopsis occidentalis*			
Hipposideridae					
738.	43368	*Rhinonicteris aurantia (Orange Leafnosed-bat)*		T	
Hirudinea					
739.		*Hirudinea sp.*			
Hirundinidae					
740.	24488	*Cheramoeca leucosternus (White-backed Swallow)*			
741.	24489	*Hirundo ariel (Fairy Martin)*			
742.	24491	*Hirundo neoxena (Welcome Swallow)*			
743.	25629	*Hirundo nigricans (Tree Martin)*			
Hubbardiidae					
744.	34152	*Draculoides mesozeirus (Middle Robe Draculoides)*		T	Y
745.	34153	*Paradraculoides anachoretus (Mesa A Paradraculoides)*		T	Y
746.	34154	*Paradraculoides bythius (Mesa B Paradraculoides)*		T	Y
747.	34155	*Paradraculoides gnophicola (Mesa G Paradraculoides)*		T	Y
748.	35956	*Paradraculoides kryptus (Mesa K Paradraculoides)*		T	Y
Hydrachnidae					
749.		*Hydrachna sp. 3 (PSW)*			
750.		*Hydrachna sp. 4/5 (PSW)*			
Hydraenidae					
751.		*Hydraena barbipes*			
752.		*Hydraena nr. rudallensis (PSW)*			
753.		*Limnebius sp.*			
754.		*Ochthebius sp. P1 (PSW)*			
755.		*Ochthebius sp. P2 (PSW)*			
Hydridae					
756.		*Hydra sp.*			
Hydrobiidae					
757.		*Hydrobiidae sp.*			
Hydrocharitaceae					
758.	138	*Najas marina (Prickly Water Nymph)*			
759.	139	*Najas tenuifolia (Water Nymph)*			
760.	17868	*Vallisneria nana*			
Hydrochidae					
761.		*Hydrochus eurypleuron*			

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762.		*Hydrochus interioris*			
763.		*Hydrochus lateviridus*			
764.		*Hydrochus obscuroaeneus*			
765.		*Hydrochus sp.*			
766.		*Hydrochus sp. P1 (PSW)*			
Hydrodromidae					
767.		*Hydrodroma sp.*			
Hydrophilidae					
768.		*Berosus dallasi*			
769.		*Berosus pulchellus*			
770.		*Berosus sp.*			
771.		*Cercyon sp.*			
772.		*Chaetarthria nigerrimus*			
773.		*Coelostoma fabricii*			
774.		*Enochrus deserticola*			
775.		*Georissus sp.*			
776.		*Helochares tatei*			
777.		*Paracymus pygmaeus*			
778.		*Paracymus spenceri*			
779.		*Paranacaena horni*			
780.		*Regimbartia attenuata*			
781.		*Sternolophus marginicollis*			
782.		*Sternolophus sp.*			
Hydropsychidae					
783.		*Cheumatopsyche wellsae*			
Hydroptilidae					
784.		*Hellyethira sp.*			
785.		*Orthotrichia sp.*			
Hydryphantidae					
786.		*Pseudohydryphantes sp. P1 (PSW)*			
Hygrobatidae					
787.		*Aspidiobates pilbara*			
788.		*Australiobates queenslandensis*			
789.		*Coaustraliobates longipalpis*			
790.		*Coaustraliobates minor*			
Hylidae					
791.	25375	*Cyclorana maini (Sheep Frog)*			
792.	25392	*Litoria rubella (Little Red Tree Frog)*			
Hyriidae					
793.		*Velesunio wilsoni*			
Ilyocryptidae					
794.		*Ilyocryptus raridentatus*			
Isopoda					
795.		*Oniscidea sp.*			
Isostictidae					
796.		*Eurysticta coolawanyah*			
Lamiaceae					
797.	6830	*Basilicum polystachyon*			
798.	13692	*Clerodendrum floribundum var. angustifolium*			
799.	13691	*Clerodendrum floribundum var. ovatum*			
800.	6907	*Ocimum basilicum (Basil)*	Y		
Lamponidae					
801.		*Asadipus barlee*			
802.		*Asadipus kunderang*			
803.		*Asadipus yundamindra*			
804.		*Bigenditia zuytdorp*			
805.		*Lampona ampeinna*			
806.		*Lampona quinqueplagiata*			
807.		*Lampona scutata*			Y
808.		*Notsodipus barlee*			
809.		*Notsodipus meedo*			
Lauraceae					
810.	2949	*Cassytha capillaris*			

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Lecanidae					
811.		*Lecane aculeata*			
812.		*Lecane batillifer*			
813.		*Lecane bulla*			
814.		*Lecane closterocerca*			
815.		*Lecane crepida*			
816.		*Lecane hamata*			
817.		*Lecane hornemanni*			
818.		*Lecane ludwigii*			
819.		*Lecane luna*			
820.		*Lecane lunaris*			
821.		*Lecane obtusa*			
822.		*Lecane papuana*			
823.		*Lecane quadridentata*			
824.		*Lecane signifera*			
825.		*Lecane stenroosi*			
826.		*Lecane thalera*			
827.		*Lecane unguitata*			
Lentibulariaceae					
828.	7125	*Utricularia australis*			
Lepadellidae					
829.		*Colurella sp.*			
830.		*Lepadella (H.) ehrenbergii*			
831.		*Lepadella (H.) heterostyla*			
832.		*Lepadella ovalis*			
833.		*Lepadella patella*			
834.		*Lepadella triptera*			
Leporidae					
835.	24085	*Oryctolagus cuniculus (Rabbit)*	Y		
Leptoceridae					
836.		*Leptocerus atsou*			
837.		*Leptocerus sp. AV2 (atsou?) (PSW)*			
838.		*Oecetis sp.*			
839.		*Oecetis sp. Pilbara 4 (PSW)*			
840.		*Oecetis sp. Pilbara 5 (PSW)*			
841.		*Triplectides australis*			
842.		*Triplectides ciuskus seductus*			
843.		*Triplectides parvus*			
Lesquereusidae					
844.		*Lesquereusia spiralis*			
Libellulidae					
845.		*Diplacodes bipunctata*			
846.		*Diplacodes haematodes*			
847.		*Diplacodes sp.*			
848.		*Orthetrum caledonicum*			
849.		*Zyxomma elgneri*			
Limnesiidae					
850.		*Limnesia maceripalpis*			
851.		*Limnesia parasolida*			
852.		*Limnesia sp. 4 (PSW)*			
Limnichidae					
853.		*Limnichidae sp. P1*			
Limnocytheridae					
854.		*Gomphodella 'hirsuta' (PSS)*			
855.		*Limnocythere dorsosicula*			
Lindeniidae					
856.		*Ictinogomphus dobsoni*			
Loranthaceae					
857.	13700	*Amyema bifurcata*			
858.	2385	*Amyema sanguinea*			
859.	2396	*Lysiana casuarinae*			
Lutjanidae					
860.		*Lutjanus carponotatus*			

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Lycosidae					
861.		*Hoggicosa castanea*			
862.		*Hogna crispipes*			
Lymnaeidae					
863.		*Austropeplea vinosa*			
Lythraceae					
864.	5276	*Ammannia auriculata*			
865.	5277	*Ammannia baccifera*			
866.	5285	*Rotala diandra*			
867.	5286	*Rotala mexicana*			
Macropodidae					
868.	25489	*Macropus robustus (Euro)*			
869.	24135	*Macropus robustus subsp. erubescens (Euro, Biggada)*			
870.	24136	*Macropus rufus (Red Kangaroo, Marlu)*			
871.	24144	*Petrogale rothschildi (Rothschild's Rock-wallaby)*			
Maluridae					
872.	25647	*Amytornis striatus (Striated Grasswren)*			
873.	25651	*Malurus lamberti (Variegated Fairy-wren)*			
874.	25652	*Malurus leucopterus (White-winged Fairy-wren)*			
875.	25656	*Stipiturus ruficeps (Rufous-crowned Emu-wren)*			
876.	24556	*Stipiturus ruficeps subsp. ruficeps (Rufous-crowned Emu-wren)*			
Malvaceae					
877.	4891	*Abutilon fraseri (Lantern Bush)*			
878.	16919	*Abutilon hannii*			
879.	4895	*Abutilon lepidum*			
880.	4898	*Abutilon macrum*			
881.	4901	*Abutilon otocarpum (Desert Chinese Lantern)*			
882.	4902	*Abutilon oxycarpum (Flannel Weed)*			
883.	42920	*Abutilon sp. Dioicum (A.A. Mitchell PRP 1618)*			
884.	14113	*Abutilon sp. Pilbara (W.R. Barker 2025)*			
885.	13659	*Corchorus laniflorus*			
886.	18408	*Corchorus lasiocarpus subsp. parvus*			
887.	4862	*Corchorus parviflorus*			
888.	4864	*Corchorus sidoides (Flannel Weed)*			
889.	18415	*Corchorus sidoides subsp. sidoides*			
890.	18414	*Corchorus sidoides subsp. vermicularis*			
891.	20242	*Corchorus sp. Hamersley Range hilltops (S. van Leeuwen 3826)*			
892.	17661	*Corchorus tectus*			
893.	4865	*Corchorus tridens*			
894.	4910	*Gossypium australe (Native Cotton)*			
895.	4918	*Gossypium robinsonii (Wild Cotton)*			
896.	29317	*Hibiscus austrinus var. austrinus*			
897.	4925	*Hibiscus coatesii*			
898.	4930	*Hibiscus goldsworthii*			
899.	4933	*Hibiscus leptocladus*			
900.	4941	*Hibiscus solanifolius*			
901.	11651	*Hibiscus sturtii var. campylochlamys*			
902.	11385	*Hibiscus sturtii var. grandiflorus*			
903.	11477	*Hibiscus sturtii var. platychlamys*			
904.	5024	*Keraudrenia nephrosperma*			
905.	5051	*Melhania oblongifolia*			
906.	5053	*Melochia pyramidata*	Y		
907.	31758	*Sida arsiniata*			
908.	4971	*Sida cardiophylla*			
909.	4972	*Sida clementii*			
910.	4976	*Sida echinocarpa*			
911.	4977	*Sida fibulifera (Silver Sida)*			
912.	4988	*Sida rohlenae*			
913.	18149	*Sida rohlenae subsp. rohlenae*			
914.	15227	*Sida sp. A Kimberley Flora (P.A. Fryxell & L.A. Craven 3900)*			
915.	33698	*Sida sp. Pilbara (A.A. Mitchell PRP 1543)*			
916.	16948	*Sida sp. verrucose glands (F.H. Mollemans 2423)*			
917.	4989	*Sida spinosa (Spiny Sida)*			
918.	4875	*Triumfetta chaetocarpa (Urchins)*			
919.	14694	*Triumfetta clementii*			
920.	4878	*Triumfetta johnstonii*			
921.	14942	*Triumfetta maconochieana*			
922.	5106	*Waltheria indica*			

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Marsileaceae					
923.	74	*Marsilea drummondii (Common Nardoo)*			
924.	76	*Marsilea hirsuta (Nardoo)*			
Megadermatidae					
925.	24180	*Macroderma gigas (Ghost Bat)*		P4	
Meliphagidae					
926.	24559	*Acanthagenys rufogularis (Spiny-cheeked Honeyeater)*			
927.	24564	*Certhionyx variegatus (Pied Honeyeater)*			
928.	24570	*Epthianura tricolor (Crimson Chat)*			
929.	25661	*Lichmera indistincta (Brown Honeyeater)*			
930.	24582	*Lichmera indistincta subsp. indistincta (Brown Honeyeater)*			
931.	24583	*Manorina flavigula (Yellow-throated Miner)*			
932.	25665	*Melithreptus gularis (Black-chinned Honeyeater)*			
933.	42310	*Sugomel niger (Black Honeyeater)*			
Melitidae					
934.		*Melitidae sp. 1 (PSS)*			
Menispermaceae					
935.	2942	*Tinospora smilacina (Snakevine, Oondala)*			
Meropidae					
936.	24598	*Merops ornatus (Rainbow Bee-eater)*		IA	
Mesoveliidae					
937.		*Mesovelia hungerfordi*			
938.		*Mesovelia vittigera*			
Microcerberidae					
939.		*Microcerberidae sp.*			
Mideopsidae					
940.		*Gretacarus bifalcisetus*			
941.		*Gretacarus nsp. P1 (PSW)*			
942.		*Gretacarus sp.*			
943.		*Guineaxonopsis sp.*			
944.		*Guineaxonopsis sp. S1 (PSS)*			
Molluginaceae					
945.	2835	*Glinus lotoides (Hairy Carpet Weed)*			
946.	2836	*Glinus oppositifolius*			
947.	29851	*Mollugo molluginea*			
Molossidae					
948.	24181	*Chaerephon jobensis (Northern Freetail-bat)*			
949.	24185	*Tadarida australis (White-striped Freetail-bat)*			
Moraceae					
950.	31578	*Ficus aculeata var. indecora (Ranji)*			
951.	19648	*Ficus brachypoda*			
Motacillidae					
952.	25670	*Anthus australis (Australian Pipit)*			
Mugilidae					
953.		*Liza subviridis*			
954.		*Mugil cephalus*			
Muridae					
955.	24217	*Leggadina lakedownensis (Short-tailed Mouse, Karekanga)*		P4	
956.	24223	*Mus musculus (House Mouse)*	Y		
957.	24224	*Notomys alexis (Spinifex Hopping-mouse)*			
958.	24233	*Pseudomys chapmani (Western Pebble-mound Mouse, Ngadji)*		P4	
959.	24234	*Pseudomys delicatulus (Delicate Mouse)*			
960.	24235	*Pseudomys desertor (Desert Mouse)*			
961.	24237	*Pseudomys hermannsburgensis (Sandy Inland Mouse)*			
962.	24248	*Zyzomys argurus (Common Rock-rat)*			
Myobatrachidae					
963.	25445	*Uperoleia russelli (Northwest Toadlet)*			
964.	41428	*Uperoleia saxatilis (Pilbara Toadlet)*			
Myrtaceae					
965.	16783	*Corymbia candida*			
966.	16782	*Corymbia candida subsp. candida*			
967.	16780	*Corymbia candida subsp. dipsodes*			

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968.	17077	*Corymbia ferriticola*			
969.	17093	*Corymbia hamersleyana*			
970.	17084	*Corymbia zygophylla*			
971.	5580	*Eucalyptus camaldulensis (River Gum, Yabalinyba)*			
972.	35345	*Eucalyptus camaldulensis subsp. obtusa (Blunt-budded River Red Gum)*			
973.	35343	*Eucalyptus camaldulensis subsp. refulgens*			
974.	18088	*Eucalyptus leucophloia subsp. leucophloia*			
975.	5875	*Melaleuca argentea (Silver Cadjeput, Bandaran)*			
976.	5879	*Melaleuca bracteata (River Teatree)*			
977.	5915	*Melaleuca glomerata*			
Mytilinidae					
978.		*Mytilina ventralis macracantha*			
NO FAMILY					
979.		*No invertebrates*			
Naididae					
980.		*Allonais pectinata*			
981.		*Allonais ranauana*			
982.		*Branchiura sowerbyi*			
983.		*Bratislavia unidentata*			Y
984.		*Dero digitata*			
985.		*Dero nivea*			
986.		*Pristina aequiseta*			
987.		*Pristina longiseta*			
988.		*Tubificidae stygo morphotype 2 (PSS)*			
989.		*Tubificidae stygo type 2A*			
990.		*Tubificidae stygo type 3*			Y
Nematoda					
991.		*Nematoda sp.*			
992.		*Nematoda sp. 11 (PSS)*			Y
993.		*Nematoda sp. 2 (PSS)*			
994.		*Nematoda sp. 3 (PSS)*			Y
995.		*Nematoda sp. P2/P4 (PSW)*			
996.		*Nematoda sp. P3 (PSW)*			
997.		*Nematoda sp. P5 (PSW)*			
998.		*Nematoda sp. P8 (PSW)*			
Nemertini					
999.		*Nemertini sp.*			
Nemesiidae					
1000.		*Aname mellosa*			
Neoniphargidae					
1001.		*Wesniphargus sp.*			Y
Nepidae					
1002.		*Ranatra diminuta*			
1003.		*Ranatra sp.*			
Nereidae					
1004.		*Nereidae sp.*			
Noteridae					
1005.		*Neohydrocoptus subfasciatus*			
Notommatidae					
1006.		*Cephalodella forficula*			
1007.		*Cephalodella gibba*			
1008.		*Cephalodella tenuiseta*			
1009.		*Monommata sp.*			
1010.		*Notommata copeus*			
Notonectidae					
1011.		*Anisops hackeri*			
Nyctaginaceae					
1012.	2769	*Boerhavia burbidgeana*			
1013.	2770	*Boerhavia coccinea (Tar Vine, Wituka)*			
1014.	2772	*Boerhavia gardneri*			
1015.	2774	*Boerhavia repleta*			
1016.	2775	*Boerhavia schomburgkiana*			
Ochteridae					

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1017.		*Ochterus sp.*			
Oleaceae					
1018.	12059	*Jasminum didymum subsp. lineare (Desert Jasmine)*			
Olibrinidae					
1019.		*Adoniscus sp.*			
Oligochaeta					
1020.		*Oligochaeta sp.*			
Olpiidae					
1021.		*Linnaeolpium linnaei*			Y
Onagraceae					
1022.	6136	*Ludwigia perennis*			
Oonopidae					
1023.		*Cavisternum clavatum*			
1024.		*Opopaea ectognophus*			Y
Ostracoda					
1025.		*Ostracoda (unident.)*			
Otididae					
1026.	24610	*Ardeotis australis (Australian Bustard)*			
Oxidae					
1027.		*Frontipoda nr tasmanica*			Y
1028.		*Frontipoda sp P3 (PSW)*			
1029.		*Frontipoda spinosa*			
1030.		*Oxus orientalis*			
Pachycephalidae					
1031.	25675	*Colluricincla harmonica (Grey Shrike-thrush)*			
1032.	24618	*Oreoica gutturalis (Crested Bellbird)*			
1033.	25680	*Pachycephala rufiventris (Rufous Whistler)*			
Papaveraceae					
1034.	17797	*Argemone ochroleuca subsp. ochroleuca*	Y		
Parabathynellidae					
1035.		*Atopobathynella sp.*			
1036.		*Atopobathynella sp. A*			
1037.		*Notobathynella sp.*			
Paramelitidae					
1038.		*Paramelitidae sp.*			
1039.		*Paramelitidae sp. 2 (PSS)*			
1040.		*Pilbarus millsi*			
Parasitiformes					
1041.		*Mesostigmata sp.*			
Parastenocarididae					
1042.		*Parastenocaris jane*			
1043.		*Parastenocaris sp.*			
Pardalotidae					
1044.	24627	*Pardalotus rubricatus (Red-browed Pardalote)*			
1045.	25682	*Pardalotus striatus (Striated Pardalote)*			
1046.	24628	*Pardalotus striatus subsp. murchisoni (Striated Pardalote)*			
Pedaliaceae					
1047.	43521	*Josephinia sp. Style-topped fruit (M. Maier BES MM 1017)*			Y
Pelecanidae					
1048.	24648	*Pelecanus conspicillatus (Australian Pelican)*			
Peritrichidae					
1049.		*Zoothamnium sp.*			
Petroicidae					
1050.	24658	*Petroica cucullata (Hooded Robin)*			
1051.	24659	*Petroica goodenovii (Red-capped Robin)*			
Pezidae					
1052.		*Peza sp.*			Y
1053.		*Pezidae sp.*			
Phalacrocoracidae					

	Name ID	Species Name	Naturalised	Conservation Code	[1]Endemic To Query Area
1054.	25698	*Phalacrocorax melanoleucos (Little Pied Cormorant)*			
1055.	24666	*Phalacrocorax melanoleucos subsp. melanoleucos (Little Pied Cormorant)*			
1056.	24667	*Phalacrocorax sulcirostris (Little Black Cormorant)*			
1057.	25699	*Phalacrocorax varius (Pied Cormorant)*			
Phalangeridae					
1058.	24157	*Trichosurus vulpecula subsp. arnhemensis (Northern Brushtail Possum)*			
Phasianidae					
1059.	25701	*Coturnix ypsilophora (Brown Quail)*			
Philodinidae					
1060.		*Dissotrocha sp.*			
Philopotamidae					
1061.		*Chimarra sp AV17 (PSW)*			
Pholcidae					
1062.		*Trichocyclus nigropunctatus*			
Phreodrilidae					
1063.		*Insulodrilus angela*			
1064.		*Phreodrilid with dissimilar ventral chaetae*			
1065.		*Phreodrilid with similar ventral chaetae*			
1066.		*Phreodrilidae sp.*			
1067.		*Phreodrilus n. sp. WA12 (PSW)*			Y
Phrymaceae					
1068.	7060	*Glossostigma diandrum*			
1069.	12486	*Peplidium aithocheilum*			
Phyllanthaceae					
1070.	12013	*Flueggea virosa subsp. melanthesoides (Dogwood, Guwal)*			
1071.	17626	*Phyllanthus erwinii*			
1072.	4680	*Phyllanthus maderaspatensis*			
1073.	4684	*Phyllanthus reticulatus*			
1074.	11990	*Phyllanthus reticulatus var. glaber*			
Pionidae					
1075.		*Piona cumberlandensis*			
Planorbidae					
1076.		*Ameriana sp.*			
1077.		*Gyraulus hesperus*			
1078.		*Gyraulus sp.*			
1079.		*Planorbidae sp.*			
Plantaginaceae					
1080.	7098	*Stemodia grossa (Marsh Stemodia, Mindjaara)*			
Pleidae					
1081.		*Paraplea n. sp. (ANIC 6)*			
1082.		*Paraplea sp.*			
1083.		*Pleidae sp.*			
Poaceae					
1084.	172	*Acrachne racemosa*			
1085.	204	*Aristida burbidgeae*			
1086.	207	*Aristida contorta (Bunched Kerosene Grass)*			
1087.	210	*Aristida holathera*			
1088.	12063	*Aristida holathera var. holathera*			
1089.	213	*Aristida ingrata*			
1090.	215	*Aristida latifolia (Feathertop Wiregrass)*			
1091.	217	*Aristida nitidula (Flat-awned Threeawn)*			
1092.	239	*Bothriochloa bladhii (Forest Bluegrass)*			
1093.	16355	*Bothriochloa decipiens var. cloncurrensis*		P1	
1094.	241	*Brachyachne convergens (Spider Grass)*			
1095.	258	*Cenchrus ciliaris (Buffel Grass)*	Y		
1096.	259	*Cenchrus echinatus (Burrgrass)*	Y		
1097.	29721	*Cenchrus setiger (Birdwood Grass)*	Y		
1098.	266	*Chloris barbata (Purpletop Chloris)*	Y		
1099.	270	*Chloris pumilio*			
1100.	279	*Cymbopogon ambiguus (Scentgrass)*			
1101.	283	*Cynodon dactylon (Couch)*	Y		
1102.	290	*Dactyloctenium radulans (Button Grass)*			
1103.	303	*Dichanthium fecundum (Curly Bluegrass)*			
1104.	13741	*Dichanthium sericeum subsp. humilius*			

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1105.	310	*Digitaria brownii (Cotton Panic Grass)*			
1106.	313	*Digitaria ctenantha (Comb Finger Grass)*			
1107.	328	*Echinochloa colona (Awnless Barnyard Grass)*	Y		
1108.	355	*Elytrophorus spicatus (Spikegrass)*			
1109.	357	*Enneapogon caerulescens (Limestone Grass)*			
1110.	375	*Eragrostis cumingii (Cuming's Love Grass)*			
1111.	378	*Eragrostis dielsii (Mallee Lovegrass)*			
1112.	380	*Eragrostis eriopoda (Woollybutt Grass, Wangurnu)*			
1113.	16731	*Eragrostis exigua*			
1114.	388	*Eragrostis leptocarpa (Drooping Lovegrass)*			
1115.	38505	*Eragrostis surreyana*		P3	
1116.	398	*Eragrostis tenellula (Delicate Lovegrass)*			
1117.	400	*Eriachne aristidea*			
1118.	403	*Eriachne benthamii (Swamp Wanderrie)*			
1119.	407	*Eriachne festucacea (Plains Wandarrie Grass)*			
1120.	411	*Eriachne helmsii (Buck Wanderrie Grass)*			
1121.	413	*Eriachne mucronata (Mountain Wanderrie Grass)*			
1122.	16485	*Eriachne pulchella subsp. dominii*			
1123.	16486	*Eriachne pulchella subsp. pulchella*			
1124.	421	*Eriachne tenuiculmis*			
1125.	11011	*Eulalia aurea*			
1126.	443	*Heteropogon contortus (Bunch Speargrass)*			
1127.	464	*Iseilema membranaceum (Small Flinders Grass)*			
1128.	471	*Leptochloa digitata (Whorled Cane Grass)*			
1129.	19061	*Leptochloa fusca*			
1130.	518	*Paspalidium clementii (Clements Paspalidium)*			
1131.	519	*Paspalidium constrictum (Knottybutt Grass)*			
1132.	523	*Paspalidium rarum (Rare Paspalidium)*			
1133.	525	*Paspalidium tabulatum*			
1134.	606	*Setaria dielsii (Diels' Pigeon Grass)*			
1135.	629	*Sporobolus australasicus (Fairy Grass)*			
1136.	673	*Themeda triandra*			
1137.	679	*Triodia angusta*			
1138.	43220	*Triodia sp. Peedamulla (A.A. Mitchell PRP 1636)*			
1139.	35843	*Triodia sp. Robe River (M.E. Trudgen et al. MET 12367)*		P3	
1140.	704	*Triodia wiseana (Limestone Spinifex)*			
1141.	706	*Triraphis mollis (Needle Grass)*			
1142.	717	*Urochloa piligera*			
1143.	730	*Xerochloa imberbis (Rice Grass)*			
1144.	732	*Yakirra australiensis*			
1145.	11894	*Yakirra australiensis var. australiensis*			
Podargidae					
1146.	25703	*Podargus strigoides (Tawny Frogmouth)*			
Podicipedidae					
1147.	24681	*Poliocephalus poliocephalus (Hoary-headed Grebe)*			
1148.	25705	*Tachybaptus novaehollandiae (Australasian Grebe, Black-throated Grebe)*			
1149.	24682	*Tachybaptus novaehollandiae subsp. novaehollandiae (Australasian Grebe, Black-throated Grebe)*			
Polycentropodidae					
1150.		*Paranyctiophylax sp AV5 (KIM-UWA)*			
Pomatostomidae					
1151.	24683	*Pomatostomus superciliosus (White-browed Babbler)*			
1152.	25706	*Pomatostomus temporalis (Grey-crowned Babbler)*			
1153.	24684	*Pomatostomus temporalis subsp. rubeculus (Grey-crowned Babbler)*			
Portulacaceae					
1154.	2864	*Calandrinia ptychosperma*			
1155.	2878	*Portulaca conspicua*			
1156.	2882	*Portulaca intraterranea*			
1157.	2884	*Portulaca oleracea (Purslane, Wakati)*			
1158.	2886	*Portulaca pilosa (Djanggara)*	Y		
Potamogetonaceae					
1159.	113	*Potamogeton tricarinatus (Floating Pondweed)*			
Prodidomidae					
1160.		*Nomindar jarrnarm*			Y
1161.		*Wydundra kennedy*			
Proteaceae					

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1162.	19570	*Grevillea pyramidalis subsp. leucadendron*			
1163.	13440	*Grevillea wickhamii subsp. aprica*			
1164.	19478	*Grevillea wickhamii subsp. hispidula*			
1165.	19074	*Grevillea wickhamii subsp. macrodonta*			
1166.	2138	*Hakea chordophylla*			
1167.	19137	*Hakea lorea subsp. lorea*			
Psittacidae					
1168.	25715	*Cacatua roseicapilla (Galah)*			
1169.	24726	*Cacatua roseicapilla subsp. roseicapilla (Galah)*			
1170.	25716	*Cacatua sanguinea (Little Corella)*			
1171.	24727	*Cacatua sanguinea subsp. westralensis (Little Corella)*			
1172.	24736	*Melopsittacus undulatus (Budgerigar)*			
1173.	24742	*Nymphicus hollandicus (Cockatiel)*			
1174.	24743	*Pezoporus occidentalis (Night Parrot)*		T	
1175.	25721	*Platycercus zonarius (Australian Ringneck, Ring-necked Parrot)*			
1176.	24751	*Platycercus zonarius subsp. zonarius (Port Lincoln Parrot)*			
Pteridaceae					
1177.	30	*Ceratopteris thalictroides*			
1178.	32	*Cheilanthes brownii*			
1179.	37	*Cheilanthes lasiophylla (Woolly Cloak Fern)*			
1180.	12818	*Cheilanthes sieberi subsp. sieberi*			
Ptilonorhynchidae					
1181.	25724	*Ptilonorhynchus maculatus (Spotted Bowerbird)*			
1182.	24757	*Ptilonorhynchus maculatus subsp. guttatus (Western Bowerbird)*			
Pygopodidae					
1183.	30906	*Delma concinna (Javelin Legless Lizard)*			
1184.	30905	*Delma concinna subsp. concinna (Javelin Legless Lizard)*			
1185.	30904	*Delma concinna subsp. major (Javelin Legless Lizard)*		P1	
1186.	24998	*Delma elegans*			
1187.	25001	*Delma nasuta*			
1188.	25002	*Delma pax*			
1189.	25004	*Delma tincta*			
1190.	25005	*Lialis burtonis*			
1191.	25009	*Pygopus nigriceps*			
Pyralidae					
1192.		*Pyralidae Pilbara sp 2 (PSW)*			
1193.		*Pyralidae sp.*			
1194.		*Pyralidae sp. 22 of JHH (PSW) (=Parapoynx stagnalis)*			Y
1195.		*Pyralidae sp. 3 of JHH (PSW) (= Margarosticha ?repetitalis)*			
Rallidae					
1196.	25727	*Fulica atra (Eurasian Coot)*			
1197.	24761	*Fulica atra subsp. australis (Eurasian Coot)*			
1198.	25730	*Gallirallus philippensis (Buff-banded Rail)*			
1199.	25732	*Porzana pusilla (Baillon's Crake)*			
Recurvirostridae					
1200.	25734	*Himantopus himantopus (Black-winged Stilt)*			
Ridgewayiidae					
1201.		*Stygoridgewayia trispinosa*			
Rubiaceae					
1202.	7338	*Oldenlandia crouchiana*			
1203.	7339	*Oldenlandia galioides*			
1204.	12964	*Pomax rupestris*			
Salticidae					
1205.		*Omoedus orbiculatus*			
1206.		*Pellenes bitaeniata*			
Sapindaceae					
1207.	4759	*Dodonaea coriacea*			
Scaridiidae					
1208.		*Scaridium sp.*			
Scatophagidae					
1209.		*Selenotoca multifasciata*			
Scincidae					
1210.	25015	*Carlia munda (Shaded-litter Rainbow Skink)*			

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1211.	25017	*Carlia triacantha (Desert Rainbow Skink)*			
1212.	30893	*Cryptoblepharus buchananii*			
1213.	30892	*Cryptoblepharus ustulatus*			
1214.	25461	*Ctenotus brooksi*			
1215.	25032	*Ctenotus calurus*			
1216.	25036	*Ctenotus duricola*			
1217.	25462	*Ctenotus grandis*			
1218.	25041	*Ctenotus grandis subsp. grandis*			
1219.	25043	*Ctenotus grandis subsp. titan*			
1220.	25044	*Ctenotus hanloni*			
1221.	25045	*Ctenotus helenae*			
1222.	25463	*Ctenotus pantherinus (Leopard Ctenotus)*			
1223.	25064	*Ctenotus pantherinus subsp. ocellifer (Leopard Ctenotus)*			
1224.	25065	*Ctenotus pantherinus subsp. pantherinus (Leopard Ctenotus)*			
1225.	25066	*Ctenotus quattuordecimlineatus*			
1226.	25072	*Ctenotus rubicundus*			
1227.	25073	*Ctenotus saxatilis (Rock Ctenotus)*			
1228.	25077	*Ctenotus serventyi*			
1229.	25466	*Cyclodomorphus melanops (Slender Blue-tongue)*			
1230.	25090	*Cyclodomorphus melanops subsp. melanops (Slender Blue-tongue)*			
1231.	41406	*Egernia cygnitos (Western Pilbara Spiny-tailed Skink)*			
1232.	25092	*Egernia depressa (Southern Pygmy Spiny-tailed Skink)*			
1233.	25094	*Egernia formosa*			
1234.	25101	*Egernia pilbarensis (Pilbara Skink)*			
1235.	42404	*Eremiascincus isolepis*			
1236.	43381	*Eremiascincus pallidus (Western Narrow-banded Skink, Narrow-banded Sand Swimmer)*			
1237.	25125	*Lerista bipes*			
1238.	30928	*Lerista clara*			
1239.	25135	*Lerista flammicauda*			
1240.	25142	*Lerista ips*			
1241.	25155	*Lerista muelleri*			
1242.	30925	*Lerista verhmens*			
1243.	25184	*Menetia greyii*			
1244.	25187	*Menetia surda subsp. surda*			
1245.	25495	*Morethia ruficauda*			
1246.	25193	*Morethia ruficauda subsp. exquisita*			
1247.	25196	*Notoscincus butleri (Lined Soil-crevice Skink)*		P4	
1248.	25499	*Notoscincus ornatus*			
1249.	25197	*Notoscincus ornatus subsp. ornatus*			
1250.	25202	*Tiliqua multifasciata (Central Blue-tongue)*			

Sciomyzidae

1251.		*Sciomyzidae sp.*			

Scirtidae

1252.		*Scirtidae sp.*			
1253.		*Scirtidae sp. 1 (PSW)*			

Scolopacidae

1254.	41323	*Actitis hypoleucos (Common Sandpiper)*		IA	
1255.	24779	*Calidris acuminata (Sharp-tailed Sandpiper)*		IA	
1256.	24806	*Tringa glareola (Wood Sandpiper)*		IA	

Scolopendridae

1257.		*Arthrorhabdus paucispinus*			
1258.		*Cormocephalus turneri*			
1259.		*Ethmostigmus curtipes*			
1260.		*Scolopendra laeta*			
1261.		*Scolopendra morsitans*			

Scorpaenidae

1262.		*Scorpaena sumptuosa*			

Scrophulariaceae

1263.	15052	*Eremophila forrestii subsp. forrestii*			
1264.	16696	*Eremophila fraseri subsp. fraseri*			
1265.	7234	*Eremophila longifolia (Berrigan, Tulypurpa)*			
1266.	23997	*Eremophila tietkensii*			

Scutigeridae

1267.		*Pilbarascutigera incola*			

Sididae

	Name ID	Species Name	Naturalised	Conservation Code	[1]Endemic To Query Area
1268.		*Latonopsis australis*			
Sillaginidae					
1269.		*Sillago ingenuua*			
Simuliidae					
1270.		*Simulium ornatipes*			
Solanaceae					
1271.	6971	*Nicotiana benthamiana (Tjuntiwari)*			
1272.	11331	*Nicotiana occidentalis subsp. obliqua*			
1273.	11856	*Nicotiana occidentalis subsp. occidentalis*			
1274.	20652	*Physalis angulata*	Y		
1275.	6989	*Solanum ashbyae*			
1276.	6995	*Solanum centrale (Desert Raisin, Kampurarpa)*			
1277.	6998	*Solanum cleistogamum*			
1278.	7002	*Solanum diversiflorum*			
1279.	7009	*Solanum gabrielae*			
1280.	7014	*Solanum horridum*			
1281.	7018	*Solanum lasiophyllum (Flannel Bush, Mindjulu)*			
1282.	7022	*Solanum nigrum (Black Berry Nightshade)*	Y		
1283.	7029	*Solanum phlomoides*			
1284.	7036	*Solanum sturtianum (Thargomindah Nightshade)*			
Sparassidae					
1285.		*Isopedella tindalei*			
Spongillidae					
1286.		*Spongillidae sp.*			
Staphylinidae					
1287.		*Staphylinidae sp.*			
Stratiomyidae					
1288.		*Stratiomyidae sp.*			
Strigidae					
1289.	25747	*Ninox connivens (Barking Owl)*			
1290.	25748	*Ninox novaeseelandiae (Boobook Owl)*			
1291.	24820	*Ninox novaeseelandiae subsp. boobook (Boobook Owl)*			
Stylidiaceae					
1292.	7729	*Stylidium fluminense*			
1293.	18123	*Stylidium weeliwolli*		P2	
Surianaceae					
1294.	3182	*Stylobasium spathulatum (Pebble Bush)*			
Syarinidae					
1295.		*Ideoblothrus linnaei*			Y
1296.		*Ideoblothrus pisolitus*			Y
Sylviidae					
1297.	25755	*Acrocephalus australis (Australian Reed Warbler)*			
1298.	24833	*Cincloramphus cruralis (Brown Songlark)*			
1299.	24834	*Cincloramphus mathewsi (Rufous Songlark)*			
1300.	24837	*Eremiornis carteri (Spinifex-bird)*			
Synchaetidae					
1301.		*Polyarthra dolichoptera*			
Tabanidae					
1302.		*Tabanidae sp.*			
Tachyglossidae					
1303.	24207	*Tachyglossus aculeatus (Short-beaked Echidna)*			
Terapontidae					
1304.	34042	*Leiopotherapon aheneus (Fortescue Grunter)*		P4	
1305.		*Terapon jarbua*			
Testudinellidae					
1306.		*Testudinella amphora*			
1307.		*Testudinella patina*			
1308.		*Testudinella sp.*			
Tetraodontidae					
1309.		*Chelonodon patoca*			

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Thermosbaenacea					
1310.		*Thermosbaenacea sp.*			Y
Thermosbaenacidae					
1311.		*Halosbaena sp.*			
1312.		*Halosbaena tulki*			
Thiaridae					
1313.		*Melanoides (Stenomelania) tuberculata*			
1314.		*Plotiopsis australis*			
Threskiornithidae					
1315.	24841	*Platalea flavipes (Yellow-billed Spoonbill)*			
1316.	24845	*Threskiornis spinicollis (Straw-necked Ibis)*			
Thymelaeaceae					
1317.	5230	*Pimelea ammocharis*			
Tipulidae					
1318.		*Tipulidae sp.*			
1319.		*Tipulidae type D (SAP)*			
1320.		*Tipulidae type E (SAP)*			
1321.		*Tipulidae type P1 (PSW)*			
1322.		*Tipulidae type P4 (nr SAP type I) (PSW)*			Y
Trichocercidae					
1323.		*Trichocerca braziliensis*			
1324.		*Trichocerca musculus*			Y
1325.		*Trichocerca pusilla*			
1326.		*Trichocerca similis*			
Trichotriidae					
1327.		*Macrochaetus altamirai*			
Trochanteriidae					
1328.		*Trachyspina capensis*			
Trochanteriidae?					
1329.		*Fissarena castanea*			
Turbellaria					
1330.		*Microturbellaria sp.*			
1331.		*Turbellaria sp.*			
Turnicidae					
1332.	24851	*Turnix velox (Little Button-quail)*			
Tytonidae					
1333.	25762	*Tyto alba (Barn Owl)*			
Unionicolidae					
1334.		*Koenikea nsp. (nr timmsi) (PSW)*			Y
1335.		*Koenikea sorpresa*			
1336.		*Koenikea sp. 2/3 (Pilbara) (PSW)*			
1337.		*Neumania sp.*			
1338.		*Recifella doomba*			
1339.		*Recifella sp.*			
1340.		*Recifella tinka*			
1341.		*Unionicola crassipalpis*			
1342.		*Unionicola flabelliseta*			
1343.		*Unionicola longiseta*			Y
1344.		*Unionicola neoaffinis*			
1345.		*Unionicolidae sp.*			
Urodacidae					
1346.		*Urodacus butleri*			
Varanidae					
1347.	25209	*Varanus acanthurus (Spiny-tailed Monitor)*			
1348.	25210	*Varanus brevicauda (Short-tailed Pygmy Monitor)*			
1349.	30825	*Varanus bushi (Pilbara Mulga Monitor)*			
1350.	25211	*Varanus caudolineatus*			
1351.	25212	*Varanus eremius (Pygmy Desert Monitor)*			
1352.	25216	*Varanus giganteus (Perentie)*			
1353.	25218	*Varanus gouldii (Bungarra or Sand Monitor)*			
1354.	25524	*Varanus panoptes (Yellow-spotted Monitor)*			
1355.	25222	*Varanus panoptes subsp. panoptes*			
1356.	25223	*Varanus panoptes subsp. rubidus*			

Australian Government

Department of the Environment

EPBC Act Protected Matters Report

This report provides general guidance on matters of national environmental significance and other matters protected by the EPBC Act in the area you have selected.

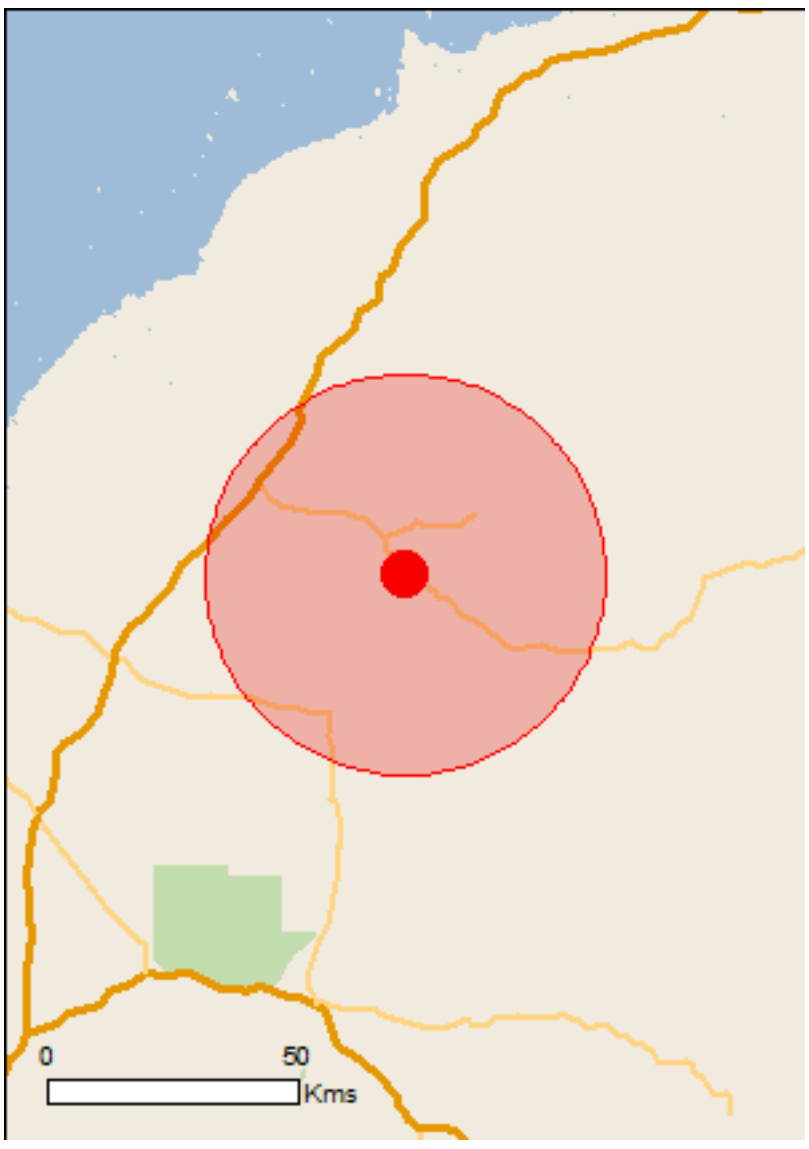
Information on the coverage of this report and qualifications on data supporting this report are contained in the caveat at the end of the report.

Information is available about Environment Assessments and the EPBC Act including significance guidelines, forms and application process details.

Report created: 21/09/15 10:16:32

Summary
Details
- Matters of NES
- Other Matters Protected by the EPBC Act
- Extra Information

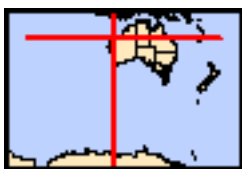
Caveat
Acknowledgements



This map may contain data which are ©Commonwealth of Australia (Geoscience Australia), ©PSMA 2010

Coordinates

Buffer: 40.0Km



Summary

Matters of National Environmental Significance

This part of the report summarises the matters of national environmental significance that may occur in, or may relate to, the area you nominated. Further information is available in the detail part of the report, which can be accessed by scrolling or following the links below. If you are proposing to undertake an activity that may have a significant impact on one or more matters of national environmental significance then you should consider the Administrative Guidelines on Significance.

World Heritage Properties:	None
National Heritage Places:	None
Wetlands of International Importance:	None
Great Barrier Reef Marine Park:	None
Commonwealth Marine Area:	None
Listed Threatened Ecological Communities:	None
Listed Threatened Species:	7
Listed Migratory Species:	10

Other Matters Protected by the EPBC Act

This part of the report summarises other matters protected under the Act that may relate to the area you nominated. Approval may be required for a proposed activity that significantly affects the environment on Commonwealth land, when the action is outside the Commonwealth land, or the environment anywhere when the action is taken on Commonwealth land. Approval may also be required for the Commonwealth or Commonwealth agencies proposing to take an action that is likely to have a significant impact on the environment anywhere.

The EPBC Act protects the environment on Commonwealth land, the environment from the actions taken on Commonwealth land, and the environment from actions taken by Commonwealth agencies. As heritage values of a place are part of the 'environment', these aspects of the EPBC Act protect the Commonwealth Heritage values of a Commonwealth Heritage place. Information on the new heritage laws can be found at http://www.environment.gov.au/heritage

A permit may be required for activities in or on a Commonwealth area that may affect a member of a listed threatened species or ecological community, a member of a listed migratory species, whales and other cetaceans, or a member of a listed marine species.

Commonwealth Land:	None
Commonwealth Heritage Places:	None
Listed Marine Species:	12
Whales and Other Cetaceans:	None
Critical Habitats:	None
Commonwealth Reserves Terrestrial:	None
Commonwealth Reserves Marine:	None

Extra Information

This part of the report provides information that may also be relevant to the area you have nominated.

State and Territory Reserves:	None
Regional Forest Agreements:	None
Invasive Species:	10
Nationally Important Wetlands:	None
Key Ecological Features (Marine)	None

Details

Matters of National Environmental Significance

Listed Threatened Species		[Resource Information]
Name	Status	Type of Presence
Birds		
Pezoporus occidentalis Night Parrot [59350]	Endangered	Species or species habitat may occur within area
Rostratula australis Australian Painted Snipe [77037]	Endangered	Species or species habitat may occur within area
Mammals		
Dasyurus hallucatus Northern Quoll [331]	Endangered	Species or species habitat known to occur within area
Macrotis lagotis Greater Bilby [282]	Vulnerable	Species or species habitat likely to occur within area
Notoryctes caurinus Kakarratul, Northern Marsupial Mole [295]	Endangered	Species or species habitat may occur within area
Rhinonicteris aurantia (Pilbara form) Pilbara Leaf-nosed Bat [82790]	Vulnerable	Roosting known to occur within area
Reptiles		
Liasis olivaceus barroni Olive Python (Pilbara subspecies) [66699]	Vulnerable	Species or species habitat known to occur within area

Listed Migratory Species		[Resource Information]
* Species is listed under a different scientific name on the EPBC Act - Threatened Species list.		
Name	Threatened	Type of Presence
Migratory Marine Birds		
Apus pacificus Fork-tailed Swift [678]		Species or species habitat likely to occur within area
Migratory Terrestrial Species		
Hirundo rustica Barn Swallow [662]		Species or species habitat may occur within area
Merops ornatus Rainbow Bee-eater [670]		Species or species habitat may occur within area
Motacilla cinerea Grey Wagtail [642]		Species or species

Name	Threatened	Type of Presence
		habitat may occur within area
Motacilla flava Yellow Wagtail [644]		Species or species habitat may occur within area
Migratory Wetlands Species		
Ardea alba Great Egret, White Egret [59541]		Species or species habitat known to occur within area
Ardea ibis Cattle Egret [59542]		Species or species habitat may occur within area
Charadrius veredus Oriental Plover, Oriental Dotterel [882]		Species or species habitat may occur within area
Glareola maldivarum Oriental Pratincole [840]		Species or species habitat may occur within area
Pandion haliaetus Osprey [952]		Species or species habitat known to occur within area

Other Matters Protected by the EPBC Act

Listed Marine Species [Resource Information]

* Species is listed under a different scientific name on the EPBC Act - Threatened Species list.

Name	Threatened	Type of Presence
Birds		
Apus pacificus Fork-tailed Swift [678]		Species or species habitat likely to occur within area
Ardea alba Great Egret, White Egret [59541]		Species or species habitat known to occur within area
Ardea ibis Cattle Egret [59542]		Species or species habitat may occur within area
Charadrius veredus Oriental Plover, Oriental Dotterel [882]		Species or species habitat may occur within area
Glareola maldivarum Oriental Pratincole [840]		Species or species habitat may occur within area
Haliaeetus leucogaster White-bellied Sea-Eagle [943]		Species or species habitat likely to occur within area
Hirundo rustica Barn Swallow [662]		Species or species habitat may occur within area
Merops ornatus Rainbow Bee-eater [670]		Species or species habitat may occur within area
Motacilla cinerea Grey Wagtail [642]		Species or species

Name	Threatened	Type of Presence
		habitat may occur within area
Motacilla flava Yellow Wagtail [644]		Species or species habitat may occur within area
Pandion haliaetus Osprey [952]		Species or species habitat known to occur within area
Rostratula benghalensis (sensu lato) Painted Snipe [889]	Endangered*	Species or species habitat may occur within area

Extra Information

Invasive Species [Resource Information]

Weeds reported here are the 20 species of national significance (WoNS), along with other introduced plants that are considered by the States and Territories to pose a particularly significant threat to biodiversity. The following feral animals are reported: Goat, Red Fox, Cat, Rabbit, Pig, Water Buffalo and Cane Toad. Maps from Landscape Health Project, National Land and Water Resouces Audit, 2001.

Name	Status	Type of Presence
Birds		
Columba livia Rock Pigeon, Rock Dove, Domestic Pigeon [803]		Species or species habitat likely to occur within area
Mammals		
Capra hircus Goat [2]		Species or species habitat likely to occur within area
Equus asinus Donkey, Ass [4]		Species or species habitat likely to occur within area
Felis catus Cat, House Cat, Domestic Cat [19]		Species or species habitat likely to occur within area
Mus musculus House Mouse [120]		Species or species habitat likely to occur within area
Oryctolagus cuniculus Rabbit, European Rabbit [128]		Species or species habitat likely to occur within area
Vulpes vulpes Red Fox, Fox [18]		Species or species habitat likely to occur within area
Plants		
Cenchrus ciliaris Buffel-grass, Black Buffel-grass [20213]		Species or species habitat likely to occur within area

Name	Status	Type of Presence
Parkinsonia aculeata Parkinsonia, Jerusalem Thorn, Jelly Bean Tree, Horse Bean [12301]		Species or species habitat likely to occur within area
Prosopis spp. Mesquite, Algaroba [68407]		Species or species habitat likely to occur within area

Caveat

The information presented in this report has been provided by a range of data sources as acknowledged at the end of the report.

This report is designed to assist in identifying the locations of places which may be relevant in determining obligations under the Environment Protection and Biodiversity Conservation Act 1999. It holds mapped locations of World and National Heritage properties, Wetlands of International and National Importance, Commonwealth and State/Territory reserves, listed threatened, migratory and marine species and listed threatened ecological communities. Mapping of Commonwealth land is not complete at this stage. Maps have been collated from a range of sources at various resolutions.

Not all species listed under the EPBC Act have been mapped (see below) and therefore a report is a general guide only. Where available data supports mapping, the type of presence that can be determined from the data is indicated in general terms. People using this information in making a referral may need to consider the qualifications below and may need to seek and consider other information sources.

For threatened ecological communities where the distribution is well known, maps are derived from recovery plans, State vegetation maps, remote sensing imagery and other sources. Where threatened ecological community distributions are less well known, existing vegetation maps and point location data are used to produce indicative distribution maps.

For species where the distributions are well known, maps are digitised from sources such as recovery plans and detailed habitat studies. Where appropriate, core breeding, foraging and roosting areas are indicated under 'type of presence'. For species whose distributions are less well known, point locations are collated from government wildlife authorities, museums, and non-government organisations; bioclimatic distribution models are generated and these validated by experts. In some cases, the distribution maps are based solely on expert knowledge.

Only selected species covered by the following provisions of the EPBC Act have been mapped:

- migratory and
- marine

The following species and ecological communities have not been mapped and do not appear in reports produced from this database:

- threatened species listed as extinct or considered as vagrants
- some species and ecological communities that have only recently been listed
- some terrestrial species that overfly the Commonwealth marine area
- migratory species that are very widespread, vagrant, or only occur in small numbers

The following groups have been mapped, but may not cover the complete distribution of the species:

- non-threatened seabirds which have only been mapped for recorded breeding sites
- seals which have only been mapped for breeding sites near the Australian continent

Such breeding sites may be important for the protection of the Commonwealth Marine environment.

Coordinates

-21.74635 116.20092

Acknowledgements

This database has been compiled from a range of data sources. The department acknowledges the following custodians who have contributed valuable data and advice:

-Office of Environment and Heritage, New South Wales
-Department of Environment and Primary Industries, Victoria
-Department of Primary Industries, Parks, Water and Environment, Tasmania
-Department of Environment, Water and Natural Resources, South Australia
-Parks and Wildlife Commission NT, Northern Territory Government
-Department of Environmental and Heritage Protection, Queensland
-Department of Parks and Wildlife, Western Australia
-Environment and Planning Directorate, ACT
-Birdlife Australia
-Australian Bird and Bat Banding Scheme
-Australian National Wildlife Collection
-Natural history museums of Australia
-Museum Victoria
-Australian Museum
-South Australian Museum
-Queensland Museum
-Online Zoological Collections of Australian Museums
-Queensland Herbarium
-National Herbarium of NSW
-Royal Botanic Gardens and National Herbarium of Victoria
-Tasmanian Herbarium
-State Herbarium of South Australia
-Northern Territory Herbarium
-Western Australian Herbarium
-Australian National Herbarium, Atherton and Canberra
-University of New England
-Ocean Biogeographic Information System
-Australian Government, Department of Defence
Forestry Corporation, NSW
-Geoscience Australia
-CSIRO
-Other groups and individuals

The Department is extremely grateful to the many organisations and individuals who provided expert advice and information on numerous draft distributions.

Please feel free to provide feedback via the Contact Us page.

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+61 2 6274 1111

	Name ID	Species Name	Naturalised	Conservation Code	[1]Endemic To Query Area
1357.	25224	*Varanus pilbarensis (Pilbara Rock Monitor)*			
1358.	25526	*Varanus tristis (Racehorse Monitor)*			
1359.	25227	*Varanus tristis subsp. tristis (Racehorse Monitor)*			
Veliidae					
1360.		*Microvelia (Austromicrovelia) peramoena*			
Vespertilionidae					
1361.	24186	*Chalinolobus gouldii (Gould's Wattled Bat)*			
1362.	42365	*Nyctophilus daedalus (Northwestern Long-eared Bat)*			
1363.	24194	*Nyctophilus geoffroyi (Lesser Long-eared Bat)*			
1364.	24200	*Scotorepens greyii (Little Broad-nosed Bat)*			
1365.	24205	*Vespadelus finlaysoni (Finlayson's Cave Bat)*			
Violaceae					
1366.	5215	*Hybanthus aurantiacus*			
Zygophyllaceae					
1367.	4368	*Tribulopis angustifolia*			
1368.	4374	*Tribulus astrocarpus*			
1369.	4379	*Tribulus macrocarpus*			
1370.	4380	*Tribulus occidentalis (Perennial Caltrop)*			
1371.	4381	*Tribulus platypterus (Cork Hopbush)*			
1372.	4383	*Tribulus terrestris (Caltrop)*	Y		

Conservation Codes
T - Rare or likely to become extinct
X - Presumed extinct
IA - Protected under international agreement
S - Other specially protected fauna
1 - Priority 1
2 - Priority 2
3 - Priority 3
4 - Priority 4
5 - Priority 5

[1] For NatureMap's purposes, species flagged as endemic are those whose records are wholely contained within the search area. Note that only those records complying with the search criterion are included in the calculation. For example, if you limit records to those from a specific datasource, only records from that datasource are used to determine if a species is restricted to the query area.

Appendix E: Previous Flora Survey Area Locations

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410000
415000
420000
425000
430000
7600000
7595000
7590000

Legend

- Mesa H Riparian Community Survey Area
- Astron (2016a)
- Astron (2016b)
- Astron (2011)
- Biota (2012)
- Biota (2011a)
- Biota (2006a)
- Biota (2003)

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Mesa H Riparian Community Assessment - June 2016

Figure E.1: Previous Flora Survey Area Locations

Datum: GDA 1994 - Projection: MGA Zone 50

0 500 1,000 1,500 2,000 2,500 3,000 metres

N

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Author: D. Roocke | Drawn: W. An | Date: 05-04-2017 | Figure Ref: 14269-16-BIDR-1RevB_170406_FigE1_PreSurveyArea

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Appendix F: Vegetation Classification and Condition Scales and Fauna Habitat Condition Scale

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Table F.1: Vegetation Classification System (Specht 1970) as modified by Aplin (1979).

Stratum	70-100% cover	30-70% cover	10-30% cover	2-10% cover	<2% cover
Trees > 30 m	Tall closed forest	Tall open Forest	Tall woodland	Tall open woodland	Scattered tall trees
Trees 10-30 m	Closed forest	Open forest	Woodland	Open woodland	Scattered trees
Trees < 10 m	Low closed forest	Low open forest	Low woodland	Low open woodland	Scattered low trees
Shrubs > 2 m	Tall closed scrub	Tall open scrub	Tall shrubland	Tall open shrubland	Scattered tall shrubs
Shrubs 1-2 m	Closed heath	Open heath	Shrubland	Open shrubland	Scattered shrubs
Shrubs < 1 m	Low closed heath	Low open heath	Low shrubland	Low open shrubland	Scattered low shrubs
Hummock grasses	Closed hummock grassland	Hummock grassland	Open hummock grassland	Very open hummock grassland	Scattered hummock grasses
Grasses, sedges, herbs	Closed tussock grassland/ sedgeland/ herbland	Tussock grassland/ sedgeland/ herbland	Open tussock grassland/ sedgeland/ herbland	Very open tussock grassland/ sedgeland/ herbland	Scattered tussock grasses/ sedges/ herbs

Table F.2: Summary of vegetation condition scale, as adapted from Trudgen (1988).

Vegetation condition	Condition description
Excellent	Pristine or nearly so, no obvious signs of damage caused by human activities since European settlement.
Very Good	Some relatively slight signs of damage caused by human activities since European settlement. For example, some signs of damage to tree trunks caused by repeated fire, the presence of some relatively non-aggressive weeds, or occasional vehicle tracks.
Good	More obvious signs of damage caused by human activity since European settlement, including some obvious impact on the vegetation structure such as that caused by low levels of grazing or slightly aggressive weeds.
Poor	Still retains basic vegetation structure or ability to regenerate to it after very obvious impacts of human activities since European settlement, such as grazing, partial clearing, frequent fires or aggressive weeds.
Very Poor	Severely impacted by grazing, very frequent fires, clearing or a combination of these activities. Scope for some regeneration but not to a state approaching good condition without intensive management. Usually with a number of weed species present including very aggressive species.
Completely Degraded	Areas that are completely or almost completely without native species in the structure of their vegetation; i.e. areas that are cleared or 'parkland cleared' with their flora comprising weed or crop species with isolated native trees or shrubs.

Table F.3: Fauna habitat condition scale (Thompson and Thompson 2010).

Habitat condition	Condition description
High Quality Fauna Habitat (1.0)	These areas closely approximate the vegetation mix and quality that would have been in the area prior to any human induced disturbance. The habitat has connectivity with other habitats and is likely to support the most natural vertebrate fauna assemblage.
Very Good Fauna Habitat (0.8)	These areas show minimal signs of human induced disturbance (e.g. grazing, clearing, fragmentation, weeds) and retain almost all of the characteristics of the habitat had it not been disturbed. The habitat has connectivity with other habitats, and fauna assemblages in these areas are likely to be minimally affected by disturbance.
Good Fauna Habitat (0.6)	These areas show signs of human induced disturbance (e.g. grazing, clearing, fragmentation, weeds) but generally retain many of the characteristics of the habitat had it not been disturbed. The habitat still retains some connectivity with other habitats but fauna assemblages in these areas are likely to be affected by disturbance. Fauna assemblages in these areas are likely to be similar to what might be expected in this habitat.
Disturbed Fauna Habitat (0.4)	These areas show signs of human induced significant disturbance (e.g. mining, clearing, tracks and roads). Many of the trees, shrubs and undergrowth have died or have been cleared. These areas may be in the early succession and regeneration stages. Areas may show signs of significant grazing, contain an abundance of weeds or have been damaged by vehicles or machinery. Habitats are fragmented or have limited connectivity with other fauna habitats. Fauna assemblages in these areas are likely to differ significantly from what might be expected in the area had the disturbance not occurred.
Highly Degraded Fauna Habitat (<0.2)	These areas often have a significant human induced loss of vegetation, and / or a large number of vehicle tracks and / or have been completely cleared, and / or areas have been heavily grazed or farmed. There is limited or no fauna habitat connectivity. Fauna assemblages in these areas are likely to differ significantly from what existed prior to the disturbance, and are often depleted compared to what existed prior to the disturbance.

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Appendix G: Vegetation and Flora Sample Site Locations

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410000 415000 420000 425000 430000

7600000 7595000 7590000

Pannawonica

Millstream Rd

Robe River

Jimmawurrada Creek

Legend

- Railway
- Main Road
- River/Creek
- Mesa H Riparian Community Survey Area

Sampling Sites

- Quadrat Astron 1 phase
- Quadrat Astron 2 phases
- Relevé Astron 2 phases
- Quadrat Ecologia 1 phase, Astron 1 phase

Robe River Mining Co. Pty Ltd

Mesa H Riparian Community Assessment - June 2016

Figure G.1: Current Survey and Previous Surveys Vegetation and Flora Sampling Locations

Datum: GDA 1994 - Projection: MGA Zone 50

0 500 1,000 1,500 2,000 2,500 3,000 metres

N

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Author: D. Roocke | Drawn: W. An | Date: 05-04-2017 | Figure Ref: 14269-16-BIDR-1RevB_170406_FigG1_SampleSites

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Appendix H: Fauna Habitat Mapping and Significant Areas

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410000 415000 420000 425000 430000

7605000 7600000 7595000 7590000

Legend

- Fauna Habitat Assessment Sites
- Mesa H Riparian Community Survey Area

Conservation Significant Areas

- Pool

Fauna Habitat

- Riverine
- Drainage
- Disturbed

HA1 HA2 HA3 HA4 HA5 HA6 HA7 HA8 HA9 HA10

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Figure H.1: Fauna Habitat Mapping

Coordinate System: GDA94 MGA zone 50

0 1,000 2,000 3,000 Metres

N

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Author: J. Trainer | Drawn: W. An | Date: 05-04-2017 | Figure Ref: 14269-16-BIDR-1RevB_170406_FigH1_FaunaHabitat

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Table H.1: Astron fauna habitat assessment locations.

Site ID	Previous Site ID	MGA Zone 50 K		Date	Habitat	Condition	Disturbance	Microhabitats	Photo
		Easting (mE)	Northing (mN)						
HA1	RHA1	407118	7594065	7/5/2016	Drainage Line	1.0	Nil	Sparse logs and leaf litter	
HA2	RHA2	413299	7595588	7/5/2016	Riverine	0.8	Grazing	Hollow logs and leaf litter	
HA3	HA01	414405	7596614	26/09/2015	Riverine	0.8	Weeds	Standing water	
HA4	HA15	417192	7598072	30/09/2015	Riverine	0.8	Grazing, weeds	Standing water	No photo

Site ID	Previous Site ID	MGA Zone 50 K		Date	Habitat	Condition	Disturbance	Microhabitats	Photo
		Easting (mE)	Northing (mN)						
HA5	HA04	418205	7598125	27/09/2015	Riverine	0.8	Grazing	Standing water, rushes	
HA6	HA13	419528	7598021	30/09/2015	Riverine	0.8	Grazing, weeds	Standing water	
HA7	HA02	419980	7597945	26/09/2015	Riverine	0.8	Weeds, grazing, vehicular tracks	Standing water	No photo
HA8	HA22	423930	7592643	02/05/2016	Drainage Line	0.4	Weeds	Standing water	

Site ID	Previous Site ID	MGA Zone 50 K		Date	Habitat	Condition	Disturbance	Microhabitats	Photo
		Easting (mE)	Northing (mN)						
HA9	HA23	424018	7592961	02/05/2016	Drainage Line	0.4	Weeds		
HA10	HA15	427030	7599901	21/06/2015	Riverine	0.6	Grazing	Ephemeral pools	

Table H.2: Location of significant areas recorded during the Astron field surveys.

Site ID	Survey	MGA Zone 50 K		Reason	Photograph
		Easting (mE)	Northing (mN)		
Water Sources					
Pool 1	Level 1 survey (Astron 2014)	414390	7597485	Permanent pool of the Robe River, likely to support MNES bat species, migratory bird species and other conservation significant fauna species.	
Pool 2	Level 1 survey (Astron 2014)	414415	7596570	Permanent pool of the Robe River, likely to support MNES bat species, migratory bird species and other conservation significant fauna species.	
Pool 3	Phase 1 Level 2 survey (Astron 2016)	414405	7596615	Permanent pool of the Robe River with abundant Typha. Important habitat for migratory listed birds.	

Site ID	Survey	MGA Zone 50 K		Reason	Photograph
		Easting (mE)	Northing (mN)		
Pool 4	Phase 1 Level 2 survey (Astron 2016)	417192	7598072	Permanent pool of the Robe River with abundant Typha. Important habitat for migratory listed birds.	
Pool 5	Phase 1 Level 2 survey (Astron 2016)	418060	7598016	Permanent pool of the Robe River with abundant Typha. Important habitat for migratory listed birds.	
Pool 6	Riparian Community Assessment	411435	7594952	Permanent pool of the Robe River with abundant Typha. Important habitat for migratory listed birds.	

Site ID	Survey	MGA Zone 50 K		Reason	Photograph
		Easting (mE)	Northing (mN)		
Pool 7	Riparian Community Assessment	420290	7597902	Small but deep permanent pool of the Robe River.	
Pool 8	Riparian Community Assessment	414438	7596216	Permanent pool of the Robe River with abundant Typha. Important habitat for migratory listed birds.	
Pool 9	Riparian Community Assessment	412021	7595303	Small but deep permanent pool of the Robe River.	

Site ID	Survey	MGA Zone 50 K		Reason	Photograph
		Easting (mE)	Northing (mN)		
Pool 10	Middle Robe and East Deepdale Level 2 Fauna Assessment (Astron 2015)	423718	7596616	Permanent pool of the Robe River with abundant Typha. Important habitat for migratory listed birds. Northern Quoll and Pilbara Olive Python scats recorded nearby, Pilbara Leaf-nosed Bat calls recorded nearby.	
Pool 11	Middle Robe and East Deepdale Level 2 Fauna Assessment (Astron 2015)	429712	7601411	Permanent pool of the Robe River with abundant Typha. Northern Quoll recorded nearby.	
Pool 12	Riparian Community Assessment	419813	7598056	Small but deep permanent pool of the Robe River.	No photo
Pool 13	Riparian Community Assessment	420948	7597275	Small but deep permanent pool of the Robe River.	No photo

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Appendix I: Priority Ecological Communities of the Riparian Community Survey Area

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400000 410000 420000 430000 440000 450000

7610000 7600000 7590000 7580000

Wona Land System

Pannawonica - Millstream Rd

PANNAWONICA

Pannawonica Rd

Robe River

Jimmawurrada Creek

Millstream - Yarraloola Rd

Triodia sp. Robe River Assemblages

Legend

- Towns
- Main Road
- Railway
- River/Creek
- Mesa H Riparian Community Survey Area

Priority Ecological Community (Department of Parks and Wildlife 2015b)

- Wona Land System (P1): Four plant assemblages of the Wona Land System (previously 'Cracking clays of the Chichester and Mungaroona Range')
- *Triodia* sp. Robe River Assemblages (P3): *Triodia* sp. Robe River assemblages of mesas of the West Pilbara

Robe River Mining Co. Pty Ltd

Mesa H Riparian Community Assessment - June 2016

Figure I.1: Priority Ecological Communities of the Mesa H Riparian Community Survey Area

Datum: GDA 1994 - Projection: MGA Zone 50

0 2 4 6 8 10 km

N

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Author: D. Roocke | Drawn: W. An | Date: 05-04-2017 | Figure Ref: 14269-16-BIDR-1RevB_170406_FigI1_PEC

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Appendix J: Threatened and Priority Flora Species Likelihood of Occurrence within the Survey Area

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Table J.1: Likelihood of occurrence of Threatened and Priority flora recorded within 20 km of the Mesa H survey area (Astron 2016b, NatureMap (Department of Parks and Wildlife 2016a), TPFL (Department of Parks and Wildlife 2015c), TP List (Department of Parks and Wildlife 2015d), WAHerb (Department of Parks and Wildlife 2015e)). The TP List database is searched using place names. As a result, many of the records obtained from this database may occur beyond 50 km of the Mesa H survey area.

Species	Habit and flowering information	Life Form	Habitat	Likelihood of occurrence	
				Pre-survey	Post-survey
Threatened					
Thyrptomene wittwerii	Spreading or rounded shrub, 0.5 m to 1.5 (-2.1) m high. White-cream flowers in April, July or August.	Perennial	Skeletal red stony soils. Breakaways, stony creek beds.	Unlikely	Unlikely
Priority 1					
Bothriochloa decipiens var. *cloncurrensis*	Herbaceous grass, to 1.4 m high.	Perennial	Seasonally damp depression. Stony clay plain.	Potential	Unlikely
Triodia sp. Pannawonica (B.M. Anderson & M.D. Barrett BMA 89)	Hummock grass.	Perennial	Shale	Unlikely	Unlikely
Priority 2					
Dicladanthera glabra	Spreading herb or shrub, to 0.6 (-1) m high.	Perennial	Alluvium. Along watercourses, near rock pools.	Potential	Unlikely
Euphorbia australis var. *glabra*	Herb	Annual	Creek banks. Red brown loam, some pebbles.	Potential	Potential
Pentalepis trichodesmoides subsp. *hispida*	Multi-stemmed shrub to 0.8 m high. Flowers July to October.	Perennial	Summits of ridges, cobbled slopes, outcrops, banks of creeks and edges of basalt screes.	Unlikely	Unlikely
Stylidium weeliwolli	Herb, 0.1 m to 0.25 m high, throat appendages 4, rod-shaped. Pink and red flowers from August to September.	Annual	Gritty sand soil, sandy clay. Edge of watercourses.	Likely	Potential

Species	Habit and flowering information	Life Form	Habitat	Likelihood of occurrence	
				Pre-survey	Post-survey
Priority 3					
Eragrostis surreyana	Grass. Culms erect or decumbent, 5-8 (-13) cm tall. Panicle linear, 9 cm to 13 cm long; 0.5 cm to 1.3 cm wide.	Annual	Soak area. Red-brown sandy clay.	Potential	Potential
Indigofera sp. Bungaroo Creek (S. van Leeuwen 4301)	Shrub or herb 0.2 m to 2 m high. May to July.	Perennial	Drainage lines, creeks in hills or plains. Brown silty loam.	Potential	Potential
Pleurocarpaea gracilis	Rounded shrub to 0.5 m. June to October.	Perennial	Summit of rounded hill, slopes, skeletal red gritty soil over massive Brockman Iron Formation rock.	Unlikely	Unlikely
Solanum albostellatum	Low herb or shrub to 0.2 m high. March.	Perennial	Floodplains, slight bedrock outcrops. Red brown silty clay loam. Cracking clay.	Unlikely	Unlikely
Terminalia supranitifolia	Spreading tangled tree or shrub to 3 m high.	Perennial	Sandy soils or among basalt rocks.	Unlikely	Unlikely
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367)	Hummock grass. June, July, September.	Perennial	Mesa tops and edges; breakaways; hillsides and hilltops.	Unlikely	Recorded
Priority 4					
Goodenia nuda	Erect to ascending herb to 0.5 m high. Yellow flowers, April to August.	Short-lived perennial	Alluvial soils over ironstone, floodplains, valleys, watercourses, orange-brown alluvial sand over ironstone.	Potential	Unlikely
Rhynchosia bungarensis	Compact, prostrate shrub, to 0.5 m high. May to November.	Short-lived perennial	Pebbly, shingly coarse sand amongst boulders. Banks of flow line in the mouth of a gully in a valley wall.	Likely	Recorded

Appendix K: Fauna Species Lists

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Table K.1: Amphibian species list – results of database searches, literature reviews and Astron survey results.

Scientific name	Common name	Introduced	Conservation codes			Nature Map	EPBC Protected Matters Search	Birdlife	Previous surveys	Current survey
			EPBC Act	WC Act	Parks and Wildlife					
HYLIDAE										
Cyclorana maini	Sheep Frog					x			x	
Litoria rubella	Little Red Tree Frog					x			x	
MYOBATRACHIDAE										
Pseudophryne douglasi	Gorge Toadlet								x	
Uperoleia russelli	Northwest Toadlet					x			x	
Uperoleia saxatilis	Pilbara Toadlet					x			x	
BUFONIDAE										
Platyplectrum spenceri	Centralian Burrowing Frog					x				

Table K.2: Reptile species list – results of database searches, literature reviews and Astron survey results.

Scientific name	Common name	Introduced	Conservation codes			Nature Map	EPBC Protected Matters Search	Birdlife	Previous surveys	Current survey
			EPBC Act	WC Act	Parks and Wildlife					
AGAMIDAE										
Amphibolurus longirostris	Long-Nosed Dragon					x			x	x
Ctenophorus caudicinctus	Ring-tailed Rock Dragon					x			x	
Ctenophorus femoralis	Dune Dragon					x				
Ctenophorus isolepis isolepis	Military Sand Dragon					x			x	
Ctenophorus nuchalis	Central Netted Dragon					x			x	
Ctenophorus reticulatus	Western Netted Dragon					x				
Pogona minor minor	Bearded Dragon					x			x	
DIPLODACTYLIDAE										
Crenadactylus ocellatus	Clawless Gecko					x			x	
Diplodactylus bilybara	Western Fat-tailed Gecko					x			x	
Diplodactylus galaxias						x			x	
Diplodactylus mitchelli						x				
Diplodactylus savagei						x			x	
Lucasium stenodactylum	Pale-snouted Ground Gecko					x			x	
Lucasium wombeyi						x			x	
Oedura marmorata	Marbled Velvet Gecko					x			x	
Rhynchoedura ornata	Beaked Gecko					x			x	
Strophurus ciliaris						x				
Strophurus elderi	Jewelled Gecko					x			x	
Strophurus wellingtonae						x				
CARPHODACTYLIDAE										
Nephrurus levis pilbarensis									x	
Nephrurus wheeleri cinctus	Banded Knob-tailed Gecko					x			x	
Nephrurus wheeleri wheeleri	Banded Knob-tailed Gecko					x			x	
GEKKONIDAE										
Gehyra pilbara						x			x	
Gehyra punctata	Spotted Rock Dtella					x			x	

Scientific name	Common name	Introduced	Conservation codes			Nature Map	EPBC Protected Matters Search	Birdlife	Previous surveys	Current survey
			EPBC Act	WC Act	Parks and Wildlife					
Gehyra variegata	Variegated Tree Dtella					x			x	
Hemidactylus frenatus	Asian House Gecko	*				x			x	
Heteronotia binoei	Bynoe's Gecko					x			x	x
Heteronotia spelea	Pilbara Cave Gecko					x			x	
PYGOPODIDAE										
Delma butleri									x	
Delma elegans						x			x	
Delma nasuta						x			x	
Delma pax						x			x	
Delma tincta						x			x	
Lialis burtonis	Burrton's Legless Lizard					x			x	
Pygopus nigiceps						x			x	
EUGONGYLIDAE										
Carlia munda						x			x	
Carlia triacantha						x				
Cryptoblepharus plagiocephalus									x	
Cryptoblepharus buchananii						x				
Cryptoblepharus ustulatus						x			x	
Menetia greyii						x			x	
Menetia surda surda						x			x	
Morethia ruficauda exquisita	Fire-tailed Skink					x			x	
AGAMIDAE										
Ctenotus brooksi						x				
Ctenotus calurus						x				
Ctenotus duricola						x			x	
Ctenotus grandis titan						x			x	
Ctenotus hanloni						x			x	
Ctenotus helenae						x			x	
Ctenotus pantherinus	Leopard Ctenotus					x			x	
Ctenotus rubicundus						x			x	

Scientific name	Common name	Introduced	Conservation codes			Nature Map	EPBC Protected Matters Search	Birdlife	Previous surveys	Current survey
			EPBC Act	WC Act	Parks and Wildlife					
Ctenotus quattuordecimlineatus						x				
Ctenotus saxatilis	Rock Ctenotus					x			x	
Ctenotus schomburgkii						x			x	
Ctenotus serventyi						x			x	
Eremiascincus isolepis						x			x	
Eremiascincus faciolatus									x	
Lerista bipes						x			x	
Lerista flammicauda						x			x	
Lerista ips						x				
Lerista muelleri						x			x	
Lerista verhmens						x				
Notoscincus butleri	Lined Soil-crevice Skink				P4	x			x	
Notoscincus ornatus						x			x	
EGERNIIDAE										
Cyclodomorphus melanops	Slender Blue-tongue					x			x	
Egernia cygnitos						x				
Ergenia depressa						x				
Ergenia formosa						x			x	
Ergenia pilbarensis	Pilbara Skink					x			x	
Tiliqua multifasciata	Central Blue-tongue					x			x	
VARANIDAE										
Varanus acanthurus	Spiny-tailed Monitor					x			x	
Varanus brevicauda	Short-tailed Pygmy Monitor					x			x	
Varanus bushi	Pilbara Mulga Monitor					x			x	
Varanus caudolineatus						x				
Varanus eremius	Pygmy Desert Monitor					x			x	
Varanus giganteus	Perentie					x			x	
Varanus gouldii	Bungarra					x			x	
Varanus hamersleyensis	Southern Pilbara Rock Monitor					x			x	

Scientific name	Common name	Introduced	Conservation codes			Nature Map	EPBC Protected Matters Search	Birdlife	Previous surveys	Current survey
			EPBC Act	WC Act	Parks and Wildlife					
Varanus panoptes panoptes						x			x	
Varanus pilbarensis									x	
Varanus tristis tristis	Racehorse Monitor					x			x	
TYPHLOPIDAE										
Anilios ammodytes						x			x	
Anilios ganei					P1	x			x	
Anilios grypus	Beaked Blind snake					x			x	
Anilios hamatus									x	
Anilios pilbarensis						x			x	
BOIDAE										
Antaresia perthensis	Pygmy Python					x			x	
Antaresia stimsoni stimsoni	Stimson's Python					x			x	
Aspidites melanocephalus	Black-headed python					x			x	
Liasis olivaceus barroni	Pilbara Olive Python		VU	S3		x	x		x	
ELAPIDAE										
Acanthopis wellsi	Pilbara Death Adder					x			x	
Brachyurophis approximans						x			x	
Demansia psammophis cupreiceps	Yellow-faced Whipsnake					x			x	
Demansia rufescens	Rufous Whipsnake					x			x	
Furina ornata	Moon Snake					x			x	
Parasuta monachus						x			x	
Pseudechis australis	Mulga Snake					x			x	
Pseudonaja mengdeni	Western Brown Snake					x			x	
Pseudonaja modesta	Ringed Brown Snake					x			x	
Pseudonaja nuchalis	Gwardar; Northern Brown Snake					x				
Simoselaps anomalus	Desert Banded Snake					x				
Suta fasciata	Rosen's Snake					x			x	
Suta punctata	Spotted Snake					x				

Table K.3: Bird species list – results of database searches, literature reviews and Astron survey results.

Scientific name	Common name	Introduced	Conservation codes			Nature Map	EPBC Protected Matters Search	Birdlife	Previous surveys	Current survey
			EPBC Act	WC Act	Parks and Wildlife					
DROMAIIDAE										
Dromaius novaehollandiae	Emu					x		x	x	
PHASIANIDAE										
Coturnix ypsilophora	Brown Quail					x			x	
ANATIDAE										
Anas gracilis	Grey Teal					x		x	x	
Anas superciliosa	Pacific Black Duck					x		x	x	x
Aytha australis	Hardhead					x		x		x
Cygnus atratus	Black Swan					x		x	x	
Chenonetta jubata	Australian Wood Duck					x			x	
Dendrocygna eytoni	Plumed Whistling Duck					x				
Dendrocygna arcuata	Wandering Whistling Duck								x	
Nettapus pulchellus	Green Pygmy Goose								x	
PODICIPEDIDAE										
Tachybaptus novaehollandiae	Australasian Grebe					x		x	x	x
Poliocephalus poliocephalus	Hoary-headed Grebe					x		x	x	
COLUMBIDAE										
Columba livia	Domestic Pigeon	*				x	x			
Geopelia cuneata	Diamond Dove					x		x	x	
Geopelia striata placida	Peaceful Dove					x		x	x	
Geophaps plumifera	Spinifex Pigeon					x		x	x	
Ocyphaps lophotes	Crested Pigeon					x		x	x	
Phaps chalcoptera	Common Bronzewing					x		x	x	x
Phaps histrionica	Flock Bronzewing					x				
PODARGIDAE										
Podargus strigoides	Tawny Frogmouth					x		x	x	
CAPRIMULGIDAE										
Eurostopodus argus	Spotted Nightjar					x			x	x

Scientific name	Common name	Introduced	Conservation codes			Nature Map	EPBC Protected Matters Search	Birdlife	Previous surveys	Current survey
			EPBC Act	WC Act	Parks and Wildlife					
AEGOTHELIDAE										
Aegotheles cristatus	Australian Owlet-nightjar					x			x	
APOPDIDAE										
Apus pacificus	Fork-tailed Swift		Mi	S5			x		x	
ANHINGIDAE										
Anhinga novaehollandiae	Darter					x		x	x	
PHALACROCORACIDAE										
Phalacrocorax melanoleucos	Little Pied Cormorant							x	x	
Phalacrocorax varius	Pied Cormorant							x	x	x
Phalacrocorax sulcirostris	Little Black Cormorant								x	
PELECANIDAE										
Pelecanus conspicillatus	Australian Pelican					x		x	x	x
CICONIIDAE										
Ephippiorhynchus asiaticus	Black-necked stork								x	
ARDEIDAE										
Ardea ibis	Cattle Egret		Mi	S5			x		x	
Ardea intermedia	Intermediate Egret					x	x		x	
Ardea modesta	Eastern Great Egret		Mi	S5		x	x	x	x	
Ardea garzetta	Little Egret					x			x	
Ardea novaehollandiae	White-faced Heron					x		x	x	x
Ardea pacifica	White-necked Heron					x		x	x	x
Butorides striata	Striated Heron							x		
Nycticorax caledonicus	Nankeen Night-heron					x		x	x	
THRESKIORNITHIDAE										
Platalea flavipes	Yellow-billed Spoonbill								x	
Threskiornis spinicollis	Straw-necked Ibis					x		x	x	
ACCIPITRIDAE										
Accipiter cirrocephalus	Collared Sparrowhawk					x			x	
Accipiter fasciatus fasciatus	Brown Goshawk					x		x	x	
Aquila audax	Wedge-tailed Eagle					x		x	x	

Scientific name	Common name	Introduced	Conservation codes			Nature Map	EPBC Protected Matters Search	Birdlife	Previous surveys	Current survey
			EPBC Act	WC Act	Parks and Wildlife					
Circus approximans	Swamp Harrier					x				
Circus assimilis	Spotted Harrier					x		x	x	
Elanus scriptus	Letter-winged Kite				P4	x				
Elanus caeruleus	Black-shouldered Kite					x			x	
Lophoictinia isura	Square-tailed Kite					x		x		
Haliaeetus leucogaster	White-bellied Sea Eagle						x	x	x	
Haliastur sphenurus	Whistling Kite					x		x	x	x
Haliastur indus	Brahminy Kite							x		
Hieraaetus morphnoides	Little Eagle					x		x	x	
Milvus migrans	Black Kite					x		x	x	
Panidon haliaetus	Eastern Osprey		Mi	S5			x			
FALCONIDAE										
Falco cenchroides cenchroides	Australian Kestrel					x		x	x	
Falco berigora berigora	Brown Falcon					x		x	x	
Falco longipennis	Australian Hobby					x		x	x	
RALLIDAE										
Gallirallus philippensis	Buff-banded Rail					x				
Fulica atra	Eurasian Coot					x		x	x	x
Porzana tabuensis	Spotless Crake					x			x	
Tribonyx ventralis	Black-tailed Native-hen								x	
OTIDIDAE										
Ardeotis australis	Australian Bustard					x		x	x	
BURHINIDAE										
Burhinus grallarius	Bush Stone-curlew					x			x	
RECURVIROSTRIDAE										
Himantopus himantopus	Black-winged Stilt					x			x	
CHARADRIIDAE										
Charadrius veredus	Oriental Plover		Mi	S5			x			
Charadrius ruficapillus	Red-capped Plover							x		
Charadrius leschenaultii	Greater Sand Plover		Mi	S5				x		

Scientific name	Common name	Introduced	Conservation codes			Nature Map	EPBC Protected Matters Search	Birdlife	Previous surveys	Current survey
			EPBC Act	WC Act	Parks and Wildlife					
Elseyornis melanops	Black-fronted Dotterel					x		x	x	
Erythrogonys cinctus	Red-kneed Dotterel								x	
Vanellus tricolor	Banded Lapwing					x		x		
CINCLOSOMATIDAE										
Psophodes occidentalis	Chiming Wedgebill					x				
ROSTRATULIDAE										
Rostratula benghalensis australis	Australian Painted Snipe		EN	S2			x			
SCOLOPACIDAE										
Actitis hypoleucos	Common Sandpiper					x		x		
Calidris acuminata	Sharp-tailed Sandpiper			S5		x				
Numenius phaeopus	Whimbrel			S5				x		
Tringa glareola	Wood Sandpiper			S5		x		x	x	
Tringa nebularia	Common Greenshank			S5				x		
TURNICIDAE										
Turnix velox	Little Button-quail					x		x	x	
GLAREOLIDAE										
Glareola maldivarum	Oriental Pratincole		Mi	S5			x			
PSITTACIDAE										
Platycercus zonarius zonarius	Australian Ringneck					x		x	x	x
Melopsittacus undulatus	Budgerigar					x		x	x	
Nymphicus hollandicus	Cockatiel					x		x	x	
Pezoporus occidentalis	Night Parrot		EN	S2		x	x			
CACATUIDAE										
Cacatua sanguinea	Little Corella					x		x	x	x
Cacatua roseicapilla	Galah					x		x	x	
CUCULIDAE										
Cacomantis pallidus	Pallid Cuckoo					x		x	x	
Chrysococcyxs basalis	Horsfield's Bronze Cuckoo					x		x	x	x
Chrysococcyxs osculans	Black-eared Cuckoo								x	
Centropus phasianinus	Pheasant Coucal							x	x	

Scientific name	Common name	Introduced	Conservation codes			Nature Map	EPBC Protected Matters Search	Birdlife	Previous surveys	Current survey
			EPBC Act	WC Act	Parks and Wildlife					
STRIGIDAE										
Ninox connivens	Barking Owl					x			x	
Ninox boobook boobook	Southern Boobook Owl					x		x	x	
TYTONIDAE										
Tyto javanica	Eastern Barn Owl					x				
ACLEDINIDAE										
Dacelo leachii leachii	Blue-winged Kookaburra					x		x	x	
Todiramphus pyrrhopygia	Red-backed Kingfisher					x		x	x	
Todiramphus sanctus	Sacred Kingfisher					x		x	x	
MEROPIDAE										
Merops ornatus	Rainbow Bee-eater		Mi	S5		x	x	x	x	x
PTILONORHYNCHIDAE										
Ptilonorhynchus maculatus guttatus	Western Bowerbird					x			x	
MALURIDAE										
Amytornis striatus	Striated Grasswren					x		x	x	
Malurus lamberti assimilis	Variegated Fairy-wren					x		x	x	x
Malurus leucopterus	White-winged Fairy-wren					x		x	x	
Stipiturus ruficeps	Rufous Crowned Emu-wren								x	
ACANTHIZIDAE										
Acanthiza apicalis	Inland Thornbill					x			x	
Acanthiza uropygialis	Chestnut-rumped Thornbill					x			x	
Gerygone fusca	Western Gerygone					x			x	x
Gerygone tenebrosa	Dusky Gerygone							x		
Smicrornis brevirostris	Weebill					x		x	x	x
PARDALOTIDAE										
Pardalotus punctatus	Spotted Pardalote					x				
Pardalotus rubricatus	Red-browed Pardalote					x		x	x	
Pardalotus striatus	Striated Pardalote					x			x	
MELIPHAGIDAE										

Scientific name	Common name	Introduced	Conservation codes			Nature Map	EPBC Protected Matters Search	Birdlife	Previous surveys	Current survey
			EPBC Act	WC Act	Parks and Wildlife					
Acanthagenys rufogularis	Spiny-cheeked Honeyeater					x		x	x	
Certhionyx variegatus	Pied Honeyeater					x			x	
Epthianura tricolor	Crimson Chat					x			x	
Ptilotula keartlandi	Grey-headed Honeyeater							x	x	
Ptilotula penicillatus	White-plumed Honeyeater							x	x	x
Gavicalis virescens	Singing Honeyeater							x	x	
Lichmera indistincta	Brown Honeyeater					x		x	x	x
Manorina flavigula	Yellow-throated Miner					x		x	x	
Melithreptus gularis	Black-chinned Honeyeater					x			x	
Sugomel niger	Black Honeyeater					x			x	
POMATOSTOMIDAE										
Pomatostomus supercilious	White-browed Babbler					x				
Pomatostomus temporalis	Grey-crowned Babbler					x		x	x	x
CAMPEPHAGIDAE										
Coracina maxima	Ground Cuckoo-shrike					x				
Coracina novaehollandiae	Black-faced Cuckoo-shrike					x		x	x	
Lalage tricolor	White-winged Triller					x		x	x	
PACHYCEPHALIDAE										
Colluricincla harmonica	Grey Shrike-thrush					x		x	x	x
Oreoica gutturalis	Crested Bellbird					x		x	x	
Pachycephala melanura	Mangrove Golden Whistler							x		
Pachycephala lanioides	White-breasted Whistler							x		
Pachycephala rufiventris	Rufous Whistler					x		x	x	x
Cincloramphus cruralis	Brown Songlark					x		x	x	
Cincloramphus mathewsi	Rufous Songlark					x		x	x	
ARTAMIDAE										
Artamus cinereus melanops	Black-faced Woodswallow					x		x	x	
Artamus leucorynchus	White-breasted Woodswallow							x	x	
Artamus minor	Little Woodswallow					x			x	

Scientific name	Common name	Introduced	Conservation codes			Nature Map	EPBC Protected Matters Search	Birdlife	Previous surveys	Current survey
			EPBC Act	WC Act	Parks and Wildlife					
Artamus personatus	Masked Woodswallow					x			x	
CRACTICIDAE										
Cracticus torquatus	Grey Butcherbird								x	
Cracticus nigrogularis	Pied Butcherbird					x		x	x	
Cracticus tibicen	Australian Magpie					x		x	x	
DICRURIDAE										
Rhipidura albiscapa	Grey Fantail					x			x	x
Rhipidura phasiana	Mangrove Grey Fantail							x		
Rhipidura leucophrys leucophrys	Willie Wagtail					x		x	x	x
Grallina cyanoleuca	Magpie-lark					x		x	x	x
CORVIDAE										
Corvus bennetti	Little Crow					x		x	x	
Corvus orru	Torresian Crow					x		x	x	x
PETROICIDAE										
Melanodryas cucullata	Hooded Robin					x			x	
Petroicas goodenovii	Red-capped Robin					x			x	
ALAUDIDAE										
Mirafra javanica	Horsfield's Bushlark					x		x	x	
Mirafra cantillans	Singing Bushlark								x	
ACROCEPHALIDAE										
Acrocephalus australis	Australian Reed Warbler								x	x
LOCUSTELLIDAE										
Eremiornis carteri	Spinifex-bird					x		x	x	
TIMALIIDAE										
Zosterops luteus	Yellow White-eye							x		
HIRUNDINIDAE										
Cheramoeca leucosternus	White-backed swallow					x				
Hirundo neoxena	Welcome Swallow							x	x	
Hirundo rustica	Barn Swallow		Mi	S5			x			
Petrochelidon ariel	Fairy Martin					x		x	x	

Scientific name	Common name	Introduced	Conservation codes			Nature Map	EPBC Protected Matters Search	Birdlife	Previous surveys	Current survey
			EPBC Act	WC Act	Parks and Wildlife					
Petrochelidon nigricans	Tree Martin					x		x	x	
DICAEIDAE										
Dicaeum hirundinaceum	Mistletoebird					x		x	x	
ESTRILDIDAE										
Emblema pictum	Painted Finch					x		x	x	
Neochmia ruficauda subclarescens	Star Finch (Western)					x		x	x	x
Taeniopygia guttata	Zebra Finch					x		x	x	
MOTACILLIDAE										
Anthus australis	Australian Pipit					x		x	x	

Table K.4: Mammal species list – results of database searches, literature reviews and Astron survey results.

Scientific name	Common name	Introduced	Conservation codes			Nature Map	EPBC Protected Matters Search	Birdlife	Previous surveys	Current survey
			EPBC Act	WC Act	Parks and Wildlife					
TACHYGLOSSIDAE										
Tachyglossus aculeatus	Short-beaked Echidna					x			x	
DASYURIDAE										
Dasycercus blythi	Brush-tailed Mulgara				P4	x				
Dasykaluta rosamondae	Little Red Kaluta					x			x	
Dasyurus hallucatus	Northern Quoll		EN	S2		x	x		x	
Ningaui ridei	Wongai Ningaui					x				
Ningaui timealeyi	Pilbara Ningaui					x			x	
Planigale ingrami	Long-tailed Planigale					x			x	
Planigale maculata	Common Planigale					x				
Planigale 'species 1'	Pilbara Planigale								x	
Pseudantechinus roryi	Rory's Pseudantechinus								x	
Pseudantechinus woolleyae	Woolley's Pseudantechinus					x			x	
Pseudantechinus sp.									x	
Sminthopsis longicaudata	Long-tailed Dunnart				P4	x				
Sminthopsis macroura	Stripe-faced Dunnart					x			x	
Sminthopsis youngsoni	Lesser Hairy-footed Dunnart					x			x	
THYLACOMYIDAE										
Macrotis lagotis	Greater Bilby, Dalgyte		VU	S3		x	x			
NOTORYCTIDAE										
Notoryctes caurinus	Northern Marsupial Mole		EN				x			
MACROPODIDAE										
Osphranter robustus erubescens	Euro, Biggada					x			x	
Osphranter rufus	Red Kangaroo, Marlu					x			x	
Petrogale rothschildi	Rothschild's Rock-wallaby					x			x	
PHALANGERIDAE										
Trichosurus vulpecula arnhemensis	Northern Brushtail Possum					x				
MEGADERMATIDAE										

Scientific name	Common name	Introduced	Conservation codes			Nature Map	EPBC Protected Matters Search	Birdlife	Previous surveys	Current survey
			EPBC Act	WC Act	Parks and Wildlife					
Macroderma gigas	Ghost Bat		VU	S3		x	x		x	
HIPPOSIDERIDAE										
Rhinonicteris aurantia	Pilbara Leaf-nosed Bat		VU	S3		x	x		x	
EMBALLONURIDAE										
Sacclaimus flaviventris	Yellow-bellied Sheathtail-bat					x			x	
Taphozous georgaianus	Common Sheathtail-bat					x			x	
VESPERTILIONIDAE										
Chalinolobus gouldii	Gould's Wattled Bat					x			x	
Nyctophilus daedalus	Northwestern Long-eared Bat								x	
Nyctophilus geoffroyi	Lesser Long-eared Bat					x			x	
Scotorepens greyii	Little Broad-nosed Bat					x			x	
Vespadelus finlaysoni	Finlayson's Cave Bat					x			x	
MOLOSSIDAE										
Chaerephon jobensis colonicus	Greater Northern Free-tailed Bat					x			x	
Ozimops lumsdenae	Northern Free-tailed Bat					x			x	
Tadarida australis	White-striped Freetail-bat					x			x	
MURIDAE										
Leggadina lakedownensis	Short-tailed Mouse				P4	x	x			
Mus musculus	House Mouse	*				x	x		x	
Notomys alexis	Spinifex Hopping-mouse					x			x	
Pseudomys chapmani	Western Pebble-mound Mouse				P4	x	x		x	
Pseudomys delicatus	Delicate Mouse					x			x	
Pseudomys desertor	Desert Mouse					x			x	
Pseudomys hermannsburgensis	Sandy Inland Mouse					x			x	
Zyzomys argurus	Common Rock-rat					x			x	
LEPORIDAE										
Oryctolagus cuniculus	Rabbit	*				x	x			
CANIDAE										
Canis dingo	Dingo	*				x			x	

Scientific name	Common name	Introduced	Conservation codes			Nature Map	EPBC Protected Matters Search	Birdlife	Previous surveys	Current survey
			EPBC Act	WC Act	Parks and Wildlife					
Canis familiaris	Dog	*							x	
Vulpes vulpes	Red Fox	*				x	x			
FELIDAE										
Felis catus	Cat	*				x	x		x	
CAMELIDAE										
Camelus dromedarius	Dromedary, Camel	*				x				
EQUIDAE										
Equus asinus	Donkey	*				x	x			
BOVIDAE										
Bos taurus	European Cattle	*				x			x	
Capra hircus	Goat	*					x			

Previous surveys

Astron 2011, Mesa J Tail Track Extension Vegetation, Flora and Fauna Survey
Astron 2014, Mesa H Level 1 Flora, Vegetation and Fauna Assessment
Astron 2016d, Mesa H Level 2 Fauna Survey
Astron 2016e, Bungaroo Iron Ore Mine and Infrastructure Project, Level 2 Fauna Survey
Astron 2016f, Middle Robe and East Deepdale Level 2 Fauna Assessment
Biologic 2014, Yarraloola Targeted Fauna Survey
Biota 2005, Fauna Habitats and Fauna Assemblage of Mesa A and Mesa G
Biota 2006b, Fauna Habitats and Fauna Assemblage of the Mesa A Transport Corridor and Warramboo
Biota 2007, Bungaroo Trial Pit and Transport Corridor to Mesa J, near Pannawonnica
Biota 2009, Mesa G Baseline Fauna Survey
Biota 2010a, Greater Bungaroo Seasonal Fauna Survey
Biota 2011, Robe Valley Mesas Fauna Survey
Ecologia Environment 2013, Middle Robe and East Deepdale Flora, Vegetation, Vertebrate and Invertebrate Fauna Survey

Appendix L: Threatened and Priority Fauna Species Records and Likelihood of Occurrence within the Survey Area

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405000 410000 415000 420000 425000 430000

7605000

7600000

7595000

7590000

Legend

Mesa H Riparian Community Survey Area

Conservation Significant Fauna Records (Current Survey)

Birds

Merops ornatus (Rainbow Bee-eater)

Conservation Significant Fauna Records (Previous Surveys)

Reptiles

Liasis olivaceus barroni (Pilbara Olive Python)

Notoscincus butleri (Lined Soil-crevice Skink)

Birds

Merops ornatus (Rainbow Bee-eater)

Ardea modesta (Eastern Great Egret)

Mammals

Rhinonicteris aurantia (Pilbara Leaf-nosed Bat)

Macroderma gigas (Ghost Bat)

Dasyurus hallucatus (Northern Quoll)

Robe River Mining Co. Pty Ltd

Mesa H Riparian Community Assessment - June 2016

Figure L.1: Threatened and Priority Fauna Species Records

Coordinate System: GDA94 MGA zone 50

0 1,000 2,000 3,000 4,000 Metres

N

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Author: J. Trainer | Drawn: W. An | Date: 06-04-2017 | Figure Ref: 14269-16-BIDR-1RevB_170406_FigL1_PFauna

Table L.1: Likelihood of occurrence of conservation listed vertebrate fauna species listed as potentially occurring in the vicinity of the survey area.

Scientific name (common name)	Conservation codes			Preferred habitat	Likelihood of occurrence	
	EPBC Act	WC Act	Parks and Wildlife		Pre-survey	Post-survey
Reptiles						
Notoscincus butleri (Lined Soil-crevice Skink)			P4	Arid, rocky, near coastal Pilbara regions. Associated with spinifex-dominated areas near creeks and river margins.	Low	Low
Anilios ganei (Blindsnake)			P1	Little information is available on this species but it is believed to be associated with moist gorges and gullies.	Low	Low
Liasis olivaceus barroni (Pilbara Olive Python)	VU	S3		Generally rocky habitats in close association to permanent and semi-permanent water sources.	High – previously recorded	High
Birds						
Apus pacificus (Fork-tailed Swift)	Mi	S5		Largely aerial species independent of the terrestrial environment.	Moderate	Moderate
Ardea ibis (Cattle Egret)	Mi	S5		Largely wetland species however can exploit drier open habitats more than other heron species.	Moderate	Moderate
Ardea modesta (Eastern Great Egret)	Mi	S5		Wide range of wetland habitats (for example inland and coastal, freshwater and saline, permanent and ephemeral).	High – previously recorded	High
Elanus scriptus (Letter-winged Kite)			P4	The Letter-winged Kite is a bird of open country and grasslands in arid and semi-arid Australia, where there are tree-lined streams or water courses.	Moderate	Moderate
Panidon haliaetus (Eastern Osprey)	Mi	S5		Favours coastal areas, especially the mouths of large rivers, lagoons and lakes.	Low	Low

Scientific name (common name)	Conservation codes			Preferred habitat	Likelihood of occurrence	
	EPBC Act	WC Act	Parks and Wildlife		Pre-survey	Post-survey
Charadrius veredus (Oriental Plover)	Mi	S5		Breeding habitat includes arid grasslands, saltpans; non-breeding habitat includes grasslands, salt-fields, and coastal regions.	Low	Low
Charadrius leschenaultii (Greater Sand Plover)	Mi	S5		This species is almost entirely coastal, inhabiting littoral and estuarine habitats. They mainly occur on sheltered sandy, shelly or muddy beaches with large intertidal mudflats or sandbanks, as well as sandy estuarine lagoons.	Low	Low
Rostratula benghalensis (sensu lato) (Australian Painted Snipe)	EN	S2		Shallow terrestrial freshwater wetlands, temporary/permanent lakes, swamps and claypans with emergent grass, sedges, rushes and samphire.	Moderate	Moderate
Actitis hypoleucos (Common Sandpiper)	Mi	S5		Non-breeding migrant to a wide variety of habitats, such as riverbanks, estuaries, freshwater seeps on coastal shores, tidal creeks, mangrove swamps and saltmarshes.	Moderate	Moderate
Calidris acuminata (Sharp-tailed Sandpiper)	Mi	S5		Muddy edges of shallow fresh/brackish wetlands with emergent sedges, saltmarsh, grass and low vegetation.	Moderate	Moderate
Numenius phaeopus (Whimbrel)	Mi	S5		Primarily found in coastal habitats such as beaches, dunes, mudflats and mangroves however there are also scattered inland records.	Low	Low
Tringa glareola (Wood Sandpiper)	Mi	S5		Occurs mainly on freshwater wetlands of the inland interior and arid regions.	Moderate	Moderate
Tringa nebularia (Common Greenshank)	Mi	S5		Inland wetlands and coastal habitats of varying salinity. Typically large mudflats, saltmarsh, mangroves and seagrass	Moderate	Moderate
Glareola maldivarum (Oriental Pratincole)	Mi	S5		Feeds in the air and roosts on bare ground besides water	Moderate	Moderate

Scientific name (common name)	Conservation codes			Preferred habitat	Likelihood of occurrence	
	EPBC Act	WC Act	Parks and Wildlife		Pre-survey	Post-survey
Merops ornatus (Rainbow Bee-eater)	Mi	S5		Lightly wooded, preferably sandy soil, near drainage channels and creek lines.	High – previously recorded	Recorded
Hirundo rustica (Barn Swallow)	Mi	S5		Coastal open country generally, especially near surface water and man-made structures such as bridges and power wires.	Low	Low
Mammals						
Dasycercus blythi (Brush-tailed Mulgara)			P4	Triodia hummock and Acacia shrublands of sand or sandy-loam.	Low	Low
Dasyurus hallucatus (Northern Quoll)	EN	S2		Dissected rocky escarpments and rocky eucalypt woodland.	High – previously recorded	High
Sminthopis longicaudata (Long-tailed Dunnart)			P4	Common in rocky screes with hummock grassland and Acacia shrubs, tall open shrubland and woodlands.	Low	Low
Macrotis lagotis (Greater Bilby, Dalgyte)	VU	S3		Sand or sandy-loam in hummock grassland (Triodia species) and or Acacia shrublands.	Low	Low
Notoryctes caurinus (Northern Marsupial Mole)	EN			Lives primarily underground of sand dunes and sandy soils along river flats.	Low	Low
Macroderma gigas (Ghost Bat)	VU	S3		A wide range from rainforest, monsoon and vine scrub in the tropics to open woodlands and arid areas.	High – previously recorded	High
Rhinonicteris aurantia (Pilbara form) (Pilbara Leaf-nosed Bat)	VU	S3		Deep warm, humid caves or rock cracks.	High – previously recorded	High

Scientific name (common name)	Conservation codes			Preferred habitat	Likelihood of occurrence	
	EPBC Act	WC Act	Parks and Wildlife		Pre-survey	Post-survey
Leggadina lakedownensis (Short-tailed Mouse, Karekanga)			P4	Open tussock and hummock grassland, Acacia shrubland and savannah woodland on alluvial clay/sandy soils.	Low	Low
Pseudomys chapmani (Western Pebble-mound Mouse)			P4	Gentle rocky slopes, hills and spurs with small pebble surface cover and sparse vegetation.	Low	Low

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Appendix M: Vegetation Association Mapping

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410000 415000 420000 425000 430000

7600000 7595000 7590000

Legend

- Survey Site
- Railway
- Main Road
- River/Creek
- Mesa H Riparian Community Survey Area

Vegetation Association Mapping

- AtrPl
- EcEvAtrApyPlTw
- Es
- EvAtrTwCspp
- MaEcCv
- Disturbed

Pannawonica

Pannawonica

Robe River

Robe River

MH363 MH203 MH204 MH337r MH397 MH398 MH354 MH379 MH332 MH321 MH385 MH44 MH43 MH394 MH303 MH381 MH384 MH388 MH387 MH389 Millstream Rd MH393 MH401 MH392 MH373 AM215 E20 E07 E09 Jimmawurrada Creek Jungroo Creek

Robe River Mining Co. Pty Ltd

Mesa H Riparian Community Assessment - June 2016

Figure M.1: Vegetation Association Mapping

Datum: GDA 1994 - Projection: MGA Zone 50

0 500 1,000 1,500 2,000 2,500 3,000 metres

N

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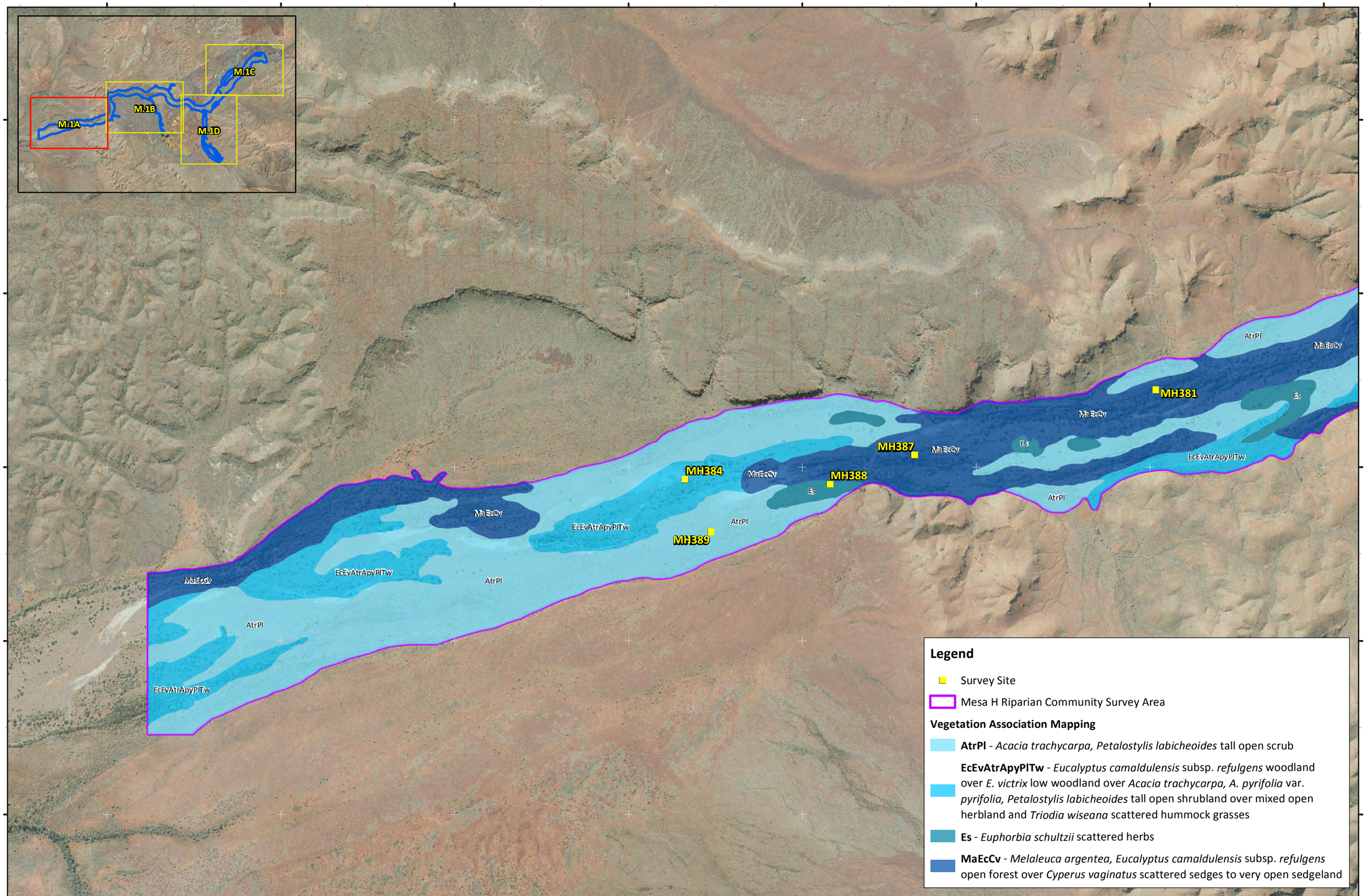
Author: D. Roocke | Drawn: W. An | Date: 06-04-2017 | Figure Ref: 14269-16-BIDR-1RevB_170406_FigM1_VegAsso



Robe River Mining Co. Pty Ltd

Mesa H Riparian Community Assessment - June 2016

Figure M.1A: Vegetation Association Mapping

Datum: GDA 1994 - Projection: MGA Zone 50

0 500 1,000 metres

N

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Author: D. Roocke | Drawn: W. An | Date: 06-04-2017 | Figure Ref: 14269-16-BIDR-1RevB_170406_FigM1_VegAsso_Subset

415000 416000 417000 418000 419000 420000 421000

7599000 7598000 7597000 7596000 7595000

MH203 MH204 MH363 MH397 MH398 MH354 MH379 MH337r MH385 MH44 MH43 MH303 MH332 MH321 MH394

Millstream Rd

AtrPl Disturbed EcEvAtrApyPlTw MaEcCv Es

M.1A M.1B M.1C M.1D

Legend

- Survey Site
- Railway
- Main Road
- Main Road
- Mesa H Riparian Community Survey Area

Vegetation Association Mapping

- **AtrPl** - *Acacia trachycarpa, Petalostylis labicheoides* tall open scrub
- **EcEvAtrApyPlTw** - *Eucalyptus camaldulensis* subsp. *refulgens* woodland over *E. victrix* low woodland over *Acacia trachycarpa, A. pyrifolia* var. *pyrifolia, Petalostylis labicheoides* tall open shrubland over mixed open herbland and *Triodia wiseana* scattered hummock grasses
- **Es** - *Euphorbia schultzii* scattered herbs
- **MaEcCv** - *Melaleuca argentea, Eucalyptus camaldulensis* subsp. *refulgens* open forest over *Cyperus vaginatus* scattered sedges to very open sedgeland
- **Disturbed**

Robe River Mining Co. Pty Ltd

Mesa H Riparian Community Assessment - June 2016

Figure M.1B: Vegetation Association Mapping

Datum: GDA 1994 - Projection: MGA Zone 50

0 500 1,000 metres

N

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Author: D. Roocke | Drawn: W. An | Date: 06-04-2017 | Figure Ref: 14269-16-BIDR-1RevB_170406_FigM1_VegAsso_Subset

425000 426000 427000 428000 429000 430000 431000

7602000 7601000 7600000 7599000 7598000

M.1A M.1B M.1C M.1D

E20 E07 E09

Disturbed
AtrPl
EcEvAtrApyPlTw
MaEcCv

Legend

- Survey Site
- Railway
- Main Road
- Mesa H Riparian Community Survey Area

Vegetation Association Mapping

- **AtrPl** - *Acacia trachycarpa, Petalostylis labicheoides* tall open scrub
- **EcEvAtrApyPlTw** - *Eucalyptus camaldulensis* subsp. *refulgens* woodland over *E. victrix* low woodland over *Acacia trachycarpa, A. pyrifolia* var. *pyrifolia, Petalostylis labicheoides* tall open shrubland over mixed open herbland and *Triodia wiseana* scattered hummock grasses
- **MaEcCv** - *Melaleuca argentea, Eucalyptus camaldulensis* subsp. *refulgens* open forest over *Cyperus vaginatus* scattered sedges to very open sedgeland
- **Disturbed**

Robe River Mining Co. Pty Ltd

Mesa H Riparian Community Assessment - June 2016

Figure M.1C: Vegetation Association Mapping

Datum: GDA 1994 - Projection: MGA Zone 50

0 500 1,000 metres

N

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Author: D. Roocke | Drawn: W. An | Date: 06-04-2017 | Figure Ref: 14269-16-BIDR-1RevB_170406_FigM1_VegAsso_Subset

422000 423000 424000 425000 426000 427000

7597000 7596000 7595000 7594000 7593000 7592000 7591000

AtrPl
EvAtrTwCspp
Es
EcEvAtrApyPlTw
MaEcCv
Disturbed
AtrPl
EcEvAtrApyPlTw
MaEcCv
Disturbed
EcEvAtrApyPlTw
AtrPl
MaEcCv
AtrPl
AM215
EcEvAtrApyPlTw
AtrPl
Es
MH393
MH401
MH392
MH373
EvAtrTwCspp
EcEvAtrApyPlTw
M.1C
M.1B
M.1A
M.1D

Legend

- Survey Site
- Railway
- Main Road
- Mesa H Riparian Community Survey Area

Vegetation Association Mapping

- **AtrPl** - *Acacia trachycarpa, Petalostylis labicheoides* tall open scrub
- **EcEvAtrApyPlTw** - *Eucalyptus camaldulensis* subsp. *refulgens* woodland over *E. victrix* low woodland over *Acacia trachycarpa, A. pyrifolia* var. *pyrifolia, Petalostylis labicheoides* tall open shrubland over mixed open herbland and *Triodia wiseana* scattered hummock grasses
- **Es** - *Euphorbia schultzii* scattered herbs
- **EvAtrTwCspp** - *Eucalyptus victrix* low open woodland over *Acacia trachycarpa* tall open shrubland over *Triodia wiseana* open hummock grassland and **Cenchrus* spp. very open tussock grassland
- **MaEcCv** - *Melaleuca argentea, Eucalyptus camaldulensis* subsp. *refulgens* open forest over *Cyperus vaginatus* scattered sedges to very open sedgeland
- **Disturbed**

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Mesa H Riparian Community Assessment - June 2016

Figure M.1D: Vegetation Association Mapping

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Author: D. Roocke	Date: 06-04-2017
Drawn: W. An	Figure Ref: 14269-16-BIDR-1RevB_170406_FigM1_VegAsso_Subset_4

Coordinate System: GDA94 MGA zone 50

0 200 400 600 800 1,000 Metres

N

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Appendix N: Vegetation and Flora Sample Site Data

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Site: MH43
Location: Map 4 **Type:** 20x125m Quadrat
Date: 2016-05-04 **Described by:** JA/LV
MGA Zone: 50 **Easting:** 419042 **Northing:** 7596362
Habitat: Major creek
Soil: Brown sandy loam
Rock type: Ironstone
Vegetation: *Eucalyptus camaldulensis* subsp. *refulgens* and *Eucalyptus victrix* woodland over *Acacia trachycarpa* scattered tall shrubs over **Cenchrus ciliaris* and **C. setiger* very open tussock grassland with *Cyperus vaginatus* scattered sedges.
Veg Condition: Good
Fire Age: >10 years

Species List

Name	Cover (%)	Height (m)
Abutilon sp. Dioicum (A.A. Mitchell PRP 1618)	0.5	0.1
Acacia bivenosa	0.5	1.5
Acacia colei var. *ileocarpa*	0.5	2.2
Acacia elachantha	0.5	2.0
Acacia pyrifolia var. *pyrifolia*	0.5	1.2
Acacia trachycarpa	1	2.5
Capparis spinosa var. *nummularia*	0.5	0.15
**Cenchrus ciliaris*	1	0.15
**Cenchrus setiger*	1	0.2
**Citrullus colocynthis*	0.5	0.1
Cleome viscosa	0.5	0.1
Corchorus lasiocarpus subsp. *parvus*	0.5	0.1
Cucumis variabilis	0.5	0.15
Cyperus vaginatus	1	0.5
Eucalyptus camaldulensis subsp. *refulgens*	14	10.0
Eucalyptus victrix	14	10.0
Euphorbia schultzii	0.5	0.1
Evolvulus alsinoides var. *villosicalyx*	0.5	0.02
Gossypium robinsonii	0.5	0.05
Hybanthus aurantiacus	0.5	0.2
Melaleuca glomerata	0.5	3.5
Notoleptopus decaisnei var. Orbicularis (A.B. Craig 428)	0.5	0.15
Petalostylis labicheoides	0.5	1.7
Phyllanthus maderaspatensis	0.5	0.1

Name	Cover (%)	Height (m)
Pterocaulon sp.	0.5	0.1
Ptilotus astrolasius	0.5	0.3
Ptilotus axillaris	0.5	0.1
Ptilotus nobilis subsp. *nobilis*	0.5	0.15
Solanum diversiflorum	0.5	0.15
Solanum horridum	0.5	0.12
Stylobasium spathulatum	0.5	1.7
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	0.5	0.25
Triodia epactia	0.5	0.5
Triumfetta appendiculata	0.5	0.4
Waltheria indica	0.5	0.01

* denotes weed species
? denotes unconfirmed ID

Site: MH44
Location: NA **Type:** 20x125m Quadrat
Date: 2016-05-04 **Described by:** JA
MGA Zone: 50 **Easting:** 418862 **Northing:** 7596737
Habitat: Major creek
Soil: Orange brown sandy clay loam
Rock type: NA
Vegetation: *Eucalyptus camaldulensis* subsp. *refulgens, E. victrix* low woodland over *Acacia trachycarpa* and *A. bivenosa* scattered tall shrubs to tall open shrubland over **Cenchrus ciliaris* and **C. setiger* very open tussock grassland.
Veg Condition: Good
Fire Age: >10 years

Species List

Name	Cover (%)	Height (m)
Abutilon lepidum	0.5	0.2
Abutilon sp. Dioicum (A.A. Mitchell PRP 1618)	0.5	0.7
Acacia bivenosa	1	2.2
Acacia pyrifolia var. *pyrifolia*	0.5	2.3
Acacia trachycarpa	2	3.8
**Cenchrus ciliaris*	2	0.15
**Cenchrus setiger*	1	0.15
Cleome viscosa	0.5	0.1
Corchorus lasiocarpus subsp. *parvus*	0.5	0.5
Cyperus vaginatus	0.5	0.7
Eriachne mucronata	0.5	0.4
Eucalyptus camaldulensis subsp. *refulgens*	20	11.0
Eucalyptus victrix	7	9.0
Flueggea virosa subsp. *melanthesoides*	0.5	1.4
Gossypium robinsonii	0.5	0.3
Hybanthus aurantiacus	0.5	0.1
**Malvastrum americanum*	0.5	0.15
Melaleuca glomerata	0.5	2.4
Notoleptopus decaisnei var. Orbicularis (A.B. Craig 428)	0.5	0.1
Petalostylis labicheoides	0.5	2.3
Phyllanthus maderaspatensis	0.5	0.25
Pterocaulon sphaeranthoides	0.5	0.1
Ptilotus nobilis subsp. *nobilis*	0.5	0.05
Rhynchosia minima	0.5	0.1

Name	Cover (%)	Height (m)
Solanum cleistogamum	0.5	0.15
Solanum diversiflorum	0.5	0.3
Solanum horridum	0.5	0.15
Stylobasium spathulatum	0.5	1.1
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	0.5	0.15
Themeda triandra	0.5	0.9
Triodia epactia	0.5	0.5
Triumfetta appendiculata	0.5	0.15
**Vachellia farnesiana*	0.5	1.8
Waltheria indica	0.5	0.1

* denotes weed species
? denotes unconfirmed ID

Site: MH203
Location: Map 4 **Type:** 50x50m Quadrat
Date: 2016-05-02 **Described by: DR/LV**
MGA Zone: 50 **Easting:** 418754 **Northing:** 7598544
Habitat: Major creek
Soil: Red brown sand
Rock type: Ironstone
Vegetation: *Acacia trachycarpa* and *A. bivenosa* tall open scrub.
Veg Condition: Excellent
Fire Age: >10 years

Species List

Name	Cover (%)	Height (m)
Acacia bivenosa	1	2.1
Acacia pyrifolia var. *pyrifolia*	0.5	2.2
Acacia trachycarpa	35	4.5
Adriana tomentosa	0.5	1.3
**Cenchrus setiger*	0.5	0.4
Cleome viscosa	0.5	0.2
Corchorus lasiocarpus subsp. *parvus*	0.5	0.3
Euphorbia schultzii	0.5	0.15
Hybanthus aurantiacus	0.5	0.2
Ptilotus auriculifolius	0.5	0.3
Rhynchosia bungarensis P4	0.5	0.4

* denotes weed species
? denotes unconfirmed ID

Site: MH204
Location: NA **Type:** 50x50m Quadrat
Date: 2016-05-03 **Described by:** DR/KMc
MGA Zone: 50 **Easting:** 417491 **Northing:** 7598178
Habitat: Major creek
Soil: Red brown sandy loam
Rock type: NA
Vegetation: *Melaleuca argentea* and *Eucalyptus camaldulensis* subsp. *refulgens* open forest over *Acacia trachycarpa* tall open shrubland over *Cyperus vaginatus* scattered sedges.
Veg Condition: Very Good
Fire Age: No fire evident

Species List

Name	Cover (%)	Height (m)
Acacia bivenosa	0.5	1.5
Acacia synchronicia	0.5	0.3
Acacia trachycarpa	3	2.5
**Cenchrus ciliaris*	0.5	0.2
Cleome viscosa	0.5	0.5
Cyperus vaginatus	1	0.9
Eucalyptus camaldulensis subsp. *refulgens*	10	17
Euphorbia australis	0.5	
Euphorbia biconvexa	0.5	0.1
**Euphorbia hirta*	0.5	0.1
Euphorbia schultzii	0.5	0.2
Ipomoea muelleri	0.5	0.3
Lobelia sp.	0.5	0.2
Melaleuca argentea	40	18
**Passiflora foetida* var. *hispida*	0.5	0.9
Petalostylis labicheoides	0.5	1.8
Phyllanthus maderaspatensis	0.5	0.2
Pluchea rubelliflora	0.5	0.2
Rhynchosia bungarensis P4	0.5	0.3
Sesbania formosa	0.5	6.7
Stemodia grossa	0.5	0.2
Streptoglossa liatroides	0.5	0.3
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	0.5	1.0
Tephrosia sp. Fortescue (A.A. Mitchell 606)	0.5	
Vigna lanceolata var. *lanceolata*	0.5	0.3

Name	Cover (%)	Height (m)
Waltheria indica	0.5	0.6

* denotes weed species
? denotes unconfirmed ID

Site: MH303
Location: NA **Type:** 25x100m Quadrat
Date: 2016-04-29 **Described by:** JA/KMc
MGA Zone: 50 **Easting:** 419534 **Northing:** 7595539
Habitat: Minor creek
Soil: Red brown silty loam
Rock type: Ironstone
Vegetation: *Eucalyptus camaldulensis* subsp. *refulgens* low open forest over *Acacia trachycarpa* and *Petalostylis labicheoides* tall open shrubland over Melaleuca glomerata and *A. bivenosa* open shrubland over *Triumfetta clementii* scattered low shrubs over **Cenchrus setiger* tussock grassland with *Cyperus vaginatus* scattered sedges.
Veg Condition: Good
Fire Age: >10 years

Species List

Name	Cover (%)	Height (m)
Abutilon lepidum	0.5	0.3
Abutilon sp. Dioicum (A.A. Mitchell PRP 1618)	0.5	2.0
Acacia bivenosa	1	1.2
Acacia colei var. *ileocarpa*	0.5	2.2
Acacia pyrifolia var. *pyrifolia*	0.5	1.5
Acacia trachycarpa	1	2.1
Boerhavia coccinea	0.5	0.1
Cleome viscosa	0.5	0.6
**Cenchrus ciliaris*	0.5	0.1
**Cenchrus setiger*	32	0.4
Corchorus lasiocarpus subsp. *parvus*	0.5	0.2
Cucumis variabilis	0.5	
Cymbopogon ambiguus	0.5	0.7
Cyperus vaginatus	1	0.6
Dactyloctenium radulans	0.5	0.2
**Echinochloa colona*	0.5	0.1
Eriachne mucronata	0.5	0.4
Eucalyptus camaldulensis subsp. *refulgens*	40	7.0
Eulalia aurea	0.5	0.6
**Euphorbia hirta*	0.5	0.05
Euphorbia schultzii	0.5	0.15
Ficus aculeata var. *indecora*	0.5	1.0
Flueggea virosa subsp. *melanthesoides*	0.5	0.4

Name	Cover (%)	Height (m)
Gomphrena cunninghamii	0.5	0.05
Gossypium robinsonii	0.5	0.1
Hybanthus aurantiacus	0.5	0.3
Ipomoea muelleri	0.5	0.2
Lepidium pholidogynum	0.5	0.1
Lobelia arnhemiaca	0.5	0.05
**Malvastrum americanum*	0.5	0.3
Melaleuca glomerata	1	1.2
Notoleptopus decaisnei var. Orbicularis (A.B. Craig 428)	0.5	0.05
Paraneurachne muelleri	0.5	0.5
Paspalidium clementii	0.5	0.2
Petalostylis labicheoides	1	2.3
Phyllanthus maderaspatensis	0.5	0.25
Ptilotus appendiculatus	0.5	0.1
Ptilotus sp.	0.5	0.1
**Setaria verticillata*	0.5	0.4
Sida sp. Articulation below (A.A. Mitchell PRP 1605)	0.5	0.3
Solanum diversiflorum	0.5	0.45
Solanum horridum	0.5	0.15
**Sonchus oleraceus*	0.5	0.15
Stylobasium spathulatum	0.5	2.0
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	0.5	0.5
Themeda triandra	0.5	0.9
Trachymene oleracea subsp. *oleracea*	0.5	0.65
Triodia wiseana	0.5	0.6
Triumfetta appendiculata	0.5	0.8
Triumfetta clementii	1	0.1
Triumfetta sp.	0.5	0.2
**Vachellia farnesiana*	0.5	0.5
Waltheria indica	0.5	0.15

* denotes weed species
? denotes unconfirmed ID

Site: MH321
Location: NA **Type:** 40x60m Quadrat
Date: 2016-05-11 **Described by:** JA/DR
MGA Zone: 50 **Easting:** 414835 **Northing:** 7596664
Habitat: Major creek
Soil: Brown loamy sand
Rock type: NA
Vegetation: *Petalostylis labicheoides* and *Acacia trachycarpa* tall shrubland.
Veg Condition: Very Good
Fire Age: >10 years

Species List

Name	Cover (%)	Height (m)
Acacia bivenosa	0.5	1.6
Acacia synchronicia	0.5	3.4
Acacia trachycarpa	6	2.5
Acacia trachycarpa x *tumida* var. *pilbarensis*	0.5	1.0
**Cenchrus ciliaris*	0.5	0.4
**Cenchrus setiger*	0.5	0.5
Cleome viscosa	0.5	0.2
Corchorus lasiocarpus subsp. *parvus*	0.5	0.5
**Cynodon dactylon*	0.5	0.1
Euphorbia schultzii	0.5	0.1
Gomphrena cunninghamii	0.5	0.15
Petalostylis labicheoides	8	2.2
Ptilotus astrolasius	0.5	0.5
Ptilotus nobilis subsp. *nobilis*	0.5	0.5
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	0.5	0.7
Triodia epactia	0.5	0.3
Triodia wiseana	0.5	0.4
Triumfetta ?*chaetocarpa*	0.5	0.5

* denotes weed species
? denotes unconfirmed ID

Site: MH332
Location: NA **Type:** 50x50m Quadrat
Date: 2016-05-11 **Described by:** JA/DR
MGA Zone: 50 **Easting:** 414398 **Northing:** 7597069
Habitat: Major creek
Soil: Red brown silty clay loam
Rock type: NA
Vegetation: *Melaleuca argentea* open forest over *Acacia trachycarpa* and *Petalostylis labicheoides* tall open shrubland over *Cyperus vaginatus* scattered sedges.
Veg Condition: Excellent
Fire Age: >10 years

Species List

Name	Cover (%)	Height (m)
Abutilon sp. Dioicum (A.A. Mitchell PRP 1618)	0.5	2.5
Acacia bivenosa	0.5	2.8
Acacia pyrifolia var. *pyrifolia*	0.5	1.5
Acacia trachycarpa	2	2.8
Capparis spinosa var. *nummularia*	0.5	0.5
**Cenchrus ciliaris*	0.5	0.45
Cleome viscosa	0.5	0.2
Corchorus crozophorifolius	0.5	1.1
**Cynodon dactylon*	0.5	0.1
Cyperus vaginatus	1	1.0
Eleocharis geniculata	0.5	0.08
Eucalyptus sp.	0.5	5.5
Eucalyptus victrix	0.5	5.5
Euphorbia schultzii	0.5	0.3
Gossypium robinsonii	0.5	2.5
Helichrysum luteoalbum	0.5	0.15
Ipomoea muelleri	0.5	
Jasminum didymum subsp. *lineare*	0.5	1.2
**Lactuca serriola*	0.5	0.2
Lobelia arnhemiaca	0.5	
Melaleuca argentea	32	15.0
**Passiflora foetida* var. *hispida*	0.5	
Petalostylis labicheoides	1	2.5
Phyllanthus maderaspatensis	0.5	0.2
Pluchea rubelliflora	0.5	0.2

Name	Cover (%)	Height (m)
Rhynchosia bungarensis P4	0.5	
Schoenoplectus subulatus	0.5	1.4
Sesbania formosa	0.5	4.5
Stemodia grossa	0.5	0.1
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	0.5	1.1
Trachymene oleracea subsp. *oleracea*	0.5	1.0
Triumfetta appendiculata	0.5	1.3
Triumfetta johnstonii	0.5	1.3
Typha domingensis	0.5	1.5
**Vachellia farnesiana*	0.5	0.7
Vigna lanceolata var. *lanceolata*	0.5	

* denotes weed species
? denotes unconfirmed ID

Site: MH337r
Location: NA **Type:** 50x50m Relevé
Date: 2016-05-05 **Described by:** DR/KMc
MGA Zone: 50 **Easting:** 419227 **Northing:** 7597959
Habitat: Major creek
Soil: Red brown silty clay loam
Rock type: NA
Vegetation: *Melaleuca argentea* open forest over *Cyperus vaginatus* scattered sedges.
Veg Condition: Very Good
Fire Age: >10 years

Species List

Name	Cover (%)	Height (m)
Acacia trachycarpa	0.5	1.5
**Argemone ochroleuca* subsp. *ochroleuca*	0.5	0.8
**Cenchrus setiger*	0.5	0.6
***Cucumis** variabilis*	0.5	0.1
Cymbopogon ambiguus	0.5	0.5
Cyperus vaginatus	1	1.0
Ipomoea muelleri	0.5	
Lobelia arnhemiaca	0.5	
Melaleuca argentea	50	25
**Passiflora foetida* var. *hispida*	0.5	
Petalostylis labicheoides	0.5	1.5
Phyllanthus maderaspatensis	0.5	0.5
Rhynchosia bungarensis P4	0.5	0.3
Stemodia grossa	0.5	0.5
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	0.5	1.2
Trachymene oleracea subsp. *oleracea*	0.5	1.1
Vigna lanceolata var. *lanceolata*	0.5	

* denotes weed species
? denotes unconfirmed ID

Site: MH354
Location: Map 4 in river north of Mesa h **Type:** 50x50m Quadrat
Date: 2016-05-05 **Described by:** DR/KMc
MGA Zone: 50 **Easting:** 418262 **Northing:** 7597672
Habitat: Major creek
Soil: Red brown sandy loam
Rock type: Ironstone
Vegetation: *Acacia trachycarpa* and *Petalostylis labicheoides* tall open scrub.
Veg Condition: Very Good
Fire Age: No fire evident

Species List

Name	Cover (%)	Height (m)
Acacia bivenosa	0.5	1.3
Acacia trachycarpa	32	3.0
**Cenchrus ciliaris*	0.5	0.3
**Cenchrus setiger*	0.5	0.2
Cleome viscosa	0.5	0.2
Corchorus lasiocarpus subsp. *parvus*	0.5	1.1
Cymbopogon ambiguus	0.5	0.8
Enneapogon caerulescens	0.5	0.3
Eucalyptus camaldulensis subsp. *refulgens*	0.5	5.0
Euphorbia schultzii	0.5	0.3
Indigofera monophylla	0.5	0.4
Petalostylis labicheoides	1	2.8
Phyllanthus maderaspatensis	0.5	0.3
Ptilotus nobilis subsp. *nobilis*	0.5	0.1
Rhynchosia bungarensis P4	0.5	0.5
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	0.5	0.6
Triodia epactia	0.5	0.4

* denotes weed species
? denotes unconfirmed ID

Site: MH363
Location: Map 3 **Type:** 50x50m Quadrat
Date: 2016-05-03 **Described by:** DR/KMc
MGA Zone: 50 **Easting:** 415908 **Northing:** 7598273
Habitat: Major creek
Soil: Red brown sandy loam
Rock type: NA
Vegetation: *Melaleuca argentea* and *Eucalyptus camaldulensis* subsp. *refulgens* open forest over *Acacia trachycarpa* scattered tall shrubs shrubland over *Cyperus vaginatus* scattered sedges.
Veg Condition: Very Good
Fire Age: No fire evident

Species List

Name	Cover (%)	Height (m)
Acacia trachycarpa	1	2.3
**Argemone ochroleuca* subsp. *ochroleuca*	0.5	0.1
Cleome viscosa	0.5	0.2
Corchorus lasiocarpus subsp. *parvus*	0.5	1.9
**Cynodon dactylon*	0.5	0.1
Cyperus vaginatus	1	0.9
Eucalyptus camaldulensis subsp. *refulgens*	2	11.0
**Euphorbia hirta*	0.5	0.1
Gossypium robinsonii	0.5	2.3
Heliotropium pachyphyllum	0.5	0.2
Melaleuca argentea	62	14.0
**Passiflora foetida* var. *hispida*	0.5	1.0
Petalostylis labicheoides	0.5	2.5
Phyllanthus maderaspatensis	0.5	0.2
Pluchea rubelliflora	0.5	0.2
Ptilotus sp.	0.5	0.1
Sesbania formosa	0.5	4.5
Sporobolus australasicus	0.5	0.1
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	0.5	1.5
Trachymene oleracea subsp. *oleracea*	0.5	0.3
Vigna lanceolata var. *lanceolata*	0.5	0.5
Wahlenbergia tumidifructa	0.5	0.2

* denotes weed species
? denotes unconfirmed ID

Site: MH373
Location: Map 11 in Bungaroo creek **Type:** 50x50m Quadrat
Date: 2016-05-10 **Described by:** KMc/LV
MGA Zone: 50 **Easting:** 424165 **Northing:** 7592224
Habitat: Major creek
Soil: Brown silty clay
Rock type: NA
Vegetation: *Eucalyptus victrix* and *E. camaldulensis* subsp. *refulgens* woodland over **Cenchrus* sp. open tussock grassland.
Veg Condition: Poor
Fire Age: No fire evident

Species List

Name	Cover (%)	Height (m)
Abutilon sp.	0.5	0.1
Acacia colei var. *ileocarpa*	0.5	0.5
Acacia pyrifolia var. *pyrifolia*	0.5	0.8
Acacia trachycarpa	0.5	2.5
Cenchrus sp.	25	0.1
Cyperus vaginatus	0.5	0.5
**Echinochloa colona*	0.5	0.05
Eucalyptus camaldulensis subsp. *refulgens*	6	13.0
Eucalyptus victrix	6	13.0
**Euphorbia hirta*	0.5	0.2
Gossypium robinsonii	0.5	0.7
Hakea chordophylla	0.5	9.0
Hybanthus aurantiacus	0.5	0.4
Indigofera boviperda	0.5	0.5
Ipomoea polymorpha	0.5	0.05
**Malvastrum americanum*	0.5	0.1
Marsilea sp.	0.5	0.02
Mollugo molluginea	0.5	0.05
Phyllanthus maderaspatensis	0.5	0.1
Phyllanthus sp.	0.5	0.01
Pterocaulon sp.	0.5	0.1
Sida fibulifera	0.5	0.05
Solanum cleistogamum	0.5	0.2
**Vachellia farnesiana*	0.5	0.1
Vigna lanceolata var. *lanceolata*	0.5	0.05

* denotes weed species
? denotes unconfirmed ID

Site: MH379
Location: Map 4 in river north east of mesa h **Type:** 60x40m Quadrat
Date: 2016-05-05 **Described by:** DR/KMc
MGA Zone: 50 **Easting:** 418345 **Northing:** 7597456
Habitat: Major creek
Soil: Red brown sandy loam
Rock type: Ironstone
Vegetation: *Eucalyptus camaldulensis* subsp. *refulgens* low woodland over *Petalostylis labicheoides* and *Acacia trachycarpa* tall open shrubland over **Cenchrus ciliaris* and *C. *setiger* very open tussock grassland with *Cyperus vaginatus* very open sedgeland.
Veg Condition: Very Good
Fire Age: No fire evident

Notes: NA
Species List

Name	Cover (%)	Height (m)
Abutilon sp. Dioicum (A.A. Mitchell PRP 1618)	0.5	1.0
Acacia bivenosa	0.5	3.0
Acacia pyrifolia var. *pyrifolia*	0.5	3.0
Acacia trachycarpa	1	4.0
**Argemone ochroleuca* subsp. *ochroleuca*	0.5	0.1
Capparis spinosa var. *nummularia*	0.5	0.05
**Cenchrus ciliaris*	1	0.4
**Cenchrus setiger*	1	0.1
**Citrullus colocynthis*	0.5	0.1
Cleome viscosa	0.5	0.2
Corchorus sp.	0.5	0.6
Cucumis variabilis	0.5	0.05
Cyperus vaginatus	2	0.8
Eucalyptus camaldulensis subsp. *refulgens*	15	8.0
Euphorbia biconvexa	0.5	0.3
Gossypium robinsonii	0.5	2.5
Hybanthus aurantiacus	0.5	0.2
Lysiana casuarinae	0.5	
**Malvastrum americanum*	0.5	0.2
**Passiflora foetida* var. *hispida*	0.5	0.3
Petalostylis labicheoides	2	3.0
Phyllanthus maderaspatensis	0.5	0.8
Ptilotus astrolasius	0.5	0.1

Name	Cover (%)	Height (m)
Ptilotus nobilis subsp. *nobilis*	0.5	0.05
Senna notabilis	0.5	1.5
Solanum diversiflorum	0.5	0.5
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	0.5	0.5
Triodia wiseana	0.5	0.6

* denotes weed species
? denotes unconfirmed ID

Site: MH381
Location: Map 2 **Type:** 50x50m Quadrat
Date: 2016-05-13 **Described by:** JA/DR
MGA Zone: 50 **Easting:** 413034 **Northing:** 7595447
Habitat: Channel
Soil: Reddish brown sandy clay loam
Rock type: NA
Vegetation: *Melaleuca argentea* woodland over *Cyperus vaginatus* open sedgeland.
Veg Condition: Very Good
Fire Age: No fire evident

Notes: NA

Species List

Name	Cover (%)	Height (m)
Acacia trachycarpa	0.5	2.0
Capparis spinosa var. *nummularia*	0.5	0.3
Cenchrus sp.	0.5	0.2
Cleome viscosa	0.5	0.05
Corchorus sp.	0.5	0.1
Crotalaria novae-hollandiae	0.5	0.3
Cucumis variabilis	0.5	0.1
**Cynodon dactylon*	0.5	0.05
Cyperus vaginatus	3	1.0
Eucalyptus camaldulensis subsp. *refulgens*	0.5	9.0
Euphorbia biconvexa	0.5	0.05
Hybanthus aurantiacus	0.5	0.2
Lobelia arnhemiaca	0.5	0.01
Melaleuca argentea	28	19
**Passiflora foetida* var. *hispida*	0.5	6.0
Petalostylis labicheoides	0.5	2.0
Phyllanthus maderaspatensis	0.5	0.3
Pluchea rubelliflora	0.5	0.3
Pterocaulon sp.	0.5	0.01
Ptilotus sp.	0.5	0.01
Rhynchosia bungarensis P4	0.5	0.2
Sesbania formosa	0.5	10
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	0.5	1.1
Typha domingensis	0.5	0.2

Name	Cover (%)	Height (m)
**Vachellia farnesiana*	0.5	0.1
Waltheria indica	0.5	0.2

* denotes weed species
? denotes unconfirmed ID

Site: MH384
Location: NA **Type:** 40x62.5m Quadrat
Date: 2016-06-06 **Described by:** JA
MGA Zone: 50 **Easting:** 410331 **Northing:** 7594931
Habitat: Major creek
Soil: Red brown loamy sand
Rock type: River stones
Vegetation: *Eucalyptus camaldulensis* subsp. *refulgens*, *Eucalyptus* ?*victrix* woodland over *Petalostylis labicheoides* and *Acacia trachycarpa* tall shrubland over *Tephrosia rosea* var. Fortescue creeks (M.I.H. Brooker 2186) scattered low shrubs.
Veg Condition: Very Good
Fire Age: >10 years

Notes: NA
Species List

Name	Cover (%)	Height (m)
Acacia bivenosa	0.5	1.6
Acacia trachycarpa	7	4.0
Boerhavia coccinea	0.5	0.1
Bonamia pilbarensis	0.5	0.05
**Cenchrus ciliaris*	0.5	0.4
**Cenchrus setiger*	0.5	0.4
Cleome viscosa	0.5	0.3
Corchorus crozophorifolius	0.5	1.0
Corchorus lasiocarpus subsp. *parvus*	0.5	1.2
Cucumis variabilis	0.5	0.5
**Cynodon dactylon*	0.5	0.15
Cyperus vaginatus	0.5	0.7
Eriachne pulchella subsp. *dominii*	0.5	0.15
Eucalyptus ?victrix	11	11.0
Eucalyptus camaldulensis subsp. *refulgens*	12	13.0
Euphorbia biconvexa	0.5	0.2
Euphorbia schultzii	0.5	0.15
Hybanthus aurantiacus	0.5	0.2
Melaleuca argentea	0.5	
Paspalidium sp.	0.5	0.2
Petalostylis labicheoides	8	4.0
Phyllanthus maderaspatensis	0.5	0.3

Name	Cover (%)	Height (m)
Rhynchosia bungarensis P4	0.5	0.4
Sida rohlenae subsp. *rohlenae*	0.5	0.3
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	1	0.5
Triodia wiseana	0.5	0.6

* denotes weed species
? denotes unconfirmed ID

Site: MH385
Location: NA **Type:** 50x50m Quadrat
Date: 2016-05-05 **Described by:** JA/LV
MGA Zone: 50 **Easting:** 421571 **Northing:** 7597120
Habitat: Channel
Soil: Brown loamy sand
Rock type: NA
Vegetation: *Melaleuca argentea* open forest over *Petalostylis labicheoides* and *Acacia trachycarpa* tall open shrubland.
Veg Condition: Good
Fire Age: No fire evident

Species List

Name	Cover (%)	Height (m)
Acacia pyrifolia var. *pyrifolia*	0.5	4.3
Acacia trachycarpa	1	3.2
Amaranthus undulatus	0.5	0.2
Capparis spinosa var. *nummularia*	0.5	0.4
**Cenchrus ciliaris*	0.5	0.4
Cleome viscosa	0.5	0.2
Cucumis variabilis	0.5	
Cyperus vaginatus	0.5	0.9
Eucalyptus sp.	0.5	1.5
Euphorbia biconvexa	0.5	0.4
Euphorbia schultzii	0.5	0.1
Hybanthus aurantiacus	0.5	0.3
Ipomoea muelleri	0.5	
Jasminum didymum subsp. *lineare*	0.5	0.7
Melaleuca argentea	60	20.0
Paspalidium clementii	0.5	0.15
**Passiflora foetida* var. *hispida*	6	
Petalostylis labicheoides	1	3.0
Phyllanthus maderaspatensis	0.5	0.3
Ptilotus sp.	0.5	0.05
Rhynchosia bungarensis P4	0.5	0.4
**Setaria verticillata*	0.5	0.4
Trachymene oleracea subsp. *oleracea*	0.5	0.1

* denotes weed species

Site: MH387
Location: NA **Type:** 50x50m Quadrat
Date: 2016-05-13 **Described by:** JA/DR
MGA Zone: 50 **Easting:** 411646 **Northing:** 7595070
Habitat: Channel
Soil: Brown loamy sand
Rock type: NA
Vegetation: *Melaleuca argentea* and *Eucalyptus camaldulensis* subsp. *refulgens* open forest over *Acacia trachycarpa* and *Petalostylis labicheoides* tall open shrubland over *Cyperus vaginatus* scattered sedges.
Veg Condition: Very Good
Fire Age: >10 years

Notes: NA
Species List

Name	Cover (%)	Height (m)
Acacia trachycarpa	4	4.0
Acacia trachycarpa x tumida var. *pilbarensis*	0.5	1.9
Alternanthera nana	0.5	0.15
Capparis spinosa var. nummularia	0.5	0.5
Cenchrus sp.	0.5	0.4
Cucumis variabilis	0.5	1.0
**Cynodon dactylon*	0.5	0.4
Cyperus vaginatus	1	1.2
Eucalyptus camaldulensis subsp. *refulgens*	10	12.0
Euphorbia schultzii	0.5	0.2
Melaleuca argentea	25	15.0
**Passiflora foetida* var. *hispida*	0.5	4.5
Petalostylis labicheoides	1	4.0
Phyllanthus maderaspatensis	0.5	0.3
Pluchea rubelliflora	0.5	0.2
Sesbania formosa	0.5	9.0
Stemodia grossa	0.5	0.6
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	0.5	1.9
**Vachellia farnesiana*	0.5	1.6
Vigna lanceolata var. lanceolata	0.5	0.4

* denotes weed species
? denotes unconfirmed ID

Site: MH388
Location: Map 2 **Type:** 50x50m Quadrat
Date: 2016-06-06 **Described by:** JA/DR
MGA Zone: 50 **Easting:** 411162 **Northing:** 7594904
Habitat: Major creek
Soil: Brown sandy loam
Rock type: River stones
Vegetation: *Euphorbia schultzii*, *Cleome viscosa* and *Hybanthus aurantiacus* very scattered herbs.
Veg Condition: Very Good
Fire Age: No fire evident

Notes: NA

Species List

Name	Cover (%)	Height (m)
**Argemone ochroleuca subsp. ochroleuca*	0.5	0.01
Cleome viscosa	0.5	0.2
Corchorus lasiocarpus subsp. parvus	0.5	1.0
Euphorbia schultzii	0.5	0.2
Hybanthus aurantiacus	0.5	0.1
Petalostylis labicheoides	0.5	1.5
Ptilotus obovatus	0.5	0.3

* denotes weed species
? denotes unconfirmed ID

Site: MH389
Location: Mesa G Robe River **Type:** 50x50m Quadrat
Date: 2016-06-06 **Described by:** DR
MGA Zone: 50 **Easting:** 410478 **Northing:** 7594630
Habitat: Major creek
Soil: Brown sandy loam
Rock type: River stones
Vegetation: *Acacia trachycarpa* and *Petalostylis labicheoides* tall shrubland.
Veg Condition: Very Good
Fire Age: No fire evident

Notes: NA

Species List

Name	Cover (%)	Height (m)
Acacia bivenosa	0.5	2.0
Acacia trachycarpa	22	4.5
**Cenchrus ciliaris*	0.5	0.3
**Cenchrus setiger*	0.5	0.4
Cleome viscosa	0.5	0.3
Corchorus crozophorifolius	0.5	1.3
Corchorus lasiocarpus subsp. *parvus*	0.5	0.9
Cucumis variabilis	0.5	0.3
Dysphania sp.	0.5	0.02
Euphorbia schultzii	0.5	0.2
Hybanthus aurantiacus	0.5	0.1
Indigofera monophylla	0.5	0.2
Ipomoea muelleri	0.5	0.4
Paspalidium sp.	0.5	0.1
Petalostylis labicheoides	7	3.0
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	0.5	0.9
Tephrosia sp. B Kimberley Flora (C.A. Gardner 7300)	0.5	0.4
Triodia epactia	0.5	0.6
Triodia wiseana	0.5	0.8

* denotes weed species
? denotes unconfirmed ID

Site: MH392
Location: NA **Type:** 50x50m Quadrat
Date: 2016-05-10 **Described by:** JA/DR
MGA Zone: 50 **Easting:** 424829 **Northing:** 7592502
Habitat: Major creek
Soil: Red brown sandy clay loam
Rock type: NA
Vegetation: *Eucalyptus victrix* open woodland over *Acacia trachycarpa* tall open shrubland over *Triodia wiseana* very open hummock grassland and **Cenchrus ciliaris* very open tussock grassland.
Veg Condition: Good
Fire Age: >10 years

Species List

Name	Cover (%)	Height (m)
Abutilon sp. Dioicum (A.A. Mitchell PRP 1618)	0.5	0.5
Acacia bivenosa	0.5	1.1
Acacia pyrifolia var. *pyrifolia*	0.5	1.6
Acacia trachycarpa	7	2.1
Boerhavia coccinea	0.5	0.1
Capparis spinosa var. *nummularia*	0.5	0.4
**Cenchrus ciliaris*	3	0.25
Cleome viscosa	0.5	0.2
Corchorus lasiocarpus subsp. *parvus*	0.5	0.5
Cymbopogon ambiguus	0.5	0.8
Cyperus vaginatus	0.5	0.6
Eucalyptus victrix	6	14.0
Euphorbia biconvexa	0.5	0.15
Euphorbia schultzii	0.5	0.05
Evolvulus alsinoides var. *villosicalyx*	0.5	0.1
Flueggea virosa subsp. *melanthesoides*	0.5	3.8
Gomphrena cunninghamii	0.5	0.05
Gossypium australe	0.5	0.4
Gossypium robinsonii	0.5	1.0
Grevillea wickhamii	0.5	0.7
Hybanthus aurantiacus	0.5	0.1
Indigofera monophylla	0.5	0.15
**Malvastrum americanum*	0.5	0.1
Notoleptopus decaisnei var. Orbicularis (A.B. Craig 428)	0.5	0.1
**Passiflora foetida* var. *hispida*	0.5	0.1

Name	Cover (%)	Height (m)
Phyllanthus maderaspatensis	0.5	0.3
Pterocaulon sphaeranthoides	0.5	0.1
Ptilotus appendiculatus	0.5	0.05
Ptilotus calostachyus	0.5	0.4
Ptilotus incanus	0.5	0.2
Ptilotus nobilis subsp. *nobilis*	0.5	0.1
Rhynchosia minima	0.5	0.05
Sida sp. Pilbara (A.A. Mitchell PRP 1543)	0.5	0.6
Solanum diversiflorum	0.5	0.1
Solanum horridum	0.5	0.15
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	0.5	0.6
Trianthema triquetrum	0.5	0.05
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	0.5	0.5
Triodia wiseana	3	0.6
Triumfetta appendiculata	0.5	0.3
Triumfetta clementii	0.5	0.1
Waltheria indica	0.5	0.2

* denotes weed species
? denotes unconfirmed ID

Site: MH393
Location: Map 11 **Type:** 25x100m Quadrat
Date: 2016-05-10 **Described by:** JA/DR
MGA Zone: 50 **Easting:** 424501 **Northing:** 7592735
Habitat: Major creek
Soil: Red brown sandy clay loam
Rock type: NA
Vegetation: *Eucalyptus victrix* low open woodland over *Acacia trachycarpa* tall open shrubland over *Triodia wiseana* very open hummock grassland and **Cenchrus ciliaris* very open tussock grassland.
Veg Condition: Good
Fire Age: >10 years

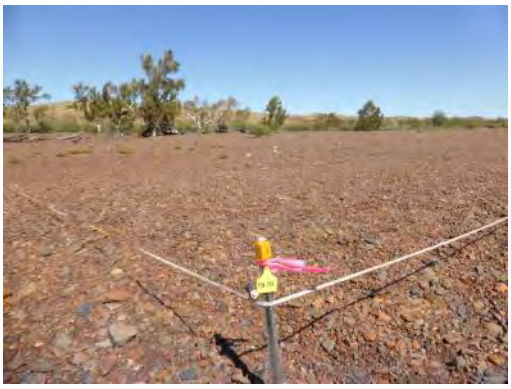
Species List

Name	Cover (%)	Height (m)
Abutilon sp. Dioicum (A.A. Mitchell PRP 1618)	0.5	0.2
Acacia bivenosa	0.5	2.1
Acacia colei var. *ileocarpa*	0.5	0.6
Acacia pyrifolia var. *pyrifolia*	0.5	2.1
Acacia synchronicia	0.5	2.2
Acacia trachycarpa	9	2.7
Acacia tumida var. *pilbarensis*	0.5	1.3
Boerhavia coccinea	0.5	0.1
**Cenchrus ciliaris*	3	0.2
Cleome viscosa	0.5	0.2
Corchorus lasiocarpus subsp. *parvus*	0.5	0.2
Cucumis variabilis	0.5	0.2
Cymbopogon ambiguus	0.5	0.3
Eriachne mucronata	0.5	0.4
Eriachne tenuiculmis	0.5	0.3
Eucalyptus victrix	2	8.0
Euphorbia australis	0.5	0.05
Euphorbia biconvexa	0.5	0.1
Euphorbia schultzii	0.5	0.02
Gossypium australe	0.5	0.3
Gossypium robinsonii	0.5	0.6
Hybanthus aurantiacus	0.5	0.1
**Malvastrum americanum*	0.5	0.3
Notoleptopus decaisnei var. Orbicularis (A.B. Craig 428)	0.5	0.1
Phyllanthus maderaspatensis	0.5	0.2

Name	Cover (%)	Height (m)
Pterocaulon sp.	0.5	0.2
Ptilotus appendiculatus	0.5	0.1
Ptilotus auriculifolius	0.5	0.1
Rhynchosia minima	0.5	0.1
Senna ferraria	0.5	1.1
Senna notabilis	0.5	0.2
Solanum diversiflorum	0.5	0.2
Solanum horridum	0.5	0.2
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	0.5	0.2
Triodia wiseana	7	0.6
Waltheria indica	0.5	0.2

* denotes weed species
? denotes unconfirmed ID

Site: MH394
Location: SW corner Map 6 **Type:** 50x50m Quadrat
Date: 2016-05-11 **Described by:** KMc/LV
MGA Zone: 50 **Easting:** 414348 **Northing:** 7595672
Habitat: Major creek
Soil: Brown sand
Rock type: Ironstone
Vegetation: *Acacia trachycarpa* very scattered shrub over *Euphorbia schultzii* very scattered low shrubs.
Veg Condition: Excellent
Fire Age: >10 years

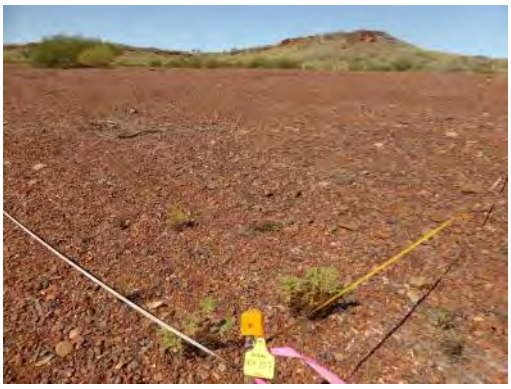


Species List

Name	Cover (%)	Height (m)
**Argemone ochroleuca* subsp. *ochroleuca*	0.5	0.3
Acacia trachycarpa	0.5	2.5
Cleome viscosa	0.5	0.01
Corchorus ?crozophorifolius	0.5	0.4
Euphorbia schultzii	0.5	0.15
Hybanthus aurantiacus	0.5	0.15
Ptilotus incanus	0.5	0.3
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)	0.5	0.35

* denotes weed species
? denotes unconfirmed ID

Site: MH397
Location: Map 3 **Type:** 50x50m Quadrat
Date: 2016-05-12 **Described by:** DR
MGA Zone: 50 **Easting:** 416275 **Northing:** 7597984
Habitat: Major creek
Soil: Brown sandy clay loam
Rock type: NA
Vegetation: *Acacia trachycarpa* and *Petalostylis labicheoides* very scattered tall shrubs over *Euphorbia schultzii* very scattered herbs.
Veg Condition: Very Good
Fire Age: No fire evident

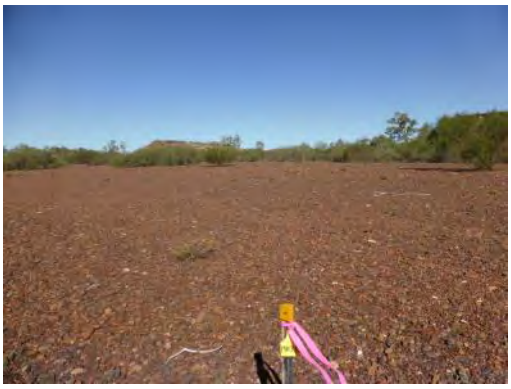


Species List

Name	Cover (%)	Height (m)
Acacia trachycarpa	0.5	2.8
Euphorbia schultzii	0.5	0.2
Ipomoea muelleri	0.5	0.1
Petalostylis labicheoides	0.5	2.5
Phyllanthus maderaspatensis	0.5	0.2

* denotes weed species
? denotes unconfirmed ID

Site: MH398
Location: NA **Type:** 60x42m Quadrat
Date: 2016-05-12 **Described by:** JA
MGA Zone: 50 **Easting:** 417606 **Northing:** 7597831
Habitat: Channel
Soil: Brown loamy sand
Rock type: NA
Vegetation: *Acacia trachycarpa* scattered tall shrubs to tall open shrubland (over *Euphorbia schultzii* very scattered herbs).
Veg Condition: Excellent
Fire Age: >10 years



Species List

Name	Cover (%)	Height (m)
Acacia trachycarpa	2	3.7
Euphorbia schultzii	0.5	0.15
Hybanthus aurantiacus	0.5	0.2
Ipomoea muelleri	0.5	0.05
Ptilotus incanus	0.5	0.2

* denotes weed species
? denotes unconfirmed ID

Site: MH401
Location: Map 11 just NE of creek **Type:** 50x50m Quadrat
Date: 2016-05-10 **Described by:** KMc
MGA Zone: 50 **Easting:** 424035 **Northing:** 7592626
Habitat: Floodplain
Soil: Light reddish brown silty clay
Rock type: NA
Vegetation: *Eucalyptus victrix* low open woodland over *Acacia trachycarpa* and *Melaleuca glomerata* tall open shrubland over *Triodia wiseana* open hummock grassland with **Cenchrus ciliaris* open tussock grassland.
Veg Condition: Good
Fire Age: No fire evident

Species List

Name	Cover (%)	Height (m)
Abutilon sp.	0.5	0.2
Acacia bivenosa	0.5	1.2
Acacia colei var. *ileocarpa*	0.5	0.6
Acacia pyrifolia var. *pyrifolia*	0.5	3.0
Acacia sclerosperma subsp. *sclerosperma*	0.5	1.3
Acacia trachycarpa	7	2.5
**Cenchrus ciliaris*	12	0.1
Eucalyptus victrix	7	8.0
Euphorbia biconvexa	0.5	0.1
Gossypium robinsonii	0.5	0.25
Indigofera boviperda	0.5	0.1
**Malvastrum americanum*	0.5	0.2
Melaleuca glomerata	2	2.2
**Passiflora foetida* var. *hispida*	0.5	0.1
Pterocaulon sp.	0.5	0.05
Rhynchosia minima	0.5	0.1
Sida fibulifera	0.5	0.05
Triodia wiseana	14	0.6
**Vachellia farnesiana*	0.5	0.6

* denotes weed species
? denotes unconfirmed ID

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Appendix O: Vegetation Condition Mapping

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410000 415000 420000 425000 430000

7600000 7595000 7590000

Legend

- Survey Site
- Railway
- Main Road
- River/Creek
- Mesa H Riparian Community Survey Area

Vegetation Condition Mapping

- Excellent
- Very Good
- Good
- Poor
- Disturbed

Pannawonica

Pannawonica

E20

E07

E09

MH203

MH363

Robe River

MH204

MH397

MH398

MH337r

MH354

MH379

MH385

AM215

MH332

MH321

MH44

MH43

MH394

MH303

MH381

MH387

MH388

MH384

MH389

Millstream Rd

MH393

MH401

MH392

MH373

Hammersley Creek

Bungaroo Creek

Robe River Mining Co. Pty Ltd

Mesa H Riparian Community Assessment - June 2016

Figure O.1: Vegetation Condition Mapping

Datum: GDA 1994 - Projection: MGA Zone 50

0 500 1,000 1,500 2,000 2,500 3,000 metres

N

astron delivering environmental intelligence™

Author: D. Roocke | Drawn: W. An | Date: 06-04-2017 | Figure Ref: 14269-16-BIDR-1RevB_170406_FigO1_VegCond

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Appendix P: Flora Species Lists

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Table P.1: Vascular flora species list for the survey area.

Family	Species name	Conservation status	Weed
Aizoaceae	*Trianthema triquetrum*		
Amaranthaceae	*Alternanthera nana*		
	Amaranthus cuspidifolius		
	Amaranthus undulatus		
	Aerva javanica		*
	Gomphrena cunninghamii		
	Ptilotus appendiculatus		
	Ptilotus astrolasius		
	Ptilotus auriculifolius		
	Ptilotus axillaris		
	Ptilotus calostachyus		
	Ptilotus incanus		
	Ptilotus nobilis subsp. *nobilis*		
	Ptilotus obovatus		
Araliaceae	*Trachymene oleracea* subsp. *oleracea*		
Arecaceae	*Livistona alfredii*	P4	
Asteraceae	*Bidens bipinnata*		*
	Flaveria trinervia		*
	Helichrysum luteoalbum		
	Lactuca serriola		*
	Pluchea rubelliflora		
	Pterocaulon sphaeranthoides		
	Sonchus oleraceus		*
	Streptoglossa liatroides		
Boraginaceae	*Heliotropium pachyphyllum*		
Brassicaceae	*Lepidium pholidogynum*		
Campanulaceae	*Lobelia arnhemiaca*		
	Wahlenbergia tumidifructa		
Capparaceae	*Capparis spinosa* var. *nummularia*		
Chenopodiaceae	*Dysphania* sp.		
Cleomaceae	*Cleome viscosa*		
Convolvulaceae	*Bonamia pilbarensis*		
	Evolvulus alsinoides var. *villosicalyx*		
	Ipomoea muelleri		
	Ipomoea polymorpha		
Cucurbitaceae	*Citrullus colocynthis*		*

Family	Species name	Conservation status	Weed
Cucurbitaceae	*Cucumis variabilis*		
Cyperaceae	*Cyperus vaginatus*		
	Eleocharis geniculata		
	Schoenoplectus subulatus		
Euphorbiaceae	*Adriana tomentosa*		
	Euphorbia australis		
	Euphorbia biconvexa		
	Euphorbia boophthona		
	Euphorbia hirta		*
	Euphorbia schultzii		
Fabaceae	*Acacia bivenosa*		
	Acacia colei var. *ileocarpa*		
	Acacia elachantha		
	Acacia pyrifolia var. *pyrifolia*		
	Acacia sclerosperma subsp. *sclerosperma*		
	Acacia synchronicia		
	Acacia trachycarpa		
	Acacia trachycarpa x tumida var. *pilbarensis*		
	Acacia tumida var. *pilbarensis*		
	Crotalaria novae-hollandiae		
	Indigofera boviperda		
	Indigofera monophylla		
	Petalostylis labicheoides		
	Rhynchosia bungarensis	P4	
	Rhynchosia minima		
	Senna ferraria		
	Senna notabilis		
	Sesbania formosa		
	Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)		
	Tephrosia sp. B Kimberley Flora (C.A. Gardner 7300)		
	Tephrosia sp. Fortescue (A.A. Mitchell 606)		
	Vachellia farnesiana		*
	Vigna lanceolata var. *lanceolata*		
Goodeniaceae	*Goodenia lamprosperma*		
Lamiaceae	*Ocimum basilicum*		*
Loranthaceae	*Lysiana casuarinae*		
Marsileaceae	*Marsilea* sp.		
Malvaceae	*Abutilon lepidum*		
	Abutilon sp. Dioicum (A.A. Mitchell PRP 1618)		

Family	Species name	Conservation status	Weed
Malvaceae	*Corchorus crozophorifolius*		
	Corchorus lasiocarpus subsp. *parvus*		
	Gossypium australe		
	Gossypium robinsonii		
	Malvastrum americanum		*
	Melochia pyramidata		*
	Sida fibulifera		
	Sida rohlenae subsp. *rohlenae*		
	Sida sp. Articulation below (A.A. Mitchell PRP 1605)		
	Sida sp. Pilbara (A.A. Mitchell PRP 1543)		
	Triumfetta appendiculata		
	Triumfetta ?chaetocarpa		
	Triumfetta clementii		
	Triumfetta johnstonii		
	Waltheria indica		
Molluginaceae	*Mollugo molluginea*		
Moraceae	*Ficus aculeata* var. *indecora*		
Myrtaceae	*Eucalyptus camaldulensis* subsp. *refulgens*		
	Eucalyptus victrix		
	Melaleuca argentea		
	Melaleuca glomerata		
Nyctaginaceae	*Boerhavia coccinea*		
Oleaceae	*Jasminum didymum* subsp. *lineare*		
Papaveraceae	*Argemone ochroleuca* subsp. *ochroleuca*		*
Passifloraceae	*Passiflora foetida* var. *hispida*		*
Phyllanthaceae	*Flueggea virosa* subsp. *melanthesoides*		
	Notoleptopus decaisnei var. Orbicularis (A.B. Craig 428)		
	Phyllanthus maderaspatensis		
Plantaginaceae	*Stemodia grossa*		
Poaceae	*Cenchrus ciliaris*		*
	Cenchrus setiger		*
	Chloris barbata		*
	Cynodon dactylon		*
	Cymbopogon ambiguus		
	Dactyloctenium radulans		
	Echinochloa colona		*
	Enneapogon caerulescens		
	Eriachne mucronata		
	Eriachne pulchella subsp. *dominii*		

Family	Species name	Conservation status	Weed
Poaceae	*Eriachne tenuiculmis*		
	Eulalia aurea		
	Paraneurachne muelleri		
	Paspalidium clementii		
	Setaria verticillata		*
	Sporobolus australasicus		
	Themeda triandra		
	Triodia epactia		
	Triodia sp. Robe River (M.E. Trudgen et al. MET 12367)	P3	
	Triodia wiseana		
Polygonaceae	*Rumex vesicarius*		*
Proteaceae	*Grevillea wickhamii*		
	Hakea chordophylla		
Solanaceae	*Datura leichhardtii*		*
	Solanum cleistogamum		
	Solanum diversiflorum		
	Solanum horridum		
	Solanum nigrum		*
Surianaceae	*Stylobasium spathulatum*		
Typhaceae	*Typha domingensis*		
Violaceae	*Hybanthus aurantiacus*		

Table P.2: Site by species matrix for the survey area.

Species	MH203	MH204	MH303	MH321	MH332	MH337r	MH354	MH363	MH373	MH379	MH381	MH384	MH385	MH387	MH388	MH389	MH392	MH393	MH394	MH397	MH398	MH401	MH43	MH44
Abutilon lepidum			0.5																					0.5
Abutilon sp.									0.5													0.5		
Abutilon sp. Dioicum (A.A. Mitchell PRP 1618)			0.5		0.5					0.5							0.5	0.5					0.5	0.5
Acacia bivenosa	1	0.5	1	0.5	0.5		0.5			0.5		0.5				0.5	0.5	0.5				0.5	0.5	1
Acacia colei var. *ileocarpa*			0.5						0.5									0.5				0.5	0.5	
Acacia elachantha																							0.5	
Acacia pyrifolia var. *pyrifolia*	0.5		0.5		0.5				0.5	0.5			0.5				0.5	0.5				0.5	0.5	0.5
Acacia sclerosperma subsp. *sclerosperma*																						0.5		
Acacia synchronicia		0.5		0.5														0.5						
Acacia trachycarpa	35	3	1	6	2	0.5	32	1	0.5	1	0.5	7	1	4		22	7	9	0.5	0.5	2	7	1	2
Acacia trachycarpa x tumida var. *pilbarensis*				0.5										0.5										
Acacia tumida var. *pilbarensis*																		0.5						
Adriana tomentosa	0.5																							
Alternanthera nana														0.5										
Amaranthus undulatus													0.5											
**Argemone ochroleuca* subsp. *ochroleuca*						0.5		0.5		0.5					0.5				0.5					
Boerhavia coccinea			0.5									0.5					0.5	0.5						
Bonamia pilbarensis												0.5												
Capparis spinosa var. *nummularia*					0.5					0.5	0.5		0.5	0.5			0.5						0.5	
**Cenchrus ciliaris*		0.5	0.5	0.5	0.5		0.5			1		0.5	0.5			0.5	3	3				12	1	2
**Cenchrus setiger*	0.5		32	0.5		0.5	0.5			1		0.5				0.5							1	1
Cenchrus sp.									25		0.5			0.5										
**Citrullus colocynthis*										0.5													0.5	
Cleome viscosa	0.5	0.5		0.5	0.5		0.5	0.5		0.5	0.5	0.5	0.5		0.5	0.5	0.5	0.5	0.5				0.5	0.5

Species	MH203	MH204	MH303	MH321	MH332	MH337r	MH354	MH363	MH373	MH379	MH381	MH384	MH385	MH387	MH388	MH389	MH392	MH393	MH394	MH397	MH398	MH401	MH43	MH44
Corchorus ?crozophorifolius																			0.5					
Corchorus crozophorifolius					0.5							0.5				0.5								
Corchorus lasiocarpus subsp. *parvus*	0.5		0.5	0.5			0.5	0.5				0.5			0.5	0.5	0.5	0.5					0.5	0.5
Corchorus sp.										0.5	0.5													
Crotalaria novae-hollandiae											0.5													
Cucumis variabilis			0.5			0.5				0.5	0.5	0.5	0.5	0.5		0.5		0.5					0.5	
Cymbopogon ambiguus			0.5			0.5	0.5										0.5	0.5						
**Cynodon dactylon*				0.5	0.5			0.5			0.5	0.5		0.5										
Cyperus vaginatus		1	1		1	1		1	0.5	2	3	0.5	0.5	1			0.5						1	0.5
Dactyloctenium radulans			0.5																					
Dysphania sp.																0.5								
**Echinochloa colona*			0.5						0.5															
Eleocharis geniculata					0.5																			
Enneapogon caerulescens							0.5																	
Eriachne mucronata			0.5															0.5						0.5
Eriachne pulchella subsp. *dominii*												0.5												
Eriachne tenuiculmis																		0.5						
Eucalyptus ?victrix												11												
Eucalyptus camaldulensis subsp. *refulgens*		10	40				0.5	2	6	15	0.5	12		10									14	20
Eucalyptus sp.					0.5								0.5											
Eucalyptus victrix					0.5				6								6	2				7	14	7
Eulalia aurea			0.5																					
Euphorbia australis		0.5																0.5						
Euphorbia biconvexa		0.5								0.5	0.5	0.5	0.5				0.5	0.5				0.5		
Euphorbia boophthona																								

Species	MH203	MH204	MH303	MH321	MH332	MH337r	MH354	MH363	MH373	MH379	MH381	MH384	MH385	MH387	MH388	MH389	MH392	MH393	MH394	MH397	MH398	MH401	MH43	MH44
**Euphorbia hirta*		0.5	0.5					0.5	0.5															
Euphorbia schultzii	0.5	0.5	0.5	0.5	0.5		0.5					0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5		0.5	
Evolvulus alsinoides var. *villosicalyx*																	0.5						0.5	
Ficus aculeata var. *indecora*			0.5																					
Flueggea virosa subsp. *melanthesoides*			0.5														0.5							0.5
Gomphrena cunninghamii			0.5	0.5													0.5							
Goodenia lamprosperma																								
Gossypium australe																	0.5	0.5						
Gossypium robinsonii			0.5		0.5			0.5	0.5	0.5							0.5	0.5				0.5	0.5	0.5
Grevillea wickhamii																	0.5							
Hakea chordophylla									0.5															
Helichrysum luteoalbum					0.5																			
Heliotropium pachyphyllum								0.5																
Hybanthus aurantiacus	0.5		0.5						0.5	0.5	0.5	0.5	0.5		0.5	0.5	0.5	0.5	0.5		0.5		0.5	0.5
Indigofera boviperda									0.5													0.5		
Indigofera monophylla							0.5									0.5	0.5							
Ipomoea muelleri		0.5	0.5		0.5	0.5							0.5			0.5				0.5	0.5			
Ipomoea polymorpha									0.5															
Jasminum didymum subsp. *lineare*					0.5								0.5											
**Lactuca serriola*					0.5																			
Lepidium pholidogynum			0.5																					
Lobelia arnhemiaca			0.5		0.5	0.5					0.5													
Lobelia sp.		0.5																						
Lysiana casuarinae										0.5														
**Malvastrum americanum*			0.5						0.5	0.5							0.5	0.5				0.5		0.5

Species	MH203	MH204	MH303	MH321	MH332	MH337r	MH354	MH363	MH373	MH379	MH381	MH384	MH385	MH387	MH388	MH389	MH392	MH393	MH394	MH397	MH398	MH401	MH43	MH44
Marsilea sp.									0.5															
Melaleuca argentea		40			32	50		62			28	0.5	60	25										
Melaleuca glomerata			1																			2	0.5	0.5
Mollugo molluginea									0.5															
Notoleptopus decaisnei var. Orbicularis (A.B. Craig 428)			0.5														0.5	0.5					0.5	0.5
Paraneurachne muelleri			0.5																					
Paspalidium clementii			0.5										0.5											
Paspalidium sp.												0.5				0.5								
**Passiflora foetida* var. *hispida*		0.5			0.5	0.5		0.5		0.5	0.5		6	0.5			0.5					0.5		
Petalostylis labicheoides		0.5	1	8	1	0.5	1	0.5		2	0.5	8	1	1	0.5	7				0.5			0.5	0.5
Phyllanthus maderaspatensis		0.5	0.5		0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5			0.5	0.5		0.5			0.5	0.5
Phyllanthus sp.									0.5															
Pluchea rubelliflora		0.5			0.5			0.5			0.5			0.5										
Pterocaulon sp.									0.5		0.5							0.5				0.5	0.5	
Pterocaulon sphaeranthoides																	0.5							0.5
Ptilotus appendiculatus			0.5														0.5	0.5						
Ptilotus astrolasius				0.5						0.5													0.5	
Ptilotus auriculifolius	0.5																	0.5						
Ptilotus axillaris																							0.5	
Ptilotus calostachyus																	0.5							
Ptilotus incanus																	0.5		0.5		0.5			
Ptilotus nobilis subsp. *nobilis*				0.5			0.5			0.5							0.5						0.5	0.5
Ptilotus obovatus															0.5									
Ptilotus sp.			0.5					0.5			0.5		0.5											
Rhynchosia bungarensis P4	0.5	0.5			0.5	0.5	0.5				0.5	0.5	0.5											

Species	MH203	MH204	MH303	MH321	MH332	MH337r	MH354	MH363	MH373	MH379	MH381	MH384	MH385	MH387	MH388	MH389	MH392	MH393	MH394	MH397	MH398	MH401	MH43	MH44
Rhynchosia minima																	0.5	0.5				0.5		0.5
Schoenoplectus subulatus					0.5																			
Senna ferraria																		0.5						
Senna notabilis										0.5								0.5						
Sesbania formosa		0.5			0.5			0.5			0.5			0.5										
**Setaria verticillata*			0.5										0.5											
Sida fibulifera									0.5													0.5		
Sida rohlenae subsp. *rohlenae*												0.5												
Sida sp. Articulation below (A.A. Mitchell PRP 1605)			0.5																					
Sida sp. Pilbara (A.A. Mitchell PRP 1543)																	0.5							
Solanum cleistogamum									0.5															0.5
Solanum diversiflorum			0.5							0.5							0.5	0.5					0.5	0.5
Solanum horridum			0.5														0.5	0.5					0.5	0.5
**Sonchus oleraceus*			0.5																					
Sporobolus australasicus								0.5																
Stemodia grossa		0.5			0.5	0.5								0.5										
Streptoglossa liatroides		0.5																						
Stylobasium spathulatum			0.5																				0.5	0.5
Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186)		0.5	0.5	0.5	0.5	0.5	0.5	0.5		0.5	0.5	1		0.5		0.5	0.5	0.5	0.5				0.5	0.5
Tephrosia sp. B Kimberley Flora (C.A. Gardner 7300)																0.5								
Tephrosia sp. Fortescue (A.A. Mitchell 606)		0.5																						
Themeda triandra			0.5																					0.5
Trachymene oleracea subsp. *oleracea*			0.5		0.5	0.5		0.5					0.5											
Trianthema triquetrum																	0.5							
Triodia epactia				0.5			0.5									0.5							0.5	0.5

Species	MH203	MH204	MH303	MH321	MH332	MH337r	MH354	MH363	MH373	MH379	MH381	MH384	MH385	MH387	MH388	MH389	MH392	MH393	MH394	MH397	MH398	MH401	MH43	MH44
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3																	0.5							
Triodia wiseana			0.5	0.5						0.5		0.5				0.5	3	7				14		
Triumfetta ?chaetocarpa				0.5																				
Triumfetta appendiculata			0.5		0.5												0.5						0.5	0.5
Triumfetta clementii			1														0.5							
Triumfetta johnstonii					0.5																			
Triumfetta sp.			0.5																					
Typha domingensis					0.5						0.5													
**Vachellia farnesiana*			0.5		0.5				0.5		0.5			0.5								0.5		0.5
Vigna lanceolata var. *lanceolata*		0.5			0.5	0.5		0.5	0.5					0.5										
Wahlenbergia tumidifructa								0.5																
Waltheria indica		0.5	0.5								0.5						0.5	0.5					0.5	0.5

Appendix Q: Conservation Significant Flora and Introduced Flora Species Locations and Descriptions

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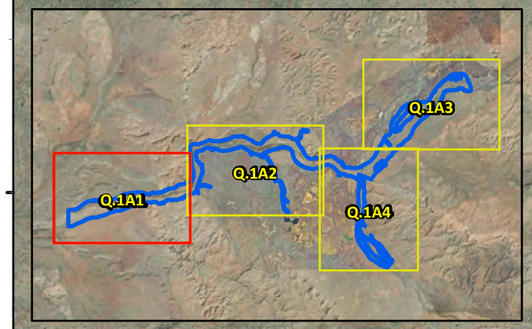
407000 408000 409000 410000 411000 412000 413000 414000

7597000 7596000 7595000 7594000 7593000



Robe River

Legend

River/Creek

Mesa H Riparian Community Survey Area

Priority Flora (Astron 2016c)

Rhynchosia bungarensis P4

Robe River Mining Co. Pty Ltd

Mesa H Riparian Community Assessment - June 2016

Figure Q.1A1: Priority Flora Locations

Datum: GDA 1994 - Projection: MGA Zone 50

0 500 1,000 metres

N

astron delivering environmental intelligence™

Author: D. Roocke | Drawn: W. An | Date: 06-04-2017 | Figure Ref: 14269-16-BIDR-1RevB_170406_FigQ1A_Pflora

415000 416000 417000 418000 419000 420000 421000

7599000 7598000 7597000 7596000 7595000

Millstream Rd

Robe River

Q.1A1 Q.1A2 Q.1A3 Q.1A4

Legend

- Railway
- Main Road
- River/Creek
- Mesa H Riparian Community Survey Area

Priority Flora (Astron 2016b, Astron 2016c)

- *Rhynchosia bungarensis* P4

Robe River Mining Co. Pty Ltd

Mesa H Riparian Community Assessment - June 2016

Figure Q.1A2: Priority Flora Locations

Datum: GDA 1994 - Projection: MGA Zone 50

0 500 1,000 metres

N

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Author: D. Roocke | Drawn: W. An | Date: 06-04-2017 | Figure Ref: 14269-16-BIDR-1RevB_170406_FigQ1A_Pflora

425000 426000 427000 428000 429000 430000 431000

7602000 7601000 7600000 7599000 7598000

Q.1A1 Q.1A2 Q.1A3 Q.1A4

Robe River

Legend

- Railway
- River/Creek
- Mesa H Riparian Community Survey Area

Priority Flora (Astron 2016a)

- *Livistona alfredii* P4
- *Rhynchosia bungarensis* P4

Priority Flora (ecologia 2013)

- *Rhynchosia bungarensis* P4
- *Triodia* sp. Robe River (M.E. Trudgen et al. MET 12367) P3

Robe River Mining Co. Pty Ltd

Mesa H Riparian Community Assessment - June 2016

Figure Q.1A3: Priority Flora Locations

Datum: GDA 1994 - Projection: MGA Zone 50

0 500 1,000 metres

N

astron delivering environmental intelligence™

Author: D. Roocke | Drawn: W. An | Date: 06-04-2017 | Figure Ref: 14269-16-BIDR-1RevB_170406_FigQ1A_Pflora

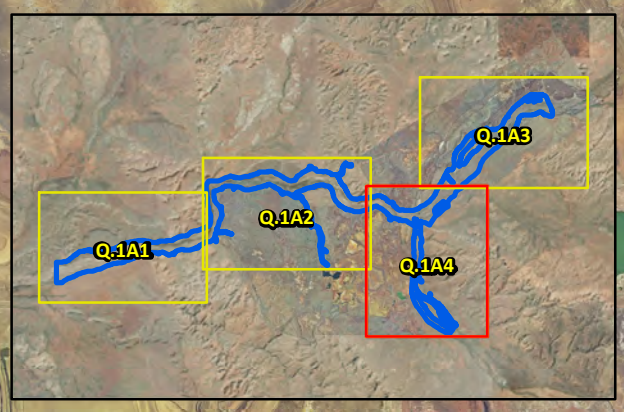
422000 423000 424000 425000 426000 427000

7597000 7596000 7595000 7594000 7593000 7592000 7591000

Robe River

Jimmawurrada Creek

Millstream Rd



Legend

- Railway
- Main Road
- River/Creek
- Mesa H Riparian Community Survey Area

Priority Flora (Astron 2016a)

- *Rhynchosia bungarensis* P4
- *Triodia* sp. Robe River (M.E. Trudgen et al. MET 12367) P3

Priority Flora (Astron 2016b)

- *Triodia* sp. Robe River (M.E. Trudgen et al. MET 12367) P3

Robe River Mining Co. Pty Ltd

Mesa H Riparian Community Assessment - June 2016

Figure Q.1A4: Priority Flora Locations

Author: D. Roocke	Date: 06-04-2017
Drawn: W. An	Figure Ref: 14269-16-BIDR-1RevB_170406_FigQ1A_Pflora_4

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delivering environmental intelligence™

Coordinate System: GDA94 MGA zone 50

0 200 400 600 800 1,000 Metres

N

Table Q.1: Locations of conservation significant flora recorded in the survey area (MGA Zone 50, GDA 94).

Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)	Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)
Livistona alfredii P4	1	5	427068	7599750	*Rhynchosia bungarensis* P4	20	1	416270	7598414
Rhynchosia bungarensis P4	2	0.5	410332	7594925		4	0.5	416272	7598043
	8	1	412722	7595283		3	0.5	416273	7598141
	20	10	414365	7596627		8	0.5	416282	7598050
	30	10	414378	7596612		2	0.5	416298	7598017
	1	0.5	414379	7596678		5	0.5	416301	7598136
	10	5	414391	7596598		3	0.5	416321	7598122
	20	10	414392	7596536		5	0.5	416454	7598142
	5	10	414397	7596506		4	0.5	416466	7598138
	30	10	414401	7596557		6	0.5	416488	7598127
	30	10	414401	7596578		2	0.5	416496	7598065
	1	0.5	414445	7597046		1	0.5	416848	7598067
	2	0.5	414449	7597007		4	0.5	417356	7598199
	2	0.5	414451	7597792		1	0.5	417371	7598516
	5	0.5	414493	7597788		20	1	417465	7598189
	1	0.5	414563	7598015		2	0.5	417491	7598142
	4	1	414747	7597960		10	1	417512	7598340
	2	0.5	414805	7598078		6	0.5	417536	7598076
	4	0.5	415373	7598344		4	0.5	417573	7598108
	1	0.5	415398	7598328		10	0.5	417611	7598095
	4	0.5	415628	7598299		5	0.5	417611	7598153
	3	0.5	415642	7598296		10	0.5	417635	7598162
	20	0.5	415660	7598289		30	1	417654	7598145
	5	0.5	415703	7598297		10	0.5	417671	7598127
	20	1	415726	7598294		5	0.5	417704	7598101
	10	0.5	415751	7598296		2	0.5	417716	7598329
	1	0.5	415933	7598303		8	0.5	417799	7598066
	3	0.5	415974	7598022		6	0.5	417816	7598095
	4	0.5	416021	7598062		6	0.5	417842	7598132
	5	0.5	416059	7598100		3	0.5	417853	7598147
	2	0.5	416077	7598100		3	0.5	417865	7598113
	2	0.5	416081	7598367		8	0.5	417903	7598110
	8	0.5	416085	7598109		5	0.5	417922	7598103
	4	0.5	416093	7598125		9	0.5	417941	7598095
	1	0.5	416123	7598081		1	0.5	417986	7597984
	1	0.5	416135	7598132		2	0.5	418158	7598016
	30	2	416135	7598369		1	0.5	418301	7597624
	2	0.5	416141	7598064		2	0.5	418344	7598236
	4	0.5	416158	7598103		7	0.5	418351	7597980
	7	0.5	416181	7598133		2	0.5	418365	7598255
	20	2	416194	7598381		3	0.5	418420	7598164
	2	0.5	416225	7598067		10	0.5	418435	7598154
	30	3	416226	7598405		2	0.5	418445	7598171
	2	0.5	416251	7598141		1	0.5	418446	7598353
	6	0.5	416254	7598073		6	0.5	418469	7598137

Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)	Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)
Rhynchosia bungarensis P4	4	0.5	416466	7598138	*Rhynchosia bungarensis* P4	5	0.5	418663	7598161
	6	0.5	416488	7598127		6	0.5	418693	7598166
	2	0.5	416496	7598065		2	2	418695	7598048
	1	0.5	416848	7598067		6	0.5	418727	7598286
	4	0.5	417356	7598199		2	0.5	418736	7598075
	1	0.5	417371	7598516		1	0.5	418737	7597974
	20	1	417465	7598189		4	0.5	418740	7598167
	2	0.5	417491	7598142		2	0.5	418759	7597794
	10	1	417512	7598340		4	0.5	418762	7598089
	6	0.5	417536	7598076		5	0.5	418773	7598077
	4	0.5	417573	7598108		4	0.5	418775	7598529
	10	0.5	417611	7598095		3	0.5	418790	7597802
	5	0.5	417611	7598153		5	0.5	418795	7598185
	10	0.5	417635	7598162		2	0.5	418806	7598187
	30	1	417654	7598145		9	0.5	418817	7598192
	10	0.5	417671	7598127		7	0.5	418849	7598163
	5	0.5	417704	7598101		5	0.5	418859	7597858
	2	0.5	417716	7598329		2	0.5	418877	7597945
	8	0.5	417799	7598066		3	0.5	418877	7598323
	6	0.5	417816	7598095		7	0.5	418899	7597853
	6	0.5	417842	7598132		3	0.5	418906	7597946
	3	0.5	417853	7598147		2	0.5	418907	7598476
	3	0.5	417865	7598113		10	0.5	418908	7597862
	8	0.5	417903	7598110		1	0.5	418909	7598126
	5	0.5	417922	7598103		3	0.5	418916	7598293
	9	0.5	417941	7598095		1	0.5	418930	7598069
	1	0.5	417986	7597984		6	0.5	418947	7597952
	2	0.5	418158	7598016		3	0.5	418948	7598180
	1	0.5	418301	7597624		2	0.5	418954	7598163
	2	0.5	418344	7598236		3	0.5	418955	7598495
	7	0.5	418351	7597980		9	0.5	418966	7597872
	2	0.5	418365	7598255		3	0.5	418979	7597957
	3	0.5	418420	7598164		1	0.5	418980	7597906
	10	0.5	418435	7598154		6	0.5	418981	7598515
	2	0.5	418445	7598171		2	0.5	418992	7598426
	1	0.5	418446	7598353		5	0.5	418998	7597953
	6	0.5	418469	7598137		4	0.5	419000	7597887
	4	0.5	418491	7598124		3	0.5	419002	7598341
	2	0.5	418499	7597981		4	1	419035	7598644
	3	0.5	418502	7598138		4	0.5	419056	7597950
	1	0.5	418504	7598399		20	2	419057	7597885
	1	0.5	418557	7598433		1	0.5	419093	7597968
	1	1	418578	7597972		50	2	419116	7597893
	10	0.5	418606	7598044		3	0.5	419129	7598357
	10	0.5	418613	7598142		20	1	419141	7597891
	20	1	418627	7598270		5	0.5	419159	7597898
	8	0.5	418629	7598148		1	0.5	419161	7597974
	2	1	418644	7597970		10	0.5	419168	7597899
	5	0.5	418645	7598481		4	0.5	419188	7597913

Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)	Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)
Rhynchosia bungarensis P4	1	0.5	419208	7598490	*Rhynchosia bungarensis* P4	50	0.5	420041	7597662
	3	0.5	419221	7597963		30	0.5	420052	7597604
	1	0.5	419227	7597968		5	0.5	420103	7598415
	4	0.5	419232	7597934		20	0.5	420133	7597620
	1	0.5	419388	7598588		5	0.5	420205	7598435
	1	0.5	419440	7598052		10	0.5	420301	7597920
	1	0.5	419441	7598295		6	0.5	420418	7597801
	1	0.5	419457	7598286		6	0.5	420440	7597773
	20	0.5	419475	7597992		15	0.5	420503	7597712
	3	0.5	419482	7598268		20	0.5	420571	7597607
	2	0.5	419490	7598605		1	0.5	420942	7596814
	4	0.5	419494	7598267		70	10	422132	7597001
	20	0.5	419495	7597999		30	1	422282	7596921
	40	0.5	419511	7597997		10	1	422363	7596860
	10	0.5	419527	7598002		20	5	422460	7596783
	2	0.5	419530	7598041		2	0.5	422562	7597259
	1	0.5	419535	7598266		20	0.5	423095	7596405
	30	0.5	419547	7598006		40	0.5	423110	7596398
	1	0.5	419556	7598008		2	0.5	423123	7596816
	20	0.5	419572	7598002		50	1	423143	7596387
	1	0.5	419573	7598594		50	2	423176	7596375
	4	0.5	419576	7598028		50	1	423186	7596355
	30	0.5	419586	7598001		7	0.5	423197	7596822
	1	0.5	419591	7598024		10	0.5	423205	7596823
	40	0.5	419609	7597991		30	1	423236	7596355
	5	0.5	419631	7598591		40	0.5	423279	7596812
	10	0.5	419657	7597960		30	0.5	423295	7596351
	2	0.5	419691	7598566		100	7	423416	7596786
	3	0.5	419796	7598175		100	3	423474	7596781
	20	0.5	419803	7597932		70	1	423527	7596785
	3	0.5	419814	7598168		60	1	423573	7596787
	20	0.5	419830	7597928		50	0.5	423619	7596790
	50	0.5	419854	7597915		20	0.5	423658	7596795
	10	0.5	419869	7597911		2	0.5	427656	7600448
	20	0.5	419883	7597904		10	0.5	427812	7600656
	50	0.5	419894	7597899		5	0.5	427990	7600923
	1	0.5	419905	7597973		5	1	428352	7600867
	50	0.5	419914	7597886		50	8	428392	7600904
	1	0.5	419917	7598059		100	1	428495	7600907
	3	0.5	419928	7598050		20	0.5	428617	7600938
	50	0.5	419942	7597858		50	0.5	428620	7600891
	2	0.5	419952	7598090		5	0.5	428642	7600994
	50	0.5	419962	7597829		400	NA	428670	7601055
	50	0.5	419968	7597818		15	NA	428937	7601233
	40	0.5	419974	7597807		50	NA	429005	7601246
	40	0.5	419989	7597784		3	NA	429093	7601254
	50	0.5	420016	7597737		2	NA	429165	7601266
	3	0.5	420023	7597990		3	NA	429215	7601269
	30	0.5	420032	7597697		2	NA	429278	7601257

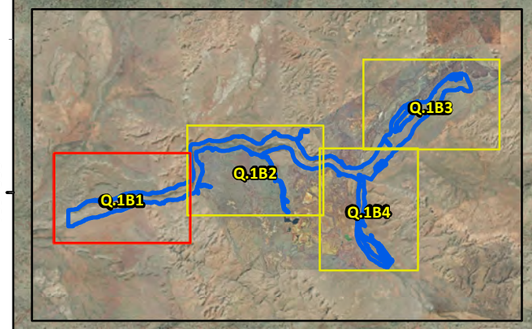
Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)	Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)
Rhynchosia bungarensis P4	3	0.5	429577	7601363	*Triodia* sp. Robe River (M.E. Trudgen et al. MET 12367) P3	10	0.5	423200	7596821
	10	0.5	429754	7601346		1	0.5	424876	7592488
	10	0.5	429757	7601347		1000	NA	429087	7601416
	40	0.5	429781	7601319					
	70	0.5	429801	7601303					

Table Q.2: Descriptions of Priority flora recorded in the survey area.

Species	Description	Habitat
Triodia sp. Robe River (M.E. Trudgen et al. MET 12367) P3	Hummock grass (WAHerb 1998-2016).	Rocky outcrops, breakaways, hillslopes and crests, and drainage lines (WAHerb 1998-2016).
Livistona alfredii P4	Perennial tree-like monocot (palm), to 10 m high (WAHerb 1998-2016).	Occurs on edges of permanent pools (WAHerb 1998-2016).
Rhynchosia bungarensis P4	Compact, prostrate shrub to 0.5 m high. Flowers yellow (WAHerb 1998-2016).	Pebbly, shingle coarse sand amongst boulders. Banks of flow line in the mouth of a gully in a valley wall (WAHerb 1998-2016).

407000 408000 409000 410000 411000 412000 413000 414000

7597000 7596000 7595000 7594000 7593000



Robe River

Legend

- River/Creek
- Mesa H Riparian Community Survey Area

Introduced Flora (Astron 2016c)

- **Aerva javanica* (Kapok Bush)
- **Cenchrus ciliaris* (Buffel Grass)
- **Cenchrus setiger* (Birdwood Grass)
- **Citrullus colocynthis* (Colocynth)
- **Cynodon dactylon* (Couch Grass)
- **Euphorbia hirta* (Asthma Plant)
- **Passiflora foetida* var. *hispida* (Stinking Passion Flower)
- **Setaria verticillata* (Whorled Pigeon Grass)
- **Vachellia farnesiana* (Mimosa Bush)

Robe River Mining Co. Pty Ltd

Mesa H Riparian Community Assessment - June 2016

Figure Q.1B1: Introduced Plant Species (Weed) Locations

Datum: GDA 1994 - Projection: MGA Zone 50

0 500 1,000 metres

N

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Author: D. Roocke | Drawn: W. An | Date: 06-04-2017 | Figure Ref: 14269-16-BIDR-1RevB_170406_FigQ1B_Weed

415000 416000 417000 418000 419000 420000 421000

7599000 7598000 7597000 7596000 7595000

Millstream Rd

Robe River

Q.1B1 Q.1B2 Q.1B3 Q.1B4

Legend

- Railway
- Main Road
- River/Creek
- Mesa H Riparian Community Survey Area

Introduced Flora (Astron 2016b, Astron 2016c)

- **Aerva javanica* (Kapok Bush)
- **Argemone ochroleuca* subsp. *ochroleuca* (Mexican Poppy)
- **Bidens bipinnata* (Bipinnate Beggartick)
- **Cenchrus ciliaris* (Buffel Grass)
- **Cenchrus setiger* (Birdwood Grass)
- **Citrullus colocynthis* (Colocynth)
- **Cynodon dactylon* (Couch Grass)
- **Echinochloa colona* (Awnless Barnyard Grass)
- **Euphorbia hirta* (Asthma Plant)
- **Flaveria trinervia* (Speedy Weed)
- **Lactuca serriola* (Prickly Lettuce)
- **Malvastrum americanum* (Spiked Malvastrum)
- **Ocimum basilicum* (Basil)
- **Passiflora foetida* var. *hispida* (Stinking Passion Flower)
- **Phoenix dactylifera* (Date Palm)
- **Rumex vesicarius* (Ruby Dock)
- **Setaria verticillata* (Whorled Pigeon Grass)
- **Sonchus oleraceus* (Common Sowthistle)
- **Vachellia farnesiana* (Mimosa Bush)

Robe River Mining Co. Pty Ltd

Mesa H Riparian Community Assessment - June 2016

Figure Q.1B2: Introduced Plant Species (Weed) Locations

Datum: GDA 1994 - Projection: MGA Zone 50

0 500 1,000 metres

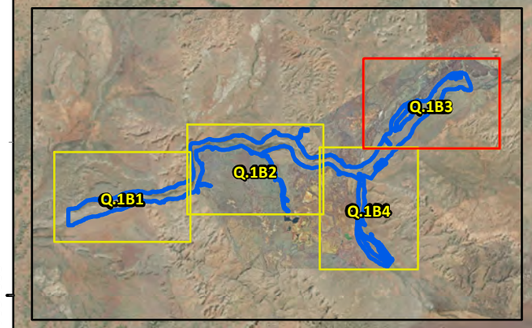
N

astron delivering environmental intelligence™

Author: D. Roocke | Drawn: W. An | Date: 06-04-2017 | Figure Ref: 14269-16-BIDR-1RevB_170406_FigQ1B_Weed

425000 426000 427000 428000 429000 430000 431000

7602000 7601000 7600000 7599000 7598000



Robe River

Legend

- Railway
- River/Creek
- Mesa H Riparian Community Survey Area

Introduced Flora (Astron 2016a)

- **Aerva javanica* (Kapok Bush)
- **Argemone ochroleuca* subsp. *ochroleuca* (Mexican Poppy)
- **Cenchrus ciliaris* (Buffel Grass)
- **Cenchrus setiger* (Birdwood Grass)
- **Citrullus colocynthis* (Colocynth)
- **Cynodon dactylon* (Couch Grass)
- **Euphorbia hirta* (Asthma Plant)
- **Lactuca serriola* (Prickly Lettuce)
- **Malvastrum americanum* (Spiked Malvastrum)
- **Passiflora foetida* var. *hispida* (Stinking Passion Flower)
- **Rumex vesicarius* (Ruby Dock)
- **Setaria verticillata* (Whorled Pigeon Grass)
- **Solanum nigrum* (Black Berry Nightshade)
- **Sonchus oleraceus* (Common Sowthistle)
- **Vachellia farnesiana* (Mimosa Bush)

Introduced Flora (Astron 2016c)

- **Argemone ochroleuca* subsp. *ochroleuca* (Mexican Poppy)
- **Cenchrus ciliaris* (Buffel Grass)
- **Cenchrus setiger* (Birdwood Grass)
- **Cynodon dactylon* (Couch Grass)
- **Echinochloa colona* (Awnless Barnyard Grass)
- **Euphorbia hirta* (Asthma Plant)
- **Malvastrum americanum* (Spiked Malvastrum)
- **Melochia pyramidata*
- **Passiflora foetida* var. *hispida* (Stinking Passion Flower)
- **Sonchus oleraceus* (Common Sowthistle)
- **Vachellia farnesiana* (Mimosa Bush)

Robe River Mining Co. Pty Ltd

Mesa H Riparian Community Assessment - June 2016

Figure Q.1B3: Introduced Plant Species (Weed) Locations

Datum: GDA 1994 - Projection: MGA Zone 50

0 500 1,000 metres

N

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Author: D. Roocke | Drawn: W. An | Date: 06-04-2017 | Figure Ref: 14269-16-BIDR-1RevB_170406_FigQ1B_Weed

422000 423000 424000 425000 426000 427000

7597000 7596000 7595000 7594000 7593000 7592000 7591000

Robe River

Jimmawurrada Creek

Millstream Rd

Legend

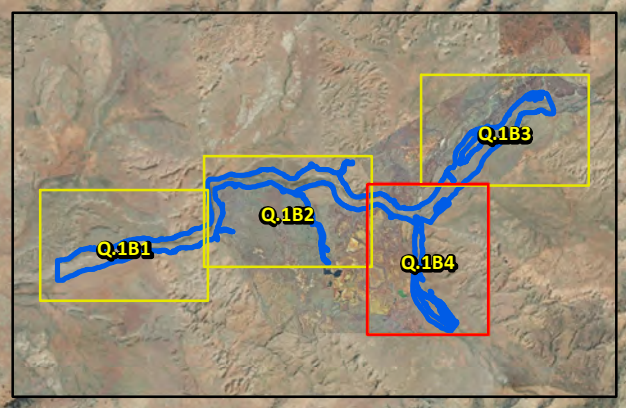
- Railway
- Main Road
- River/Creek
- Mesa H Riparian Community Survey Area

Introduced Flora (Astron 2016a)

- **Aerva javanica* (Kapok Bush)
- **Argemone ochroleuca* subsp. *ochroleuca* (Mexican Poppy)
- **Cenchrus ciliaris* (Buffel Grass)
- **Cenchrus setiger* (Birdwood Grass)
- **Chloris barbata* (Purpletop Chloris)
- **Citrullus colocynthis* (Colocynth)
- **Cynodon dactylon* (Couch Grass)
- **Datura leichhardtii* (Native Thornapple)
- **Echinochloa colona* (Awnless Barnyard Grass)
- **Flaveria trinervia* (Speedy Weed)
- **Lactuca serriola* (Prickly Lettuce)
- **Malvastrum americanum* (Spiked Malvastrum)
- **Passiflora foetida* var. *hispida* (Stinking Passion Flower)
- **Rumex vesicarius* (Ruby Dock)
- **Setaria verticillata* (Whorled Pigeon Grass)
- **Solanum nigrum* (Black Berry Nightshade)
- **Sonchus oleraceus* (Common Sowthistle)
- **Vachellia farnesiana* (Mimosa Bush)

Introduced Flora (Astron 2016b, Astron 2016c)

- **Cenchrus ciliaris* (Buffel Grass)
- **Cenchrus setiger* (Birdwood Grass)
- **Chloris barbata* (Purpletop Chloris)
- **Citrullus colocynthis* (Colocynth)
- **Echinochloa colona* (Awnless Barnyard Grass)
- **Euphorbia hirta* (Asthma Plant)
- **Flaveria trinervia* (Speedy Weed)
- **Malvastrum americanum* (Spiked Malvastrum)
- **Passiflora foetida* var. *hispida* (Stinking Passion Flower)
- **Rumex vesicarius* (Ruby Dock)
- **Setaria verticillata* (Whorled Pigeon Grass)
- **Vachellia farnesiana* (Mimosa Bush)



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Mesa H Riparian Community Assessment - June 2016

Figure Q.1B4: Introduced Plant Species (Weed) Locations

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Author: D. Roocke	Date: 06-04-2017	Coordinate System: GDA94 MGA zone 50
Drawn: W. An	Figure Ref: 14269-16-BIDR-1RevB_170406_FigQ1B_Weed_4	0 200 400 600 800 1,000 Metres; N

Table Q.3: Locations of introduced flora recorded in the survey area (MGA Zone 50, GDA 94).

Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)	Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)
**Aerva javanica*	1	0.5	408971	7594632	**Argemone ochroleuca* subsp. *ochroleuca*	100	1	418525	7598278
	1	0.5	414512	7597629		25	1	418814	7598215
	1	0.5	417776	7598306		20	0.5	418823	7598115
	4	0.5	417818	7598277		50	0.5	418824	7598082
	5	0.5	417845	7598268		100	10	418826	7598453
	10	5	418310	7598211		50	0.5	418876	7598081
	500	20	419016	7598782		25	0.5	418878	7598452
	1	0.5	419734	7598561		50	0.5	418932	7598480
	10	0.5	419854	7597914		20	0.5	418991	7598074
	3	0.5	419872	7597913		15	0.5	418993	7598520
	8	0.5	420083	7598409		50	0.5	419009	7598339
	50	10	420487	7598715		250	10	419044	7598151
	2	0.5	423846	7596818		20	0.5	419076	7598442
	1	0.5	425713	7598973		25	1	419081	7597897
	50	5	426057	7598867		25	0.5	419097	7598522
	20	0.5	426074	7599563		20	0.5	419119	7598478
	1	0.5	426203	7600051		10	0.5	419133	7597936
	5	2	427137	7599894		50	5	419141	7598195
	4	0.5	429957	7601526		100	0.5	419187	7598362
**Argemone ochroleuca* subsp. *ochroleuca*	50	0.5	414400	7595938		7	0.5	419190	7597935
	50	1	414411	7595777		15	0.5	419243	7597954
	250	40	414440	7596026		50	0.5	419295	7597951
	50	2	414446	7596068		50	0.5	419329	7597968
	500	30	414454	7595887		25	0.5	419333	7598320
	10	0.5	414529	7595497		100	0.5	419371	7598007
	100	2	414550	7595627		20	0.5	419374	7597986
	250	20	414664	7596122		10	0.5	419458	7598045
	10	1	414695	7596117		20	0.5	419483	7595796
	20	0.5	415500	7598159		5	0.5	419488	7597998
	20	0.5	415576	7598226		20	0.5	419522	7595075
	10	0.5	415916	7598222		5	0.5	419534	7598006
	1	0.5	415945	7598237		75	0.5	419587	7598051
	25	0.5	416415	7598321		75	0.5	419692	7597959
	25	0.5	416663	7598135		50	0.5	419822	7598415
	25	0.5	416751	7598139		20	0.5	419870	7597911
	100	10	416870	7598064		25	0.5	419924	7598395
	75	2	417228	7598024		25	0.5	420019	7598419
	10	0.5	417547	7597929		3	0.5	420374	7597827
	10	0.5	418210	7598162		50	0.5	420517	7597654
	50	10	418250	7598181		100	2	422276	7597391
	50	1	418362	7598193		50	2	422553	7596707

Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)	Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)
**Argemone ochroleuca* subsp. *ochroleuca*	500	0.5	422638	7597167	**Cenchrus ciliaris*	100	1	414897	7596613
	75	0.5	423139	7596809		500	10	415971	7597885
	1	0.5	418373	7597453		7	1	416050	7597874
	10	0.5	418426	7598187		500	2	416080	7597876
	50	0.5	423228	7596434		2	0.5	416423	7598116
	50	0.5	423462	7596519		1	0.5	416435	7598043
	2500	10	423968	7596855		100	20	416983	7598570
	50	0.5	423968	7596194		250	20	417029	7598583
	2500	40	424062	7596859		100	10	417234	7598543
	50	0.5	424114	7596936		500	10	417522	7598452
	250	0.5	424649	7597182		500	10	417610	7598412
	0	0.5	424653	7597185		250	1	417629	7598380
	250	0.5	425090	7597510		25	1	417738	7598321
	50	0.5	425998	7598607		1	0.5	417769	7597687
	250	0.5	426416	7598922		1	0.5	417769	7597667
	250	5	427700	7600417		1	0.5	417769	7597708
	100	2	427754	7600593		1	0.5	417787	7597889
	250	5	427956	7600835		6	0.5	417828	7598128
	0	0.5	428366	7601264		4	0.5	417937	7598118
	100	0.5	428368	7601235		2	0.5	417940	7598092
	2	0.5	428445	7601006		3	0.5	417967	7597966
	100	0.5	429158	7601303		250	30	418280	7597464
	5	0.5	429163	7601361		50	0.5	418381	7597453
	200	0.5	429169	7601400		500	2	418397	7597458
	500	0.5	429177	7601437		400	3	418417	7597454
	100	0.5	429344	7601395		20	1	418434	7597978
	100	0.5	429354	7601456		50	0.5	418436	7597450
	10	0.5	430008	7601565		99	3	418442	7597418
**Bidens bipinnata*	100	1	418229	7598181		850	16	418462	7597415
	500	50	414440	7595989		600	4	418482	7597412
**Cenchrus ciliaris*	200	2	408945	7594759		10	0.5	418645	7598042
	500	2	408946	7594749		10	1	418820	7597894
	200	0.5	408951	7594720		10	5	418841	7597975
	1	0.5	408960	7594667		400	2	418866	7596762
	11	0.5	410208	7594869		5	0.5	418952	7598082
	2	0.5	412676	7595360		10	0.5	418965	7597968
	6	0.5	412691	7595294		2	0.5	419101	7597972
	11	0.5	412704	7595288		1000	20	419168	7597898
	17	0.5	413880	7595587		10	2	414376	7597615
	20	0.5	413880	7595625		250	5	414547	7595466
	2	0.5	413881	7595577		100	2	414655	7595430
	5	0.5	413895	7595561		75	1	419463	7595062

Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)	Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)
**Cenchrus ciliaris*	250	4	414843	7596468	**Cenchrus ciliaris*	250	1	419494	7595530
	250	5	414858	7596503		1000	30	419503	7595060
	300	8	419516	7595527		50	0.5	424028	7595766
	2500	20	419520	7595076		1000	10	424029	7596796
	350	10	419529	7595518		1000	10	424042	7592639
	5000	20	419530	7595649		100	1	424057	7592259
	5000	20	419532	7594945		2500	20	424062	7592356
	100	5	419534	7598005		2500	20	424156	7592276
	250	4	419553	7595510		2500	20	424166	7592224
	75	5	419565	7598002		400	8	424267	7592020
	1000	35	419574	7595497		600	20	424277	7592036
	100	5	419620	7597986		2500	20	424278	7596268
	5	0.5	419631	7594408		500	12	424293	7592050
	75	0.5	419685	7597962		150	2	424311	7592071
	20	0.5	419871	7597911		500	4	424324	7592085
	10	0.5	419969	7597816		500	10	424337	7592100
	2500	10	420053	7598410		2500	20	424476	7596659
	8	0.5	420117	7597420		100	5	424505	7592739
	5	0.5	420166	7597963		500	40	424542	7591624
	100	5	420357	7598195		10	0.5	424649	7597184
	1000	10	420359	7598474		0	0.5	424653	7597185
	2	0.5	420723	7597303		100	30	424866	7597679
	20	1	420734	7598904		250	5	424870	7592464
	100	10	422732	7596490		100	10	424915	7592330
	25	0.5	423192	7596362		1250	12	425262	7591196
	75	0.5	423573	7596445		800	1	425274	7591211
	1000	10	423795	7593086		700	10	425288	7591226
	500	5	423800	7593009		700	6	425304	7591248
	500	5	423822	7592926		2500	80	425313	7591848
	350	10	423829	7595090		350	6	425317	7591263
	900	16	423841	7595017		700	3	425332	7591275
	3000	20	423848	7595095		100	5	425481	7598498
	1000	10	423853	7592795		250	5	425522	7598120
	1000	1	423864	7595023		0	15	425684	7599079
	500	1	414692	7595778		1000	10	425702	7599268
	5	0.5	419294	7598014		1000	30	425706	7591423
	50	0.5	419418	7598327		1000	10	425715	7598982
	2	0.5	419453	7598049		1000	10	425731	7599042
	1000	15	423869	7595099		50	5	423930	7592607
	1500	18	423885	7595036		1000	10	423950	7596049
	1000	10	423888	7592708		200	1	423967	7595850
	1000	10	423925	7592625		250	5	423970	7596197

Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)	Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)
**Cenchrus ciliaris*	150	0.5	423983	7595775	**Cenchrus setiger*	100	5	419510	7595523
	15	0.5	423997	7595850		5000	40	419521	7595076
	12	0.5	424002	7595773		200	10	419526	7595524
	300	1	424017	7595839		5000	40	419530	7595649
	250	20	426967	7599913		50	5	422731	7596521
	450	14	427114	7600166		500	10	422758	7597149
	1000	4	427127	7600151		250	3	423660	7596795
	3	0.5	427139	7600135		1000	10	423795	7593087
	40	0.5	427172	7600100		500	5	423801	7593009
	100	20	427187	7599901		500	5	423822	7592926
	100	10	428013	7600984		350	10	423823	7595097
	10	0.5	428444	7601003		900	16	423837	7595024
	100	3	428591	7601574		1000	8	423842	7595099
	2500	10	428602	7601679		1000	10	423854	7592794
	5	0.5	429185	7601478		500	1	423856	7595029
	2500	30	429206	7602125		100	5	423862	7595102
	1000	5	429529	7601476		1500	18	423875	7595035
	2500	30	429605	7602138		1000	10	423887	7592709
	0	15	425853	7599612		1000	10	423924	7592626
	500	7	426002	7599722		2500	20	423928	7592576
	2500	20	426057	7598867		2500	20	423947	7592519
	2500	20	426073	7599459		1000	10	423951	7596047
	500	7	426219	7600052		2500	0.5	423972	7592427
	250	20	426353	7599815		2500	20	423975	7596669
	500	10	426555	7600114		12	0.5	424012	7595773
	250	30	426934	7600181		10	0.5	424017	7595849
**Cenchrus setiger*	50	0.5	408953	7594770		400	8	424258	7592020
	20	0.5	408956	7594751		100	5	424272	7592035
	100	0.5	408959	7594731		500	12	424299	7592051
	250	3	414868	7596529		150	2	424303	7592070
	250	5	414892	7596572		100	1	424323	7592093
	2	0.5	417764	7597683		500	10	424336	7592107
	1	0.5	417962	7597984		1000	60	424394	7592003
	1	0.5	417965	7597959		1000	10	424478	7596663
	25	0.5	418365	7597428		2500	80	424503	7591796
	500	2	418401	7597452		2500	80	424632	7591691
	400	3	418421	7597448		2500	20	424663	7597368
	70	1	418432	7597455		2500	30	424759	7596788
	99	1	418446	7597411		5000	20	419540	7594931
	850	16	418456	7597410		250	4	419558	7595513
	100	0.5	418486	7597405		10	0.5	419577	7595506
	100	1	419488	7595537		99	10	419617	7594394

Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)	Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)
**Cenchrus setiger*	25	0.5	419676	7598570	**Citrullus colocynthis*	3	0.5	408948	7594739
	100	1	419801	7598537		10	2	414449	7595898
	100	1	419852	7598520		4	1	414510	7597987
	100	1	419938	7598471		15	30	416018	7597876
	250	2	419982	7598441		1	1	417090	7598588
	100	10	420511	7598785		4	1	417314	7598554
	2500	80	425320	7591866		3	5	417374	7598480
	1000	50	425328	7591935		2	0.5	417944	7598041
	300	1	425338	7591279		1	0.5	418086	7598077
	1000	30	425576	7598616		1	1	418159	7598107
	0	4	425684	7599079		1	0.5	418398	7597429
	1000	10	425700	7599260		3	0.5	418476	7597984
	1000	10	425716	7598982		1	0.5	418815	7597862
	1000	10	425731	7599042		1	0.5	419050	7596320
	0	10	425853	7599612		1	0.5	419060	7597915
	500	10	425943	7599486		1	0.5	420258	7597177
	1000	10	426056	7598867		1	0.5	424715	7592542
	2500	20	426073	7599460		3	0.5	425116	7597362
	100	2	426275	7600088		1	0.5	426503	7600124
	100	2	426555	7600115		1	0.5	428374	7601470
	450	14	427113	7600160	**Cynodon dactylon*	15	0.5	408949	7594729
	500	5	428591	7601574		5	0.5	408958	7594676
	2500	10	428602	7601679		25	0.5	412666	7595356
	2500	30	429204	7602124		3	0.5	412687	7595304
	1000	5	429531	7601476		3	0.5	412694	7595285
	2500	30	429606	7602138		1	0.5	412710	7595270
	1000	10	424760	7596791		5	0.5	413871	7595622
	2500	70	425087	7591333		2	0.5	413885	7595557
	2500	80	425125	7592076		1	0.5	413886	7595600
	250	10	425125	7597192		75	1	414396	7596748
	2500	80	425164	7591825		1	0.5	414397	7597027
	1250	12	425254	7591197		1	0.5	414402	7597069
	800	1	425266	7591213		1	0.5	414405	7597083
	700	10	425279	7591228		3	0.5	414837	7596656
	600	5	425296	7591250		3	0.5	415952	7598235
	350	6	425310	7591264		50	2	418702	7598300
**Chloris barbata*	3	0.5	423645	7596794		10	0.5	418903	7597956
	1	0.5	423967	7592443		1	0.5	418928	7598067
	5	0.5	425365	7591157		10	2	418991	7598191

Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)	Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)
**Cynodon dactylon*	100	0.5	419295	7597953	**Euphorbia hirta*	1	0.5	412698	7595275
	1	1	419482	7598571		2	0.5	413876	7595645
	1	0.5	419394	7598589		7	0.5	413889	7595548
	1	0.5	419409	7598604		2	0.5	415953	7598268
	1	1	419435	7598585		10	0.5	424189	7592093
	1	0.5	419547	7598580		7	0.5	424265	7592028
	1	0.5	420736	7597337		25	5	425147	7591399
	1	0.5	421871	7597055		1	0.5	425285	7591236
	100	60	422591	7596682		2	0.5	425310	7591251
	1000	50	423322	7596406		20	0.5	425886	7599393
	10	0.5	423871	7595103		10	0.5	427526	7600339
	2	0.5	424755	7597476		15	0.5	428488	7600934
	7	0.5	427183	7600085		3	0.5	429182	7601459
	20	1	427765	7600615	**Flaveria trinervia*	6	0.5	418787	7597881
**Datura leichhradtii*	3	0.5	424178	7596839		2	0.5	422744	7596453
						10	0.5	425111	7591962
**Echinochloa colona*	1	0.5	419534	7595539	**Lactuca serriola*	1	0.5	414411	7597087
	15	0.5	423361	7596400		4	0.5	417739	7598059
	3	0.5	423936	7592562		15	0.5	417757	7598064
	1	0.5	424165	7592224		10	0.5	417911	7598016
	1	0.5	429173	7601444		10	0.5	422676	7596598
**Euphorbia hirta*	4	0.5	416413	7598144		2	0.5	427577	7600393
	1	0.5	416419	7598111		6	0.5	427876	7600719
	5	0.5	417532	7598132		3	0.5	427918	7600783
	5	0.5	419500	7595491	**Malvastrum americanum*	2	0.5	419446	7598575
	2	0.5	420367	7597873		1	5	419527	7598002
	100	0.5	423795	7593086		100	0.5	419530	7595650
	100	0.5	423799	7593010		1	0.5	419555	7595503
	100	0.5	423822	7592927		10	0.5	419572	7595501
	2	0.5	423833	7595099		4	0.5	419617	7594401
	1	0.5	423847	7595026		2	0.5	419911	7598491
	100	0.5	423851	7592796		3	0.5	420530	7598776
	100	0.5	423889	7592707		15	0.5	422702	7596380
	20	0.5	423899	7592664		5	0.5	423817	7592882
	50	0.5	423924	7592626		10	0.5	423822	7592927
	50	20	423928	7592576		6	0.5	423834	7595089
	50	20	423946	7592520		5	0.5	423849	7595016
	50	0.5	423970	7592432		30	0.5	423852	7595101
	20	0.5	423977	7595850		50	0.5	423853	7592796
	2	0.5	423993	7595775		1	0.5	423873	7595094
	25	0.5	424167	7592221		50	20	423947	7592520

Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)	Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)
**Malvastrum americanum*	50	0.5	423889	7592707	**Melochia pyramidata*	1	0.5	427171	7600093
	50	0.5	423922	7592626					
	50	20	423924	7592572	**Ocimum basilicum*	15	5	417910	7598016
	1	0.5	416347	7598053					
	1	0.5	418366	7597442	**Passiflora foetida* var. *hispida*	3	0.5	411094	7594963
	1	0.5	418397	7597454		3	0.5	412704	7595257
	15	1	425398	7591887		2	0.5	413873	7595638
	20	1	425449	7591709		4	0.5	418347	7597418
	0	0.5	425684	7599079		5	1	418371	7597974
	10	1	425718	7591486		3	0.5	418440	7597973
	15	0.5	425730	7599042		20	2	418510	7597972
	4	0.5	426202	7600052		3	0.5	418613	7597961
	2	0.5	427798	7600634		3	1	418698	7598058
	5	0.5	428603	7601680		1	0.5	418705	7597957
	2	0.5	429171	7601434		5	5	418748	7598081
	15	0.5	429208	7602131		2	0.5	418778	7598079
	50	0.5	429606	7602138		1	0.5	418869	7598396
	1000	5	423952	7596047		4	0.5	418879	7598063
	15	0.5	423971	7592432		1	0.5	418929	7598073
	1	0.5	423993	7595765		6	10	418938	7598153
	10	0.5	424043	7592639		1	0.5	418984	7598424
	3	0.5	424062	7592356		1	0.5	419004	7598340
	3	0.5	424153	7592277		4	0.5	419023	7597958
	25	0.5	424168	7592222		2	0.5	413874	7595612
	3	0.5	424272	7592022		2	1	414355	7597175
	1	0.5	424286	7592036		1	0.5	414377	7595951
	50	0.5	424310	7592757		8	2	414405	7596632
	10	1	424459	7591764		1	0.5	414415	7597050
	1	0.5	424528	7592651		3	0.5	414437	7597080
	10	1	424553	7591676		4	0.5	414509	7596776
	15	0.5	424643	7597353		1	0.5	414753	7597974
	3	0.5	424867	7592496		1	0.5	414964	7595806
	50	0.5	425060	7591269		5	5	416329	7598047
	15	0.5	425142	7592200		3	0.5	416414	7598114
	2	0.5	425260	7591205		1	0.5	416423	7598091
	5	0.5	425273	7591220		3	0.5	416432	7598038
	30	0.5	425293	7591229		5	2	416479	7598061
	8	0.5	425302	7591251		6	0.5	416629	7598140
	1	0.5	425324	7591265		1	1	416723	7598125
	15	0.5	425375	7591164		5	2	416758	7598069

Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)	Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)
**Passiflora foetida* var. *hispida*	10	0.5	416794	7598164	**Passiflora foetida* var. *hispida*	75	0.5	419329	7597968
	2	0.5	417004	7598208		20	0.5	419357	7598043
	2	0.5	417194	7598153		1	0.5	419358	7598331
	3	0.5	417260	7598136		75	0.5	419370	7598008
	1	0.5	417931	7598105		20	0.5	419390	7598007
	20	4	417933	7598119		20	0.5	419402	7598047
	3	0.5	417964	7598084		1	0.5	419413	7598324
	4	0.5	417968	7597991		1	0.5	419415	7598327
	5	0.5	418111	7597998		20	0.5	419440	7598052
	3	0.5	418218	7597978		10	0.5	419446	7597991
	20	0.5	419490	7597999		1	0.5	423823	7592926
	20	0.5	419505	7598050		25	3	423825	7595096
	10	0.5	419511	7598119		1	0.5	423828	7592847
	20	0.5	419534	7598006		30	2	423842	7595021
	10	0.5	419542	7598104		2	0.5	423850	7592796
	10	0.5	419552	7598031		3	0.5	423865	7595098
	10	0.5	419561	7598139		15	1	423866	7595031
	20	0.5	419564	7598002		1	0.5	423887	7595027
	5	0.5	419586	7598095		1	0.5	423888	7592759
	1	0.5	419616	7598277		2	0.5	423890	7592706
	10	0.5	419625	7598131		1	0.5	423923	7592625
	10	0.5	419647	7598115		2	0.5	423929	7592593
	10	0.5	419684	7597962		50	2	423935	7596392
	1	0.5	419055	7598271		5	0.5	419701	7598112
	10	2	419084	7598204		1	0.5	419821	7598126
	2	0.5	419101	7597976		1	0.5	419855	7598276
	4	3	419102	7598317		2	0.5	419875	7597993
	10	0.5	419134	7598206		20	0.5	419895	7597898
	1	0.5	419146	7597961		3	0.5	419920	7597951
	10	2	419149	7598234		20	0.5	419942	7597859
	1	0.5	419162	7598298		10	0.5	419944	7597933
	1	0.5	419169	7598362		10	0.5	419970	7597814
	1	0.5	419188	7597970		20	0.5	419982	7597906
	20	0.5	419190	7597935		1	0.5	419985	7598058
	20	0.5	419212	7597949		2	0.5	419986	7597809
	7	0.5	419213	7597986		20	0.5	419989	7597932
	10	0.5	419248	7598000		2	0.5	420018	7597732
	20	0.5	419265	7597974		2	0.5	420586	7597598
	20	0.5	419292	7598014		2	0.5	420695	7597393
	10	0.5	419323	7598029		4	1	420718	7597298

Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)	Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)
**Passiflora foetida* var. *hispida*	4	1	420724	7597328	**Rumex vesicarius*	5	0.5	419241	7598357
	6	2	420735	7597351		15	0.5	419274	7598332
	6	6	421875	7597096		1	0.5	419577	7598287
	5	3	421875	7597071		6	0.5	419728	7598444
	7	3	421877	7597050		1	0.5	419912	7598280
	4	0.5	421886	7596993		100	1	422196	7597231
	5	1	422196	7597111		10	0.5	422460	7597344
	50	10	422479	7596768		2	0.5	422760	7597095
	10	5	422737	7596420		1	0.5	424643	7596978
	25	1	423087	7596423		1	0.5	414474	7595610
	10	0.5	423132	7596810		10	0.5	414504	7597491
	10	0.5	423219	7596825		4	0.5	418550	7598288
	5	0.5	423389	7596788		1	0.5	419097	7598274
	20	0.5	423773	7596419		5	0.5	419194	7598359
	1	0.5	423938	7592560		10	0.5	419220	7598312
	5	0.5	423953	7596047		1	1	425435	7591151
	3	0.5	423957	7592480		2	0.5	427726	7600478
	15	0.5	423977	7596671	**Setaria verticillata*	1	0.5	413877	7595619
	4	0.5	423977	7595840		2	0.5	418392	7597457
	1	0.5	423997	7595840		50	0.5	418437	7597413
	1	0.5	424007	7595849		500	2	419521	7595076
	1	0.5	424012	7595763		99	0.5	420726	7597338
	20	0.5	424031	7596800		5	0.5	423353	7596395
	1	0.5	424040	7592637		50	0.5	423830	7595096
	20	0.5	424061	7596863		5	0.5	423837	7592784
	8	0.5	424135	7596902		40	0.5	423845	7595020
	6	0.5	424211	7596904		100	0.5	423853	7595091
	6	0.5	424308	7597028		30	1	423868	7595021
	1	0.5	424514	7597025		10	0.5	423869	7595095
	1	0.5	424839	7592491		1000	10	423954	7596048
	3	2	427651	7600448		20	0.5	423970	7595846
	4	2	427699	7600581		10	0.5	423986	7595772
	20	20	427783	7600631		40	0.5	423987	7595850
	3	5	427985	7600549		1000	10	424032	7596799
	1	0.5	429162	7601305		4	0.5	424298	7592069
	3	0.5	429182	7601442		1000	10	424641	7597350
	1	0.5	430042	7601579		10	0.5	425286	7591228
**Phoenix dactylifera*	3	10	415371	7598339		12	0.5	425302	7591257
	5	10	415568	7598295		1	0.5	425316	7591271

Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)	Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)
**Setaria verticillata*	10	0.5	425454	7591200	**Vachellia farnesiana*	1	0.5	419549	7595438
	0	0.5	425684	7599079		10	0.5	419563	7595502
	5	0.5	425701	7599267		1	0.5	419568	7595510
	15	0.5	425730	7599042		1	0.5	419881	7598512
	0	0.5	425853	7599612		1	0.5	419602	7598562
	3	0.5	426206	7600024		4	0.5	408955	7594726
	20	1	428043	7601028		8	10	414586	7595503
	10	0.5	428591	7601574		15	2	414627	7595452
	100	0.5	428636	7601704		2	0.5	414636	7595813
	1	0.5	429795	7601309		1	0.5	414912	7595795
**Solanum nigrum*	2	0.5	422629	7596629		1	5	416002	7597896
	50	0.5	423826	7595093		1	0.5	416293	7598059
	1	0.5	423860	7595027		2	1	417065	7598586
	1	0.5	423877	7596758		1	0.5	417482	7598129
	5	0.5	424178	7596831		2	2	418204	7597525
	4	0.5	427556	7600390		2	0.5	418868	7596739
	2	0.5	427680	7600450		1	0.5	418999	7598649
	3	0.5	427735	7600593		2	2	419037	7597967
	6	0.5	427836	7600664		1	0.5	419522	7595466
	2	0.5	428005	7600965		6	1	424557	7591640
**Sonchus oleraceus*	4	0.5	417926	7598079		3	0.5	424760	7596790
	10	0.5	417954	7598071		1	0.5	424797	7592472
	5	0.5	419527	7595459		4	0.5	424891	7597740
	1	0.5	419540	7595516		1	0.5	419936	7598465
	250	0.5	423088	7596425		10	10	420536	7598797
	25	0.5	423237	7596442		7	3	420645	7598965
	5	0.5	423388	7596458		2	0.5	420694	7598934
	15	0.5	423906	7596659		1	0.5	423641	7596793
	100	0.5	423974	7595843		9	0.5	423822	7592925
	2	0.5	423988	7595768		1	0.5	423831	7595093
	1	0.5	423999	7596656		2	0.5	423879	7592697
	20	0.5	424029	7596796		10	0.5	423891	7592706
	10	0.5	424433	7597069		10	0.5	423921	7592626
	15	0.5	427520	7600359		10	0.5	423931	7592579
	20	0.5	427722	7600581		5	0.5	423953	7596047
	10	0.5	427758	7600492		3	0.5	423966	7592449
	10	0.5	427814	7600648		1	0.5	424006	7595769
	5	0.5	429165	7601407		6	0.5	424042	7592639
	70	0.5	429173	7601438		1	0.5	424062	7592356

Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)	Species	Estimated abundance	Density (%)	Easting (mE)	Northing (mN)
**Vachellia farnesiana*	4	0.5	424168	7592222	**Vachellia farnesiana*	20	3	425780	7598818
	3	0.5	424263	7592020		0	0.5	425853	7599612
	1	0.5	424278	7592043		9	6	425943	7599340
	99	0.5	424285	7592050		25	5	425957	7598911
	2	0.5	424333	7592766		3	0.5	425979	7599216
	5	2	424439	7591781		10	1	426050	7598909
	1	0.5	424987	7592353		15	10	426386	7599825
	20	5	425207	7591403		1	0.5	426504	7600127
	1	0.5	425268	7591198		2	0.5	427064	7600086
	2	0.5	425280	7591214		1	0.5	427182	7600078
	1	0.5	425324	7591278		3	1	427198	7599923
	10	2	425454	7591685		3	2	427484	7600534
	0	0.5	425684	7599079		10	2	428421	7601506
	15	0.5	425729	7599042		50	10	429609	7602138

Table Q.4: Description of introduced flora recorded in the survey area.

Species	Description	Habitat
**Aerva javanica* (Kapok Bush) 	An erect, much-branched perennial, herb between 0.4 m and 1.6 m high. It has white woolly flowers arranged in spikes between January and October (WAHerb 1998-2016).	Often on sandy soils, along drainage lines (WAHerb 1998-2016).
**Argemone ochroleuca* subsp. *ochroleuca* (Mexican Poppy) 	An erect, prickly, glaucous annual herb between 0.2 m and 1 m in height with white, cream and yellow flowers between February/March and July/November (WAHerb 1998-2016).	Generally along creek edges, riverbanks and roadsides. Occurs in red/white/grey sand and red-brown clay loam (WAHerb 1998-2016).
**Bidens bipinnata* (Bipinnate Beggartick) 	An erect annual herb growing to 1 m high. Produces yellow flowers from March to September (WAHerb 1998-2016).	Occurs in a variety of soils including alluvium, clay, loam over sandstone and limestone. Habitat preferences include rivers, creeks, coastal areas and rocky hillsides (WAHerb 1998-2016).
**Cenchrus ciliaris* (Buffel Grass) 	A tufted or sometimes stoloniferous perennial grass between 0.2 m and 1.5 m in height with purple, ciliate flowers between February and October. Seedheads form a dense hairy cylindrical spike to 10 cm long (WAHerb 1998-2016).	**C. ciliaris* favours sand but may also establish in loamy and clayey soils. It is a widespread weed of roadsides, creek lines and river edges (WAHerb 1998-2016).

Species	Description	Habitat
**Cenchrus setiger* (Birdwood Grass) 	An erect, tussock, stoloniferous perennial grass that grows to 0.5 m high. It has cream to purple flowers that occur from April to May (WAHerb 1998-2016).	**C. setiger* favours brown sands, red loam and pindan soils. It is often found on sand dunes, plains, rangelands, stony hillsides and floodplains (WAHerb 1998-2016).
* *Chloris barbata* (Purpletop Chloris) 	Annual or perennial (short-lived), grass, between 0.4 m and 1.1 m high. It has purple flowers in February or between April and October (WAHerb 1998-2016).	Occurs on white or red sand, loam, and black clay, often on sand dunes and river levees (WAHerb 1998-2016).
**Citrullus colocynthis* (Colocynth) 	A trailing perennial, herb or climber with deeply lobed, scabrous leaves. It has greenish yellow flowers between January and October. Fruits are a spherical melon, mottled green and yellow or all yellow with dull yellow-brown seeds (WAHerb 1998-2016).	Commonly occurs on sandy, rocky, stony loam, clay and wet soils; often in floodplains and disturbed areas (WAHerb 1998-2016).
**Cynodon dactylon* (Couch Grass) 	A rhizomatous (or stoloniferous), prostrate perennial grass from 0.05 m to 0.3 m high. Flowers are green or purple June to November (WAHerb 1998-2016).	**C. dactylon* occurs in sand, loam or clay habitats (WAHerb 1998-2016).

Species	Description	Habitat
**Datura leichhardtii* (Native Thornapple) 	A stout annual herb, between 0.2 m and 1 m high. It has solitary white flowers between June and October. The fruits are bright green (WAHerb 1998-2016).	Occurs mostly on alluvial soils, often along watercourses (WAHerb 1998-2016).
**Echinochloa colona (*Awnless Barnyard Grass) 	A tufted annual grass between 0.2 m and 0.9 m high. It has a green/purple inflorescence between February and July (WAHerb 1998-2016).	Occurs on black sand and black clay, near watercourses and swamps (WAHerb 1998-2016).
**Euphorbia hirta (*Asthma Plant) 	An erect or prostrate much branched hairy annual herb, growing between 0.1 m and 0.8 m high. Leaves are opposite, narrowly ovate with dark red blotches. Yellow-green-white axillary flowers are produced between January and October (WAHerb 1998-2016).	Occurs on alluvial soils, often along watercourses (WAHerb 1998-2016).
**Flaveria trinervia* (Speedy Weed) 	An erect annual herb, with ovate leaves. It has yellow flowers clustered to form a dense inflorescence (WAHerb 1998-2016).	Occurs in a variety of soils, particularly sandy and clayey sites. Typically occurs in drainage lines (WAHerb 1998-2016).

Species	Description	Habitat
**Lactuca serriola* (Prickly Lettuce) 	Erect annual or biennial herb 0.4 m to 2 m high. Flowers yellow, October to February (WAHerb 1998-2016).	Roadsides, gardens, cultivated fields, disturbed sites (WAHerb 1998-2016).
**Malvastrum americanum* (Spiked Malvastrum) 	An erect, hairy perennial herb or shrub between 0.5 m and 1.3 m in height. Flowers are yellow and orange, between April and July (WAHerb 1998-2016).	**M. americanum* occurs in a variety of sandy and clayey soils, as well as in limestone and calcrete. It typically occurs along stony ridges and hillsides, floodplains and along drainage lines (WAHerb 1998-2016).
**Melochia pyramidata* (Basil) 	A sprawling to erect woody perennial shrub 0.3 m to 1.5 m high. Flowers are white or pink or purple or blue, flowering from March to October (WAHerb 1998-2016).	**M. pyramidata* grows in alluvium, sand and black clay, and occurs along rivers and creeks (WAHerb 1998-2016).
**Ocimum basilicum* (Basil) 	Aromatic annual or perennial herb to 0.6 m high. Blue-purple, pink and/or white flowers from February to August (WAHerb 1998-2016).	Sandy soils and disturbed areas (WAHerb 1998-2016).

Species	Description	Habitat
**Passiflora foetida* var. *hispida* (Stinking Passion Flower) 	A woody climber to 9 m high with an unpleasant smell. It produces cream-white or blue flowers from February to November (WAHerb 1998-2016).	**P. foetida* var. *hispida* is commonly found in coastal areas, rivers and creek banks (WAHerb 1998-2016).
**Phoenix dactylifera* (Date Palm) 	A perennial tree-like monocot (palm) between 0.4 m to 8 m high. It produces flowers from July to September (WAHerb 1998-2016).	It is found on the edges of permanent pools and watercourses (WAHerb 1998-2016).
**Rumex vesicarius* (Ruby Dock) 	An erect, fleshy annual herb to 1 m high. Produces red-pink flowers from July to September (WAHerb 1998-2016).	Occurs in a variety of habitats and soils, including sandy alluvial and gravelly ironstone soils. Often occurs along roadsides and other disturbed areas (WAHerb 1998-2016).
**Setaria verticillata* (Whorled Pigeon Grass) 	A loosely tufted annual grass, 0.1 m to 1.3 m high. It flowers from December to June (WAHerb 1998-2016).	**S. verticillata* is found on sand, clay and loam. It is a common weed of disturbed areas and riverine edges (WAHerb 1998-2016).

Species	Description	Habitat
**Solanum nigrum* (Black Berry Nightshade) 	An erect perennial (short-lived) herb or shrub from 0.3 m to 1 m high. It produces flowers from January to December. It has dull black or purplish fruits (WAHerb 1998-2016).	It is a common weed in agriculture and bushland. Occurs in disturbed areas, pastures, creeklines, wetlands, woodland in sand, yellow-clayey sand, brown gritty clay, red sandy clay (WAHerb 1998-2016).
**Sonchus oleraceus* (Common Sowthistle) 	An erect, fleshy annual herb to 1 m high. Produces red-pink flowers from July to September (WAHerb 1998-2016).	Occurs in a variety of habitats and soils, including sandy alluvial and gravelly ironstone soils. Often occurs along roadsides and other disturbed areas (WAHerb 1998-2016).
**Vachellia farnesiana* (Mimosa Bush) 	An erect, sprawling, thicket-forming shrub or tree up to 4 m in height. It has dark grey, rough bark, pinnate leaves and long stiff thorns at right angles to the stems. Branchlets are also covered in rough, light coloured “wart”-like markings. It produces globular yellow flowers from June to August (WAHerb 1998-2016).	**V. farnesiana* favors low lying areas, disturbed areas and river and creeks banks (WAHerb 1998-2016).

Appendix R: Flora Survey Effort

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410000
415000
420000
425000
430000
7600000
7595000
7590000
Pannawonica
Millstream Rd
Robe River
Jimmawurrada Creek

Legend

- Railway
- Main Road
- River/Creek
- GPS Tracklogs
- Mesa H Riparian Community Survey Area

Robe River Mining Co. Pty Ltd
Mesa H Riparian Community Assessment - June 2016

Figure R.1: Flora Survey Effort

Datum: GDA 1994 - Projection: MGA Zone 50

0 500 1,000 1,500 2,000 2,500 3,000 metres

N

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delivering environmental intelligence™

Author: D. Roocke | Drawn: W. An | Date: 06-04-2017 | Figure Ref: 14269-16-BIDR-1RevB_170406_FigR1_SurveyEffort

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Assessment of Groundwater Dependent Vegetation distribution on the Robe River - Targeted Riparian Vegetation Survey – Stage 1

High confidence mapping of the distribution of Obligate and Facultative Phreatophytic Vegetation between Mesa A and East Deepdale deposits on the Robe River

June 2018

RTIO-HSE-0325261

Disclaimer and Limitation

This report has been prepared by Rio Tinto Iron Ore (Rio Tinto). Neither the report nor its contents may be referred to without the express approval of Rio Tinto, unless the report has been released for referral and assessment of proposals.

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1 INTRODUCTION

In the West Pilbara region of Western Australia the Robe River drains a sizeable portion of the catchment of the Western Hamersley Ranges. The historic paleo-channel of this River system has formed a string of pisolitic mesa shaped hills (also known as Channel Iron Deposits (**CID**)). Concurrent to this process, the hydrology of the West Pilbara in combination with local geology and topography have created the current pathway of the drainage has formed the Robe River, which provides habitats, riparian ecosystems and ecological values of local and potentially sub-regional significance.

As part of the process of recovering CID mineral resources, consideration of the potential to impact these local environmental assets is essential. For riparian systems, where the resident biological features are typically a clear reflection of the hydrological (and physical) characteristics of the river system, identifying the sensitivity and significance of these features is critical to inform an assessment of potential hydrological change.

In addition to considering potential impacts, the respective spatial distribution and significance of the ecological values present are of key importance to better understand the characteristics of riparian communities in the Robe River. Of particular focus is the distribution of Groundwater Dependent Ecosystems (**GDE**s) and Groundwater Dependent Vegetation (**GDV**) within the area, in addition to the varying scales of hydrological sensitivity held by resident vegetation types throughout the relevant stretches of the Robe River.

The groundwater dependent ecosystems of Australia represent a diverse, yet distinct component of the nation's biological diversity. Based on initial work by Hatton and Evans (1998), and further considerations by SKM (2001); six major types have been identified:

- **terrestrial vegetation** – vegetation communities and dependent fauna that have seasonal or episodic dependence on groundwater;
- **river base flow systems** – aquatic and riparian ecosystems that exist in or adjacent to streams that are fed by groundwater base flow;
- **aquifer and cave ecosystems** – aquatic ecosystems that occupy caves or aquifers;
- **wetlands** – aquatic communities and fringing vegetation dependent on groundwater fed lakes and wetlands;
- **terrestrial fauna** – native animals that directly use groundwater rather than rely on it for habitat;
- **estuarine and near-shore marine ecosystems** – coastal, estuarine and near shore marine plant and animal communities whose ecological function has some dependence on discharge of groundwater.

Three GDEs are of relevance to the Robe River; Pools (Wetland or River base-flow system types), Riparian Vegetation (Terrestrial vegetation type), and stygofaunal assemblages (Aquifer and cave ecosystem type).

The current study focusses on identifying GDV as an indicator for the presence of "Terrestrial Vegetation" type GDEs. As part of this process, key pools within the study area will be delineated to provide information about the distribution and abundance of Aquifer type GDEs.

Vegetation mapping is one of the primary tools for identifying key riparian ecological values; their spatial location within a system; and their inherent sensitivity to perturbations. Accurate, sufficiently detailed and complete riparian vegetation mapping is also important for guiding current and future riparian monitoring, and contextualising local to sub-regional significance. Furthermore; when considering in detail the potential for complex hydrological impacts, a more detailed scale of mapping is required for accurate, measured and more meaningful management and mitigation.

The four key aims of this study are:

1. To gather widespread, detailed and high confidence spatial information on the distribution of Robe River GDV, particularly those Obligate Phreatophytic Vegetation (**OPV**) communities surrounding resources in the Robe Valley.

2. Gather and incorporate information on the structure, age distribution, maturity and potential permanence/transience of resident OPV communities such that the resultant vegetation mapping is more strongly positioned to assess significance and groundwater dependence.

3. Describe and map all riparian communities throughout the study area, to a high level of detail, and in a manner prioritising the identification of all potentially groundwater dependent ecosystems and their distribution.

4. Based on the structure, maturity and distribution of mapped phreatophytic vegetation: provide an interpretation of the significance and inherent sensitivity of these communities to potential hydrological change in the form of interpreted risk mapping throughout the area of interest.

The current report outlines the Stage 1 work undertaken to achieve these aims within the relevant stretches of the Robe River surrounding Rio Tinto Robe Valley operations. Figure 1-1 shows the extent of the current study area and the boundaries of previous flora and vegetation surveys.

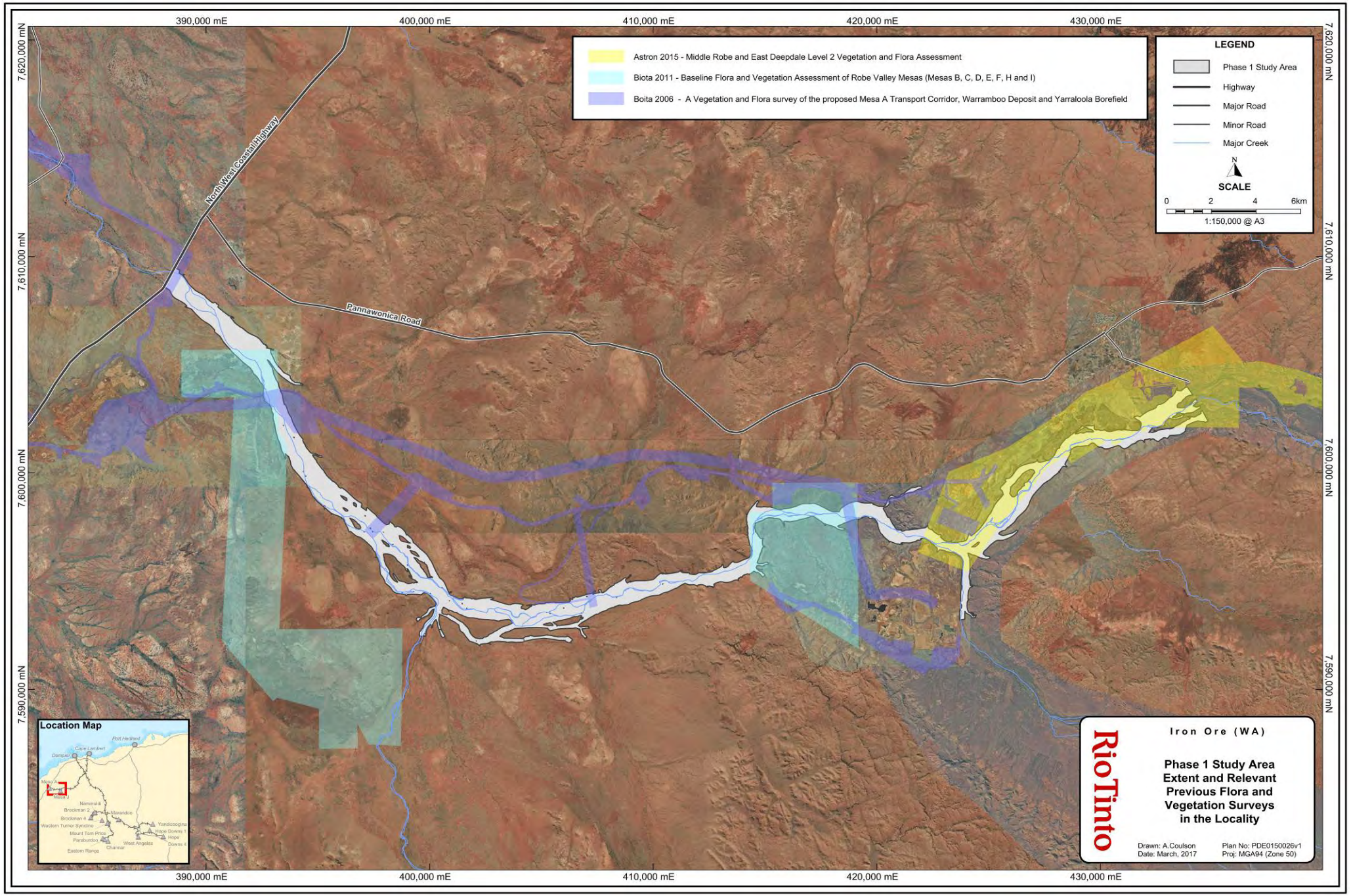

Figure 1-1: Extent of Robe River covered by the Stage 1 Study Area; includes the study boundaries of previous key flora and vegetation surveys.

2 BACKGROUND

2.1 RIVERS OF THE PILBARA REGION

The Pilbara is a relatively large arid region of the North West of WA. This region incorporates a number of large rivers which includes but is not limited to; the De Grey, Maitland, Harding, Turner, Oakoaver, Nullagine, Shaw, Yule, Fortescue Ashburton and Robe. Within the Pilbara region; major catchment divides are provided by the Chichester and Hamersley Ranges. The Chichester Range, a great undulating plateau forms a water shed between north flowing river systems (including the Harding, Maitland, Yule Turner and De-Grey) and the westerly flowing Fortescue River. The north flowing rivers begin dendritic and lead downstream to well-developed coastal drainage systems; with braided channels and discontinuous anabranches. On the southern flank of the Chichester Range and the north and south flanks of the Hamersley Plateau; streams are generally relatively short, dendritic, and often terminate in coalescing outwash fans on the alluvial plains of the Fortescue and Ashburton Rivers. The Fortescue River is long but is interrupted by extensive floodout lowlands of the Fortescue Marsh and associated claypans (Massini 1988).

The ephemeral rivers of the Pilbara are generally dry, experiencing major seasonal flows in a number of rivers almost every year. These flows are typically derived from tropical lows and cyclones which frequent the tropical north between December and April.

2.2 PHREATOPHYTIC VEGETATION / SPECIES, AND GROUNDWATER DEPENDENT ECOSYSTEMS IN THE PILBARA

Riparian systems of the Pilbara bioregion are subjected to extremely seasonal and variable hydrologic regimes in which stream flow typically occurs following cyclonic rainfall events (Ruprecht and Ivanescu 2000). Large flow events can result in the formation of isolated pools, replenish floodplain soil moisture and recharge groundwater within the riparian system.

In creeks and rivers of the Pilbara, groundwater is typically contained within shallow, unconsolidated sedimentary aquifers close (<20 m) to the surface (Landman 2001). In some instances, groundwater reaches the surface and natural springs are formed, maintaining permanent surface water pools. These shallow aquifers and springs often support GDEs; natural ecosystems that require access to groundwater to meet some or all of their water requirements to maintain their communities of plants and animals, and ecological processes (Sommer and Froend 2011).

While this study is focused on identifying GDV as an indicator of the broad “terrestrial vegetation” GDE type, it is also of importance to consider the hydrogeological processes and characteristics which might be supporting such vegetation to further understand the potential dependency of local phreatophytic vegetation. In recognition of the river landforms which are the focus of this study, it is also pertinent to consider broad GDE linked to such landforms and how they might influence the characteristics of local GDV. In Australia, several types of GDEs have been recognised (Clifton and Evans 2001), including river base-flow systems that comprise lotic aquatic and riparian ecosystems that rely wholly or partially on groundwater for their maintenance, function and integrity. Base flow is the component of total stream flow that is derived from groundwater, and reflects aquifer permeability, local and regional geology, bank and floodplain storage and the topography of the water table (Newson 1994). Under certain geomorphic conditions, some of this groundwater enters

streams and rivers from discrete springs and seeps, frequently supporting specialised aquatic fauna and flora (Williams *et al.* 1997; Halse *et al.* 2002; Fensham *et al.* 2004). More commonly, most base flow derives from groundwater that seeps in from the channel margins and floodplains via the parafluvial zone or enters from below via the hyporheic zone. The hyporheic zone is defined as the saturated sediments below and alongside the river channel where stream and groundwater exchange, and its functional significance to the ecology of surface river ecosystems is being increasingly recognised (Brunke and Gonser 1997; Boulton *et al.* 1998; Dent *et al.* 2000).

In many rivers draining arid and semi-arid Australia, discharge for most of the time is solely from the base flow (Boulton and Williams 1996). Furthermore; in many ephemeral rivers of the arid tropical zone, base flow typically only ever appears as very intermittent surface expressions (pools). For this reason, the ongoing interaction of the various source and sink components which influence the magnitude and at times cessation of local base flow, are generally wholly unknown.

GDEs comprise plant species that, in the absence of rainfall, rely directly on groundwater (and associated surface expressions) but may also contain grass and herbaceous species relying on recent rainfall (Sommer and Froend 2011). Plant species which draw water from the saturated zone (the phreatic zone) or capillary fringe of the water table are known as phreatophytes and the presence of GDEs is often inferred from the presence of such species (Eamus *et al.* 2006). Phreatophytes can usually be found along streams where there is a steady flow of surface or groundwater, or consistent still pools in areas where the water table is near the surface.

At the opposite end of the scale is a “xerophyte”, which is essentially a species of plant which has adapted to survive in an environment with little access to water (Salisbury and Ross 1992). Terms used to describe the water use strategies of plants occupying various positions within the Phreatophyte to Xerophyte scale are: “Obligate Phreatophyte”; “Facultative Phreatophyte”; and “Vadophyte”.

It is generally considered that any vegetation that uses groundwater is potentially at risk of impact if it occurs in a location where the groundwater would be lowered beyond assumed natural groundwater variation. However, the impact on vegetation from lowering the groundwater table is likely to be relative to the species’ dependence upon groundwater, and on the alternative sources of moisture available to it in any one situation. For example, plants that rely on water sourced directly from the groundwater table (phreatophytes) are more likely to show signs of decline or be lost than those that can rely on sources of soil moisture (i.e. vadophytes) such as precipitation and soil pore moisture anomalies from other sources. An assessment of the groundwater dependence of species present within the study area has been informed by a desktop literature review, with specific reference to previous vegetation association mapping and an understanding of the surface water and underlying groundwater environment.

Not all phreatophytic species display the same degree of dependency on groundwater and the dependency within species has been shown to vary both spatially and temporally (Eamus and Froend 2006). Obligate phreatophytes are those species for which access to groundwater is critically important to their presence in the landscape. Such species can only inhabit areas where they have access to groundwater in order satisfy at least some proportion of their environmental water requirements (**EWR**) (Eamus *et al.* 2006). Facultative phreatophytes, on the other hand, are plant species for which access to groundwater is not necessarily important to their presence in the

landscape. Facultative phreatophytes may utilise groundwater to satisfy a proportion of their EWR but, if required, may also satisfy their total EWR via stored soil water reserves (Eamus *et al.* 2006).

The tree species *Eucalyptus camaldulensis* subsp*. refulgens* Brooker & M.W. McDonald (River Red Gum), *Eucalyptus victrix* L.A.S.Johnson & K.D.Hill (Coolibah) and *Melaleuca argentea* W.Fitzg (Silver Cadjeput – historically identified as *M. leucadendra*) are the three most common phreatophytic species within riparian systems of the Pilbara bioregion. A fourth, *Sesbania formosa*, while less widespread and less accepted as a phreatophytic species, is also a relevant phreatophyte in Pilbara riparian systems. The presence of these species is often used to infer the presence of a GDE. These species vary in their degree of dependence on groundwater and this variation has a strong influence on their patterning and abundance within riparian systems. The most dependent of these species upon groundwater is *Melaleuca argentea*, which is considered to be an obligate phreatophyte.

Melaleuca argentea have previously been recorded within the study area in varying quantities. *Sesbania formosa*, another potentially obligate phreatophyte, is commonly scattered throughout those more mesic communities present within the study area. Table 2-1 presents an interpretation of the different classes of groundwater dependence (water use strategies) relevant to riparian plant groups in the Pilbara, and the most relevant species considered as being attributable to each. It should be noted that some of the detail presented in this table is the culmination of substantial observational experience gained by the author in the Pilbara. While broad concepts presented tend to be agreed with by relevant studies, some of the nuances presented in Table 2-1 are neither well accepted nor adequately supported by empirical data. Instead the detail is presented as a guide as to how these species are broadly observed to behave, for the purpose of informing the risk assessment conducted in this report. What is generally well accepted is that *Melaleuca argentea* is an obligate phreatophyte, and that *Eucalyptus camaldulensis* and *E. victrix* are facultative phreatophytes. Generally speaking there is a paucity of data on the remainder of species presented in the table.

Table 2-1: Tree species dependence on groundwater*

Species dependence on Groundwater	Plant Physiology/water use strategy	Relevant Species in the Pilbara
High	Obligate Phreatophyte	*Melaleuca argentea, Sesbania formosa (?)*
Moderate	Facultative phreatophyte (in anomalous cases a vadophyte)	*Eucalyptus camaldulensis*
Low to Moderate	Vadophyte or Facultative phreatophyte (in anomalous cases)	*Eucalyptus victrix, Melaleuca glomerata and Eucalyptus xerothermica*
Low (virtually negligible)	Xerophyte	E.g. *Eucalyptus leucophloia*, *Corymbia hamersleyana*, *Corymbia deserticola*, Corymbia candida

*The degrees of dependence on groundwater implied in this table are more relevant to specific species listed in this table rather than individuals of each species. It is acknowledged that individuals of a specific species may have established under conditions of high water availability, and thus may possess high degrees of groundwater dependence (and vise versa). Furthermore plant water use strategies listed are not mutually exclusive; vadophytes may access groundwater, and vice versa, phreatophytes will also access vadose soil water.

Vegetation associations occurring along the main drainage channels and associated flood plains within the study area support three native tree species that are considered to be at moderate or lower risk from groundwater drawdown: *Eucalyptus camaldulensis* subsp*. refulgens* (moderate risk);

Eucalyptus victrix (low to moderate risk); and *Corymbia candida* (low to minimal risk). These tree species are classified facultative phreatophytes or at times as vadophytes.

Eucalyptus camaldulensis is the most widespread Australian Eucalypt species and is known to tolerate an apparently wide range of water regimes (Colloff 2014). Eucalyptus camaldulensis (River Red Gum) is considered a facultative phreatophyte as it obtains its water for transpiration via three main sources: groundwater, river flooding (which over tops creek and river banks thereby replenishing floodplain soil moisture), and rainfall (Wen *et al*. 2009). The degree to which *E. camaldulensis* depends on groundwater and soil moisture has been found to vary both spatially and temporally (Mensforth *et al*. 1994, O'Grady *et al*. 2009, Wen *et al*. 2009, O'Grady *et al*. 2010). *E. camaldulensis* typically occurs along inland rivers and may be dependent on shallow groundwater for survival, although the root system may penetrate considerably deeper than 10 m. Studies in the Pilbara indicate that *E. camaldulensis* occurring along the larger drainage lines may have access to groundwater up to 21 m below the surface (AGC Woodward-Clyde 1992). Investigations at Marillana Creek found the vigour of large *E. camaldulensis* trees (>10 m tall) declined in response to lowering of groundwater levels caused by test pumping of water, while the vigour of smaller *E. camaldulensis* remained unchanged (Onshore Environmental 2013). This observation suggests that the species is capable of being both a vadophyte and a phreatophyte, using the former strategy when young and the latter strategy when mature (Halpern, Glink Maunsell 1999). Muir Environmental (1995) indicates that River red gum (*E. camaldulensis*) and Coolibah (*E. victrix*) are generally not restricted in their occurrences along Marillana Creek and thus cannot be considered as being true phreatophytes, but as vadophytes (i.e. primarily unsaturated soil dependent). In the case of *E. camaldulensis*, general observations in the Pilbara by Rio Tinto Botanists suggests that there is some degree of restriction to the distribution of this species along large creeks, and so the concept that this species can be both a phreatophyte and a vadophyte (depending on the circumstances) appears most accurate.

Eucalyptus victrix is a small to medium sized eucalypt which typically occurs on the drier zones of creeks and rivers throughout semi-arid Western Australia. Like *E. camaldulensis*, *E. victrix* is also considered to be a facultative phreatophyte. This species has been shown to access groundwater in areas where the depth to groundwater is low (O'Grady *et al.* 2009) but in non-riparian habitats, has also been shown to exploit shallow soil water to meet its transpiration needs (Grigg *et al.* 2008). *Eucalyptus victrix* is known to inhabit an ephemeral wetland (i.e. Mount Bruce Flats, Karijini National Park) despite the absence of a permanently saturated regolith (Rio Tinto 2011a). Comparisons of groundwater and stem xylem water stable isotope compositions as well as pre-dawn and midday leaf water potential measurements suggest that *E. victrix* within the Mount Bruce Flats in Karijini National Park uses water drawn from the unsaturated soil profile during extended dry periods (Rio Tinto 2011a). Further to this, *Eucalyptus victrix* (and potentially *Corymbia candida*) are generally considered to be examples of vadophytes being relatively drought tolerant but susceptible to decline when groundwater becomes limiting (Muir Environmental 1995).

Melaleuca argentea is a tree which grows to approximately 20 m (and higher) and is found along larger watercourses of the Pilbara. *Melaleuca argentea* is thought to be dependent on groundwater almost exclusively to meet its water requirements and is therefore considered to be an obligate phreatophyte (Lamontagne *et al.* 2005, Graham *et al.* 2003, Landman *et al.* 2003, O'Grady *et al.* 2006). Due to its dependence on groundwater, this species is typically found in parts of creeks and rivers characterised by permanently inundated pools and springs or where the water table is

permanently close to the surface (McLean *et al.* 2013). *Melaleuca argentea* is generally considered to be the plant taxon within the Hamersley Ranges at highest risk of impact through changes to groundwater availability associated with drawdown.

The water use characteristics of *E. camaldulensis, E. victrix* and *M. argentea* influences their response to mining related impacts such as dewatering and discharge. Dewatering, which causes localised lowering of groundwater levels, may be expected to have a significant impact on the health of *M. argentea* but lesser impacts on *E. victrix* and *E. camaldulensis*, provided adequate soil moisture is maintained from periodic, rainfall-generated stream flow. On the other hand, artificial discharge of surplus groundwater along ephemeral creeks and rivers may favour *M. argentea* (resulting in increased recruitment and vigour) by creating a perennial hydrologic regime. Change from a steady-state ephemeral hydrologic regime to a more perennial one may adversely impact *E. victrix* and to a lesser extent *E. camaldulensis*. Florentine (1999) found that *E. victrix* exhibits some tolerance to waterlogging (e.g. production of adventitious roots) but overall growth, transpiration rate and net photosynthesis are negatively affected under waterlogged conditions. By contrast, *E. camaldulensis* is considered to be one of the most waterlogging-tolerant eucalypt species (Bell 1999; van der Moezel *et al.* 1988), though empirical studies of its waterlogging tolerance in the Pilbara bioregion are lacking and results may be somewhat dependent on subspecies. At the local and micro scale the impacts of excess water will differ depending on the substrate and channel morphology and thus the relative position of trees (particularly on a vertical plane) to available water.

Probably the most important concept to consider when classifying the water use of plant species by attributing particular species to one of the above described water use strategies, is that typically plants and their associated environments do not always behave in definitive manners. While the physiological constraints and demands of the plant tend to be quite definite, the way in which the environment provides for this physiology and the way in which the plant acquires its needs from the environment can vary quite considerably in time and space (O'Grady *et al*. 2009). The most relevant area of variability in relation to the risk of death from changes in water availability is represented by a plants ratio of resource allocation between its canopy and root systems. The size and distribution of a plants root system (and conversely the size of its canopy and associated water demands) has a direct link to its ability to acquire sufficient moisture when soil conditions change (Salisbury and Ross 1992). The rate of water availability change therefore has important consequences for the ability of a plant to re-allocate these resources in time and therefore potentially to transition between the bounds of a phreatophyte and a vadophyte. Furthermore; the stem density of the vegetation a tree resides in has a strong influence on the stand water demands per unit of area and hence the resources available for each individual tree to compete for.

Another important point to consider when assigning species or communities to phreatophytic water use strategies is the source of moisture. While phreatophytic species are considered to be dependent on groundwater this is not always accurate in the context of the typical definition for groundwater. Groundwater is often considered to be represented by the underlying water table, but in the case of plant water use it is more accurately any source of water on, in or under the ground as long as its presence remains fairly consistent. For example; phreatophytic species can establish because stream morphology and/or underlying geology are such that specific areas sustain consistent alluvial water bodies or surface water pools and patches of moisture which are perched well above the underlying groundwater table. Subsequently these communities can be sustained by intermittent but relatively consistent fluvial flows, regardless of the behavior of deeper groundwater bodies. The reason such distinctions are important, is that in an impact assessment scenario,

potential changes to clearly detectable and therefore more broadly evident groundwater aquifers often comprise the only measurable features of hydrological influence acting on riparian systems. However despite such a focus, changes to broad scale groundwater features can often occur with little or no influence on small scale aquifers and surface water features consistently present in certain fluvial positions and situations.

The resounding message which becomes apparent when considering phreatophytic species is that not all phreatophytic species are equal. Each species considered has evolved in a different habitat using different life strategies and each habitat has varying degrees of water availability. An additional layer of complexity is represented by the various niches which these species have adapted to take advantage of within each habitat. As a result *Eucalyptus victrix* and *E. camaldulensis* have quite different adaptive capabilities and as such can survive and prosper in quite different water availability regimes.

GDEs and their associated species and landforms represent features of elevated ecological value. Phreatophytic species often represent fast growing pioneers which are highly resistant to disease. They also provide, shelter, specialised foraging grounds, and nesting/denning areas for native fauna. Phreatophytes are also known to be indicators of potable groundwater, and to provide water purification services, as their roots are known to fix heavy metals via the provision of bacteria driven filtration (World Heritage Encyclopedia 2014).

GDEs, generally represent areas with relatively permanent water (surface and/or groundwater), and as such tend to support relatively dense and diverse vegetation communities. Such vegetation tends to contain an above average proportion of mesic perennial and ephemeral species diversity, and so represents repositories of genetic diversity which are often restricted in their distribution and areal extent. Coupled with the diversity of fauna species (particularly avifauna, and nocturnal invertebrate fauna) which they support; their value is generally accepted to be high. It is for this reason that those species which are considered obligate phreatophytes, and therefore most dependent on water permanence, are those species which are the key indicators for the presence of these high value ecosystems. As an obligate phreatophyte *Melaleuca argentea* is a key indicator species for the Pilbara; the distribution, abundance and age structure of this species in the environment is often the best available measure for the presence and quality of high value groundwater dependent ecosystems. However, communities which occur in generally ephemeral habitats, and which do not possess an "obligate phreatophytic species" such as *Melaleuca argentea*, but instead only possess facultative phreatophytes such as *Eucalyptus camaldulensis;* can also be described as GDEs. For this reason it becomes important to make the distinction between general groundwater dependent ecosystems/vegetation, and those which are more specifically highly groundwater dependent, or "truly phreatophytic".

In the Pilbara, *M. argentea* is widely considered a strict obligate phreatophyte, and because of the potentially variable water use strategies of some of the other phreatophytic species in the Pilbara (namely facultative phreatophytes), *M. argentea* clearly represents the best indicator for true groundwater dependence. Therefore to provide a term or label which can be used to make the distinction between the less significant vegetation types, generally dominated by one or more facultative of phreatophytic species (general GDEs) and those adequately possessing "true" or obligate phreatophytes, the terms "Obligate Phreatophytic Vegetation" (**OPV**), and "Facultative Phreatophytic Vegetation (**FPV**) are proposed.

For the purpose of this study, the label/term "Obligate Phreatophytic Vegetation" (OPV) is defined as representing communities which:

> *Encompass vegetation associations and sub-associations, whose structure is at least co-dominated by one obligate phreatophyte, namely Melaleuca argentea (i.e. possesses vegetation described as being dominated by one or more species within the tree or tall shrub stratum and which includes the obligate phreatophyte Melaleuca argentea as one of these described dominant species). Note: this is not a well-recognized term, and has been created for the purpose of this and other studies from associated, well accepted terms such as "Obligate Phreatophytes" and "Groundwater Dependent Vegetation").*

The distinction this term makes is important for this study, as communities in which this species comprises a significant component, are best placed to indicate perennial water availability, and therefore indicate the distribution of ecological values associated with permanent water availability. By making this distinction this study can then differentiate between OPV and more commonly distributed GDEs represented by facultative phreatophytic vegetation (FPV) such as the *Eucalyptus camaldulensis* woodlands which tend to surround OPV. Consequently, for the purpose of this study, and to aid in the process of assessing the significance of riparian communities and their distribution within the study area; communities and vegetation associations/sub-associations within which *Melaleuca argentea* forms a co-dominant species are described as OPV (Obligate Phreatophytic Vegetation). The remaining communities only dominated by other facultative phreatophytic species (but potentially including those possessing *M. argentea* as an associated species only), are from here on in to be termed "Facultative Phreatophytic Vegetation" (**FPV**).

While it is acknowledged that such terms are not accepted in the wider ecological community, their use in this type of assessment is advantageous. Obviously it is acknowledged that vegetation includes all plant species in an area/ecosystem/habitat, and whilst some species may be phreatophytic, many are not. As a result the Terms OPV and FPV are not suggesting all components of the vegetation in question are groundwater dependent. Instead such labels are suggesting that the presence of the relevant phreatophytes are important riparian characteristics/components of the vegetation; particularly in relation to targeted vegetation surveys focusing on potential presence of GDE's. Phreatophytic components whose continued existence is likely dependent on continued access to groundwater are distinctive in terms of their attribution to vegetation units. For such vegetation; hydrological change leading to phreatophyte removal would in turn convert the resident vegetation into a vegetation unit which is compositionally, structurally and functionally different to the original unit to which the OPV/FPV label was applied.

The set of statutory listings for vegetation communities and ecosystems by the WA State or Commonwealth Government are not exhaustive and are generally based on a system of nomination, such that they do not represent a systematic treatment of features of high value or significance. Therefore unlisted flora and vegetation may be locally or regionally significant for similar reasons to those features chosen or nominated for listing. The EPA's Factor Guideline for flora and vegetation states that flora may be considered significant if the flora is locally endemic or associated with a restricted habitat type (e.g. surface water or groundwater dependent ecosystems), and vegetation may be considered significant if it provides an important function required to maintain ecological integrity of a significant ecosystem (EPA 2016a). However, this is not the only means by which biota can be attributed significance. Based on the *Technical Guide; Flora and Vegetation Surveys for*

Environmental Impact Assessment (EPA 2016b), and other sources; vegetation may be significant because its areal extent is below a threshold level and a range of other reasons, including:

- scarcity;
- high diversity or species richness;
- high diversity or species richness within special functional plant groups (e.g. mesic species, ephemeral taxa, xerophytic taxa etc.);
- unusual species, or range extension species;
- novel combinations of species (associations);
- a role as a refuge;
- a role as a key habitat for threatened species or large populations representing a significant proportion of the local to regional total population of a species;
- being representative of the range of a vegetation association (particularly; a good local and/or regional example of an association in "prime" habitat, at the extremes of known range, recently discovered range extensions, or isolated outliers of the main range);
- of restricted distribution at a local/sub-regional/regional scale or occupying a rare landform; and
- exceptional condition.

When considering development and associated impacts to vegetation, it is also important that a measure of sensitivity/resilience and in relevant cases transience be considered and attributed to riparian features of significance so that an element of risk can be attributed to their ultimate significance.

While *Melaleuca argentea* dominated/co-dominated communities generally represent the high significance OPV communities of the Pilbara because of their associated values and local perennial water availability, it is this dependence on a perennial water source which makes them the most sensitive to anthropogenic hydrological changes. Despite the inherent sensitivity of these communities the age structure and distribution of the respective sub-associations of *M. argentea* co-dominated communities present has some degree of influence on their sensitivity to impact. While young obligate phreatophyte individuals (when compared to mature individuals), typically tend to be more sensitive to changes in groundwater height (than mature individuals); this is not the full picture. Compared to mature obligate phreatophyte individuals; the temporal stability of young individuals/populations is generally significantly reduced due to the magnitude of peak flow scouring/deposition processes. Furthermore areas devoid of mature individuals can indicate that water availability is not stable enough to support their long term development. Based on field observations, the distribution of OPV communities dominated by a young age class appear to be restricted to specific habitats and areas where water availability is changing (either reducing, or increasing). As a result it is inferred that riparian OPV communities with an age frequency distribution restricted to young to semi-mature age classes are likely to delineate zones within the fluvial system where flow patterns and locally higher variability in water availability are limiting factors determining that the presence of OPV is highly transient. This temporal instability inferred to be a character of immature OPV communities is most likely to be a product of the increased degree of hydrological variability present in such areas. This conclusion is supported by the fact that

an age structure dominated by a narrow age range can often be aligned with a significant and recent hydrological (and/or potentially physical change) change that has enabled a mass colonisation event. Importantly; if hydrological change is high in such areas, and vegetation stability is low, then this will also determine that the vegetation supported will be inherently variable and so will the attributed significance. As a consequence; for such communities it is concluded that the significance of resident communities at any one time is significantly reduced.

For mature OPV communities the opposite is generally true. Those communities with structures increasingly dominated by large mature obligate phreatophytes are delineating the areas where vegetation is relatively stable and water availability is highly consistent thus enabling colonisation and development of high value ecosystems. The temporal stability and significant ecological values provided by such climax OPV determine that the attributed significance is inherently high. Furthermore; the most mature and commensurately significant representations of *M. argentea* woodland/forest are likely to be the most sensitive to change due to their generally high water demands (per unit of area), often broader lateral distribution within the fluvial profile, and their mature age frequency distribution. *Melaleuca argentea* communities which fall in between these two ends of the scale of maturity will generally possess sensitivities and associated significance commensurate to their water demands, predominant age and maximum distance from areas of consistent water availability.

2.3 LANDSCAPE FEATURES, FLUVIALS SYSTEMS AND THEIR ROLE IN SUPPORTING HIGH-VALUE RIPARIAN VEGETATION COMMUNITIES WITHIN THE HAMERSELY SUB-REGION

The climate of the Pilbara is essentially classified as arid-tropical possessing an average precipitation to evaporation ratio of less than 0.2 (McKnight and Hess 2000). With precipitation generally falling within the range of 250-450 mm, the Pilbara can be mistaken for being semi-arid, but with high average temperatures and an average evaporation rate in the vicinity of 2,000 mm per year, the effective precipitation in the region is minimal and therefore classified as arid. Because of such climatic factors, water gaining sites which are exposed to surface water supply from larger catchments and which can lock away significant amounts of water from evaporation, become quite important. Such fluvial systems create riparian corridors which provide refuge for a diversity of moisture loving species which wouldn't otherwise be present in areas possessing a similar climate classification. Consequently these features provide value to the region as custodians of biological diversity through their provision of ecological services and habitat diversity/complexity.

Beyond the general importance and functions of large river/creek systems in hot and often dry climates such as that of the Pilbara; drainage systems which provide the right catchment size and subsequent environmental conditions to create surface or groundwater permanence are considered most valuable. Those factors helping to create or contribute to surface and groundwater permanence within fluvial systems are generally represented by combinations of underlying geology (such as porous or impervious lithologies), topographic confinement, elevation, slope, meander shape and creek profile. Other landscape factors influencing water availability within fluvial systems can also be represented by the intersection of local perched aquifers, the distribution and size of groundwater recharge zones, sources and sinks to river base-flow, adjacent extensive clay-pan landforms (important for storage and sustained moisture release) and physical intersection of barriers to groundwater flow. These factors and more combine to provide the range of unique conditions valuable for the maintenance of permanent water availability and consistent groundwater levels. This value is primarily a product of the highly restricted and diverse ecosystems

they can sustain, and by association the fauna assemblages they support. These landscape attributes become increasingly valuable in arid environments due to the restricted distribution of their associated habitats and their ability to buffer the influence of climate variability and change.

2.4 THE ROLE OF MESIC SPECIES, PHREATOPHYTIC VEGETATION AND GDES IN IDENTIFYING VARYING DEGREES OF WATER AVAILABILITY

Within the Pilbara, riparian habitats which provide permanent surface or groundwater access are only common along certain reaches of the regions large river systems. While the more mesic reaches of such river systems are not common, they are large, and OPV is generally common through such areas. Beyond the river systems of the Pilbara, the remaining representations of OPV are quite restricted to parts of those large creek systems which function as drainage for significant catchments and contain optimal substrate conditions to maintain perennial surface and groundwater sources.

As discussed earlier; in the Pilbara, obligate phreatophytes such as *Melaleuca argentea* are highly dependent on permanent access to shallow freshwater. As a result of this dependence; this species is considered one of the best indicators of water permanence in the Pilbara. In general; the structure and composition of river and creekline vegetation tends to be driven by the degree of moisture present, and so vegetation is an important indicator of surface and groundwater permanence and can be used to assess the associated value and significance of the system. This approach is important as there are often no effective alternatives (at a finer scale) for establishing water permanence in an area. Human records are generally not extensive or detailed enough to truly determine if a site actually possesses surface or groundwater permanency. Furthermore, climatic factors can have a strong influence from year to year, and the underlying water table heights established from an often limited array of bores are difficult to accurately interpolate. Generally, the best and often only true indicator (over relevant timescales) of surface and groundwater permanence is the composition and structure of resident vegetation.

In the Pilbara, a list of sub-perennial to perennial moisture indicating (i.e. combinations of moisture present from 1 or more sources such as soil pore moisture, groundwater, capillary fringe etc.) genera/species (mesic indicator species) are likely to contain a number of the species presented in order of importance within Table 2-2 (Western Australian Herbarium 2018) (bold species identifies the best indicators). It should be noted that a paucity of information available on the ecophysiology of the majority of the species listed in Table 2-2 determines that empirical data to determine whether these species truly possess plant functional traits associated with low water use efficiency is relatively unavailable. Instead their attribution to mesic-habitats/wetlands and the implied hierarchy within this list is based on known spatial distribution patterns (some gained from the Western Australian Herbarium (2018), with the remainder gained from field observations by the author). Consequently, riparian zones or water gaining sites which contain *Melaleuca argentea* and varying proportions of the following species are considered to provide good evidence of perennial water availability. Conversely if a riparian zone instead only supports some of the mid-level species/genera in this table moisture availability is considered to be below, but approaching levels equivalent to perennial/permanent availability. It is important to note that it is not yet clear which of these species are more associated with increasing volumes of water, or which are more associated with increasing degrees of consistency in availability. What is clear is that their presence is clearly correlated with increasing degrees of water availability and consistency, and therefore of value as an indicator of either.

Table 2-2: Flora genera and species of the Pilbara determined to be good indicators of increasingly high moisture availability/consistency.

• ***Melaleuca argentea***	• *Samolus spp.*
• ***Acacia ampliceps***	• *Cullen leucanthum*
• ***Eucalyptus camaldulensis***	• *Acacia coriacea subsp. pendens*
• ***Melaleuca bracteata***	• *Eucalyptus victrix*
• ***Muehlenbeckia spp.***	• *Melaleuca linophylla*
• ***Sesbania formosa***	• *Acacia citrinoviridis*
• ***Imperata cylindrica***	• *Acacia sclerosperma*
• *Atalaya hemiglauca*	• *Acacia coriacea subsp. pendens*
• *Cyperus iria*	• *Lobelia spp.*
• *Marsilea spp.*	• *Stylidium spp.*
• *Potamogeton spp.*	• *Typha domingensis*
• *Date palm*	• *Cyperus vaginatus*
• *Various sedge spp.* including *Schoenus spp. , Baumea spp., Fimbristylis spp., etc.*	• *Sesbania spp.*
• *Cladium procerum*	• *Stemodia spp.*
• *Schoenoplectiellia spp.*	• *Sorghum spp.*
• *Eleocharis spp.*	• *Eragrostis surreyana*
• *Fuirena ciliaris (L.) Roxb.*	• *Vallisneria nana*
• *Pteris vittata*	• *Senecio hamersleyensis*
• *Adiantum capillus-veneris L.*	• *Geijera salicifolia*
• *Gossypium sturtianum*	• *Commelina ensifolia R.Br.*
• *Peplidium sp. E Evol. Fl. Fauna Arid Aust. (A.S. Weston 12768)*	• *Trigonella suavissima Lindl.*

Note: Species in **bold** identify some of the best upper level indicators of moisture availability / permanence. Order of importance reads down the page, left to right.

While the species composition of vegetation provides a significant insight into water permanency; an additional level of detail on the degree of water permanency is observable in the structure of the vegetation present. This essentially involves making inferences about the degree and extent of permanency based on the age structure and relative dominance of resident obligate phreatophyte populations. If water remains permanently available to these phreatophytic species then at least a percentage of the population is likely to present as “semi-mature” to “mature” individuals of approximately 40-100 cm diameter. While environmental perturbations such as floods and similar peak flow events will have an influence on the age structure; where conditions are suitable, it is still considered likely that mature trees (older large individuals) will resist flooding and remain to provide insight into the stability of the moisture conditions present over reasonable temporal scales.

In addition to the maturity of OPV communities; the degree of lateral restriction within the fluvial system may also be a good indicator of groundwater proximity and persistence. In many cases within the Pilbara, woodlands of OPV are represented by a very thin (almost single tree width) strip of vegetation which forms on the banks (often the lowest colonisable position in the landscape) of some permanent to near permanent surface pools. In some areas mature OPV vegetation is spread across a broader lateral range of the bed; indicating more general groundwater persistence through a larger proportion of the creek profile, and thus providing greater habitat and structural diversity

values. Laterally broader representations appear to be relatively restricted in their distribution within the Hamersley subregion, and can be considered locally to sub-regionally significant.

Beyond the more extensive and significant stands of *M. argentea/Eucalypt* spp. woodland; where water availability is generally perennial; surface and groundwater availability in the remaining sections of the larger Hamersley Range fluvial systems are generally more variable. However at the smaller scale, fluvial landforms and features such as bends & corners, constricted channels and complimentary small scale geological anomalies can combine to more consistently retain surface water (or close proximity groundwater and small perched alluvial aquifers) than the majority of the general creek bed. In such cases, narrow isolated patches of OPV can be found lining large pools or occupying the low points in the bed profile.

The remainder of the phreatophytic vegetation within fluvial systems of the Hamersley Ranges are essentially represented by woodland (to open forests) of *E. camaldulensis* and/or *E. victrix* over patches of mixed low open woodland/tall open shrubland scattered throughout anabranching channels and broad, open bed zones. This vegetation community is typically one of the more common of the larger topographically confined riparian systems within the Hamersley Ranges (i.e. those dissecting range systems rather than occupying the finer soils of plains and broad alluvial valleys). The other more common and least significant community on systems such as these is represented by low open woodland (to scattered low trees) of *Eucalyptus victrix* over mixed *Acacia* spp. tall open shrublands. In the larger riparian systems, this community typically occupies the outer drier extremities, high flow channels, and elevated points within the fluvial profile with less frequent flooding and inundation.

2.5 STUDY AREA

The study area determined to be the focus of this work incorporates a 60 km stretch of the Robe River and approximately 3 km of Jimmawurrada Creek. With over two thirds of the area of interest located within the Yarraloola Pastoral Station and the remainder within Yalleen Station, the combined area of both River and Creek systems are herein referred to as the “study area”. The stretch of the Robe River represented by the study area is wholly located within the Hamersley subregion of the Pilbara Bioregion (IBRA 7.1) (DoE 2014a).

The boundaries of this study area are presented in Figure 2-1 (and previously in Figure 1-1).

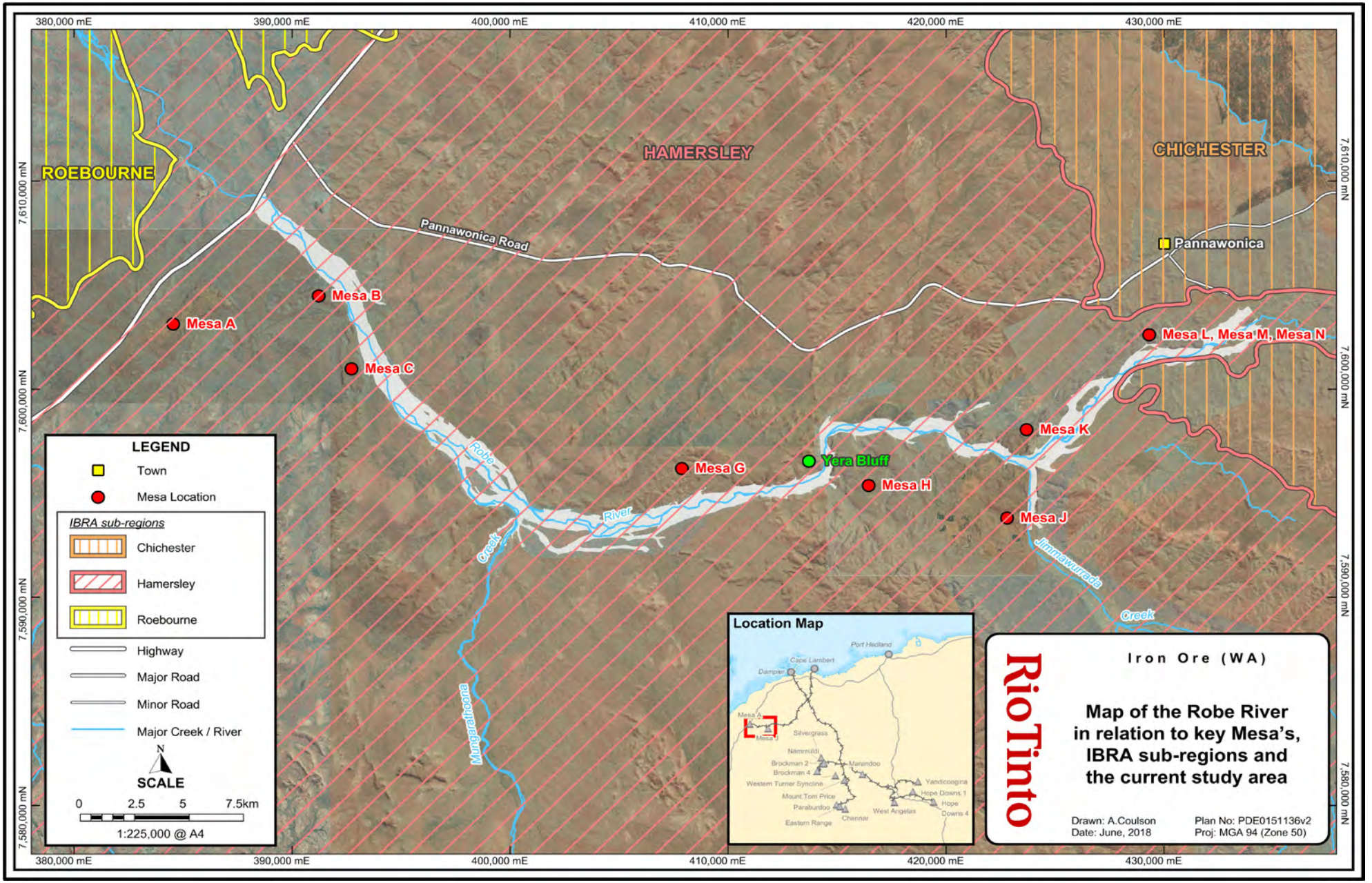

Figure 2-1: Map of the Robe River in relation to key mesas, IBRA sub-regions and the current study area.

2.6 THE ROBE RIVER RIPARIAN SYSTEM

The Robe River is situated in the north-west corner of the Pilbara region of Western Australia. The river itself is approximately 280 km long and has a catchment size of 3,350 km^2. The headwaters rise in the Hamersley Range near Marana Spring then flow in a north westerly direction through the Robe Valley, crossing the North West Coastal Highway near the Pannawonica turnoff then discharging into the Indian Ocean near Robe Point. The Robe River has three main tributaries; Jimmawurrada Creek & Mungarathoona Creek, both of which are partly covered by this survey; and Kumina Creek.

The Robe River is ephemeral and surface water is restricted to a series of permanent pools that act as important refugia for native fauna through the dry season. Those pools which are considered relatively permanent are described in long term monitoring work conducted by Dobbs & Davies (2009). Key pools identified in the study area are presented in the vegetation mapping within section 4.1.

The Pilbara biogeographical region is characterised by low annual rainfall (annual average 400 mm) and, when coupled with high annual evapo-transpiration rates (e.g. typically about 12 times the annual rainfall) results in restricted aquatic ecosystems. Pannawonica receives the majority of its rainfall over summer in association with cyclone events. Peaks in rainfall typically occur during January to March with months of lowest rainfall occurring in September and October.

Rainfall is highly episodic as well as highly variable and rainfall across years can be highly unpredictable with significant variation in annual rainfall. The coefficient of variation (**CV**) for the Pilbara ranges from 0.4 to 0.7 in comparison with a CV for south-west Western Australia of 0.2 and for the Kimberley of 0.3 (DoE 2004). River discharge patterns are tightly coupled to the seasonality of rainfall events. Following trends in rainfall data, maximum flows are typically recorded between January and April and low or no flow from September to December. As a result the Robe River experiences periodical flooding. The Robe River was last in full flood following Cyclone Monty in 2004. In 2009; following heavy rainfall, the river burst its banks cutting roads and railway lines.

The Robe River / Jimmawurrada Creek riverine habitat is dominated by moderately-dense to dense mixed woodlands to open forests of Cajeput (*Melaleuca argentea*), River Red Gum (*Eucalyptus camaldulensis*) and Coolibah (*Eucalyptus victrix*). The open understorey of tall shrubs is dominated by *Petalostylis labicheoides* and *Acacia trachycarpa* with scattered *Sesbania formosa* and *Gossypium robinsonii* over sedges and mixed herbs. Filamentous green algae are common in the waterways, together with emergent macrophytes, such as *Typha domingensis*, *Potamogeton* and *Vallisneria* species, and fringing rushes such as *Schoenoplectus* sp. and *Eleocharis* sp. Further from the water's edge, the narrow zone of riparian vegetation gives way to low plains of soft spinifex (*Triodia epactia*) and hard spinifex (*Triodia wiseana*) steppe with scattered gums *Eucalyptus leucophloia* (Snappy Gum) and *Corymbia hamersleyana* over-mixed *Acacia* species, *Hakea chordophylla* and *Grevillea pyramidalis* (Beard 1975a; 1975b).

Major disturbances to river bed and pool vegetation have resulted from variation in the pattern and volume of rainfall. The local topography, and resultant force of floodwaters can uproot young to semi-mature plants and other plants may die from being submerged for extended periods. Qualitative assessments of riparian vegetation have shown significant physical uprooting evident in both riparian and floodplain vegetation. These changes were a direct result of the high flows and

widespread flooding associated with high flow events, particularly Tropical Cyclone Monty in early March 2004. In the Robe River, the distribution and abundance of the weed, Indian Water Fern (*Ceratopteris thalictroides*), is considered related to both patterns of river flow and unrestricted livestock access to drainage channels (Streamtec 2008).

The peak flow patterns and flow regime of the Robe River, coupled with the confining topography in the areas of relevance to this study have determined that the resultant river profile is dominated by a large and broad gravel bed flood zone flanked by rarely breached terraces or steep rocky sides. Within the broad gravel bed, a main (primary) incised low-flow channel, and one or more secondary incised channels punctuate the relatively flat gravel bed zone. In certain zones, raised finer grained sediment islands support woodlands over hummock/tussock grass communities, while the bulk of more densely vegetated communities are restricted to within and flanking the primary and secondary incised channels. In some areas secondary channels leave the main gravel bed and follow other low zones before re-joining further downstream. Terrace zones are substantially higher than the gravel bed, and are generally composed on fined grained sediments with shrublands over relatively dense hummock/tussock grasslands. A cross-sectional schematic of this typical creek profile within the study area is provided in Plate 2-1.

In initial reports (ecologia & Streamtec 1992); pools within the Robe River were considered dependant on the high rates of algal primary production to drive ecological processes. High algal growth is often observed in monitored pools and it is likely that this is a major contributor to secondary water quality issues as the vegetation decays i.e. highest levels of nutrients have been recorded in pools with increased algal growth and increased turbidity levels.

Stream discharge volumes and water levels of the Robe River are monitored by the Department of Water (**DoW**) at the Yarraloola gauging station (DoW 2017). At present, the Robe River has experienced a relatively extended dry period (with respect to flows) after a relatively long period of seasonally wet years (see Figure 2-2). Recently, water levels in the River were anecdotally reported to be the lowest they have been observed for over two decades (Mr Peter Davies, pers. comm., 28 March 2017).

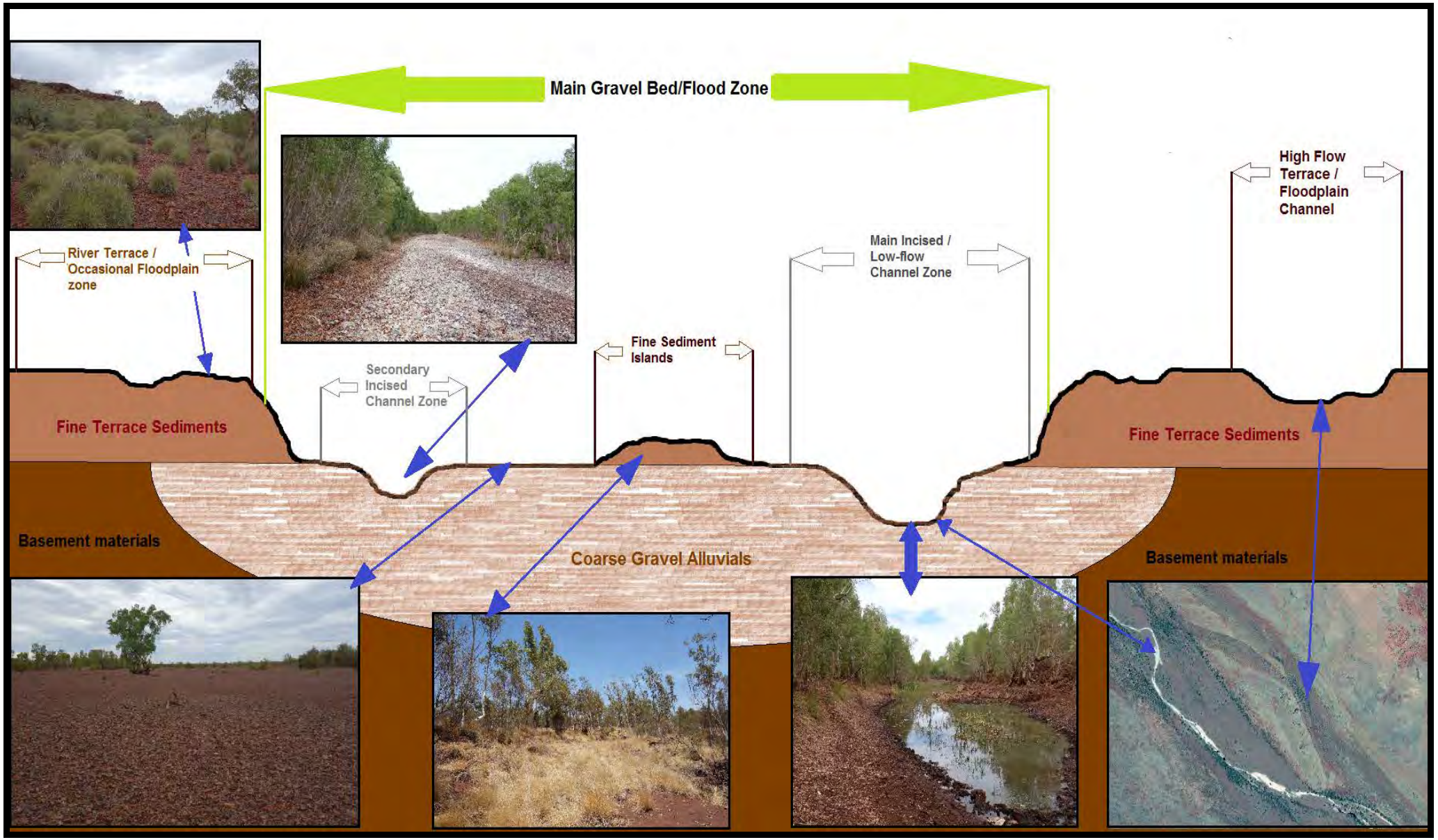

Plate 2-1: Cross-section schematic showing the typical channel profile of the Robe River within the study area, along with photos illustrating the typical appearance of key zones.

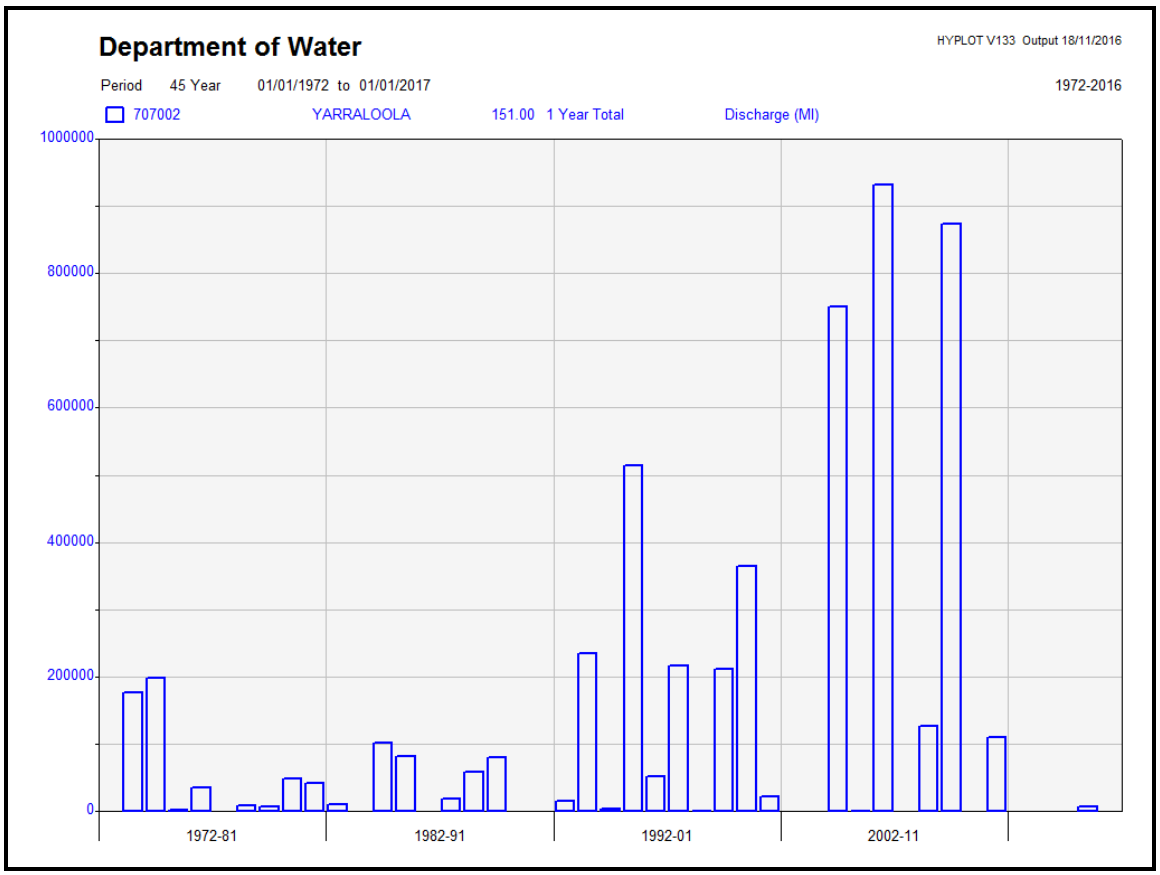

Figure 2-2: Department of Water (DoW 2016) historical river flow data from the Yarraloola gauging station on the Robe River.

2.7 JIMMAWURRADA CREEK

Jimmawurrada Creek, and the adjoining Bungaroo Creek, is part of a pair of broad, low-gradient valleys (with substantial adjoining rugged upland areas), which are prone to flooding after seasonal, tropical storms and cyclones. Cutting through the Buckland Hills and Mount Dempster areas, the creek valleys are bounded to the south, and in some parts to the north by steep scarps, mostly formed of the resistant Dales Gorge member of the Brockman Iron Formation (Rio Tinto 2011b). The Bungaroo Valley is approximately 0.5 km wide at the upstream end and 4 km wide where it confluences with Jimmawurrada Creek about 30 km downstream. The valley formed by Jimmawurrada Creek is approximately 9 km wide at the eastern end. Both valleys (particularly Bungaroo Valley) contain numerous braided, dry creek beds that are prone to flooding during the wet season (Rio Tinto 2011b).

Bungaroo Creek joins Jimmawurrada Creek in the lower part of the catchment area, to provide approximately 1600 square kilometres of total catchment area. On its own, Jimmawurrada Creek has a catchment area of about 400 square kilometres, while the catchment for Bungaroo Creek is in the order of 1200 square kilometres.

2.8 ROBE RIVER HYDROGEOLOGY

The major aquifer underlying the Robe River is contained within the gravelly alluvium which has a saturated thickness of up to 15 m adjacent to the main channel and extends laterally up to 5 km across the Robe River Valley (Antao & Braimbridge 2010). Groundwater flow through the gravels is thought to maintain permanent pools in the Robe River (Wetland Research and Management (WRM) 2016). The gravelly aquifer is underlain by fractured, permeable Trealla Limestone and highly transmissive Robe Pisolite. Robe Pisolite is a pisolitic alluvial sedimentary rock that fills the broad

valley between ridges of the Brockman Iron Formation and outcrops along the Robe palaeochannel (EPA 1991). The ore deposits at in the mesas along the Robe Valley are CIDs derived from pisolite limonite within the Robe Pisolite. The CID is comprised of iron ore detritus from weathering and erosion of the Brockman and Marra Mamba Iron Formations (Morris & Ramanaidou 2007).

Groundwater flow in the Pisolite is towards the Robe River and where the Pisolite is deepest, probably contributes to base-flow within the Robe River (Aquaterra 2005). The gravel and Pisolite aquifers are recharged primarily via river discharge. Modelling by DoW indicates the aquifers have the potential to absorb a significant percentage of river flow, however, due to the unpredictable flow regime, recharge is very low in two out of every five years (Antao & Braimbridge 2010). Near the Jimmawurrada-Robe confluence, the Pisolite is very shallow and unsaturated. Stream-aquifer interaction upstream in the Bungaroo and Jimmawurrada valleys contributes to recharge along with direct rainfall infiltration (WRM 2016).

2.9 PREVIOUS SURVEYS

A significant amount of survey work has been conducted in the Robe Valley locality since mining development began in the 1980's. Table 2-3 outlines the relevant flora and vegetation surveys conducted in the area which intersects the Robe River. The most relevant and recent studies have been conducted by Astron Environmental Services Pty Ltd and Biota Environmental Sciences Pty Ltd (Table 2-3). This body of work has essentially sampled/surveyed a riparian environment which had already seen some degree of impact from pastoralism, mining and from surplus dewater discharge from mining activities at Mesa J and natural events (cyclones, flooding and fires). The survey boundaries of previous relevant flora and vegetation studies are presented in Figure 1-1 in relation to the Boundary of the current study area. A recently conducted flora and vegetation survey (MWH Australia Pty Ltd (MWH) 2016) which intersects the Robe River in the vicinity of Mesa A, does not shed any additional light on the riparian communities of the Robe, as it covers the same region of the Robe River as that covered by Biota (2011). The sampling work conducted as part of MWH's 2016 survey does however elevate the survey coverage in this area to that of a seasonal survey given that Biota only conducted one phase of sampling in 2011.

Table 2-3: Summary of relevant vegetation and flora surveys intersecting the Robe River.

Study (Reference)	Area Surveyed Within Study Area	Survey Description Survey Timing (Conditions for Plant Growth)	Available Data
Middle Robe and East Deepdale Level 2 Vegetation and Flora Assessment, September 2015 (Astron Environmental Services Pty. Ltd.) (Astron 2015) (plus an additional phase of work conducted by ecologia (2013)	11,816 ha	Two phase (Level 2 - Detailed) vegetation and flora assessment survey of the Middle Robe to East Deepdale area to expand upon previous work conducted by Biota (2006), Astron (2011), and ecologia (2013). 15 to 27 June 2015 (favourable); 21 September to 3 of October 2015 (acceptable). ecologia – single phase – July & August 2012 (Sub-Optimal conditions)	– Quadrats/relevés/mapping notes. – Conservation significant flora and weeds. – Floristic analysis – Vegetation mapping. – Vegetation condition assessment. – Species list.
Baseline Flora and Vegetation Assessment of Robe Valley Mesas (Mesas B, C, D, E, F, H and I), April 2011 (Biota Environmental Sciences) (Biota 2011) (plus an additional phase of work conducted by Astron (2014)).	9,494 ha	Single phase (level 1 – reconnaissance) vegetation and flora assessment of various mesas in the vicinity of Pannawonica. This comprised; Mesa B (980 ha), Mesa C (850 ha), Mesa D (737 ha), Mesa E (1,502 ha), Mesa F (2,626 ha), Mesa H (2,252 ha), and Mesa I (547 ha). 11 to 19 October 2011 (sub-optimal) Second phase conducted by Aston 2014 (acceptable conditions)	– Quadrats/relevés/mapping notes. – Conservation significant flora and weeds. – Vegetation mapping. – Vegetation condition assessment. – Species list.
Level 2 Flora and Vegetation Survey: Mesa B-C, Warramboo BWT, Highway to Tod Bore and Mesa A Extension, August 2016 (MWH Australia Pty. Ltd. (MWH) 2016).		Two Phase (Level 2 – Detailed) vegetation and flora assessment over a study area that incorporated four separate Project Areas; Mesa B-C, Highway to Tod Bore, Warramboo BWT and Mesa A Extension, as well as the establishment of a vegetation monitoring program and baseline assessment at Warramboo Creek. 8 to 21 June 2015 (acceptable) 2 to 8 September 2015 (sub-optimal) 3 and 8 May 2016 (sub-optimal)	– Quadrats/relevés/mapping notes. – Conservation significant flora and weeds. – Floristic analysis – Vegetation mapping. – Vegetation condition assessment. – Vegetation monitoring establishment – Species list.
A Vegetation and Flora Survey of the Proposed Mesa A Transport Corridor, Warramboo Deposit and Yarraloola Borefield, January 2006 (Biota 2005; Biota 2006)	7,878 ha	Two phase (seasonal) vegetation and flora survey of two transport corridors (haul road (500m wide) and Rail (200m wide)) from Mesa A to Mesa J, the Warramboo deposit study area (approximately 2.5 x 2.5 km in size), and a bore field on Yarraloola station with pipeline corridor to Mesa A. July 2004 (Favourable) September 2005 (Favourable)	– Quadrats/relevés/mapping notes. – Conservation significant flora and weeds. – Floristic analysis – Vegetation mapping. – Vegetation condition assessment. – Species list.

2.9.1 Resultant Vegetation Mapping

Previous vegetation mapping covering the study area has been completed at a resolution commensurate with the environmental impact assessment (**EIA**) objectives for which it was commissioned. Generally, flora and vegetation surveys conducted for the purpose of EIAs are commissioned with the aim of sampling and documenting all the values present. As a result sampling effort is spread widely and the level of detail attained is typically proportionate to the size of the area, number of landforms present, and the extent of areas of elevated ecological value.

The "Middle Robe" flora and vegetation survey conducted by Astron (2015) represents the most detailed and extensive of the vegetation models available on the Robe River. This mapping provides an important platform for the current study; however the objectives of the current study determined that mapping with much greater spatial confidence and at a finer resolution was required. Improving the spatial confidence and detail of riparian vegetation mapping would help increase knowledge in the riparian zone and increase the understanding of the local environmental values (and their distribution), and hence increase the effectiveness of environmental management. The key point of difference between the current study and previous vegetation studies is the consideration of age structures within OPV, the resultant degree of differentiation proposed within these communities and the focus on accurately mapping the distribution of the higher sensitivity OPV and Facultative Phreatophytic Vegetation (**FPV**) communities.

3 METHODOLOGY

3.1 VEGETATION MAPPING WITH A FOCUS ON GDE CHARACTERISTICS AND DISTRIBUTION

3.1.1 Introduction

To achieve the vegetation mapping aims of this study; a "Targeted Survey" was conducted as defined under the EPA Technical Guidance; Flora and Vegetation Surveys for Environmental Impact Assessment (EPA 2016b). The vegetation mapping conducted as part of this study focused on gathering high confidence and relatively detailed information on the distribution and characteristics of GDEs within the Robe River. This was achieved by primarily focusing on gathering information about the maturity and distribution of OPV. A secondary data focus was placed on gathering information on the distribution of FPV; particularly the distribution patterns exhibited by *Eucalyptus camaldulensis* (River Red Gums). The primary focus on OPV is motivated by the fact that this vegetation represents that possessing the highest degree of sensitivity to surface and groundwater hydrological changes potentially associated with mining.

As the most hydrologically sensitive Pilbara communities are typically those with a significant component of *Melaleuca argentea*; an initial review was undertaken to identify desktop tools and resources suitable for helping identify the likely distribution of OPV communities. A field plan capable of ground-truthing the predicted and potential spatial distribution markers for OPV and FPV communities in the study area was developed following completion of the desktop mapping process. This field plan was also developed with the aim of compiling additional fine scale information about the spatial distribution and composition of other less sensitive/significant vegetation communities (FPV) within the study area, for the purpose of supplementing the vegetation mapping process.

The desktop resources and mapping, together with the field plan allow for the acquisition of a relatively comprehensive dataset on the spatial distribution (mapping) of key riparian vegetation communities throughout the study area. This desktop and field-based assessment is also designed in a way which collects information which provides a framework for contextualising and assessing the potential for hydrological changes to impact riparian communities in the study area.

It should be noted that the vegetation mapping process and the resultant field survey effort attributed to the study area was conducted on riparian units occurring within the major riparian habitats of the study area. As part of this process, a high degree of survey effort was afforded to the riparian units in the main incised channel zone (low flow channels) of the river compared to the outer fringing communities and the river terrace and outer floodplain communities (see plate 2-1 for a schematic of the key river profile features of the Robe River).

In an effort to maintain the logic and intent of coding attributed to recent GDE mapping conducted by the author, the same coding regime as Rio Tinto (2015) was attributed to vegetation types identified in this study.

With respect to data collection methods; this survey noted the adequate amount of Quadrat/Relevé based data collection which has previously been conducted within various parts of the study area. This survey also noted that mapping traverses had previously been used to a lesser extent than quadrat/relevé based techniques in the riparian zone of the study area. Coupled with the GDE focus of the study; it was concluded that the degree of information on the associated floristic composition

of riparian communities already captured within the Robe Valley area was sufficient to meet the objectives of this study. Mapping traverses were, therefore, considered to be the most effective method for targeted vegetation mapping in this study. Mapping traverses, generally comprise walking through the target area and regularly taking notes and spatial information on the apparent vegetation associations/sub-associations present, and the location and pattern of boundaries which separate them (see Section 3.1.3). By aligning these traverses to maximise their potential to regularly test the spatial position of these vegetation boundaries, the resultant traverse pattern quickly establishes an effective and extensive database with which to correlate on ground vegetation distribution with vegetation signatures present within aerial photography. The use of mapping traverses oriented to repeatedly intersect and establish the location of vegetation boundaries allows for the development of robust (high confidence) fine scale vegetation mapping in the areas investigated.

It should be noted that vegetation mapping is essentially a model, such that the spatial validity of boundaries and the vegetation associations depicted to lie within those boundaries, is only true a portion of the time. In general, the proportion of time which the model is correct is directly correlated to the amount of ground-truthing which is done per unit area of the model, and the scale of the community descriptions created. The third influencing factor is generally considered to be the complexity of environmental factors influencing vegetation ecology, but for the surveyor this is an uncontrolled factor and is therefore not generally considered in detail.

For the vegetation mapping model presented as a part of this study; a key aim was to provide a high degree of accuracy in relation to the spatial location and distribution of resident OPV communities. As a result the degree of ground-truthing effort conducted within the core riparian zone (particularly the incised channel zone) was very high, such that the mapping is considered to be significantly more accurate than typical quadrat/relevé dominated sampling methodology and subsequent vegetation mapping undertaken in typical flora and vegetation surveys within WA.

3.1.2 Tools developed at a desktop level for increasing the effectiveness of in field mapping traverses

Photosynthesising vegetation covering the Robe River was assessed using Normalised Difference Vegetation Index (**NDVI**) images generated from high resolution (0.5 m pixel) remotely sensed digital multispectral imagery (**DMSI**). NDVI relies on the fact that photosynthetic organisms have the unique characteristic of reflecting nearly all infra-red electromagnetic radiation, and absorbing significant amounts of the red visible wavelength of electromagnetic radiation (used for photosynthesis) (Specterra Services 2010). As a result, an index calculating the ratio between the intensity of the two wavelength ranges provides a simple measure of vegetation cover/density or greenness. NDVI imagery of the relevant river stretches were visually assessed by a specialist botanist for patterns in and occurrences of high-density vegetation signatures (i.e. areas where a comparatively high degree of vegetation cover was evident in comparison to surrounding riparian vegetation cover signatures) likely to indicate the presence of mesic conditions, and therefore potential GDEs. GDEs such as OPV are recognised to be associated with a high degree of water availability and often groundwater presence. This persistent presence of moisture generally facilitates the establishment of relatively dense combined vegetation cover (i.e. canopy cover, combining with shrub and groundcover strata to provide aerially dense cover signatures) when compared to surrounding, more widespread riparian vegetation. Areas of the riparian system showing comparatively higher measures of vegetation cover are often the areas where groundwater

is close enough to the surface to provide adequately consistent soil moisture availability and conditions suitable for the establishment of species such as *M. argentea*. Plate 3-1 presents an example of a high density NDVI signature and one example of a sparse NDVI signature. At a desktop level, anomalously high vegetation cover signatures were identified and mapped throughout the study area, and used in conjunction with NDVI maps for the purpose of guiding field based ground-truthing of mesic vegetation signatures. Plate 3-2 presents an example of the summarised NDVI imagery (for the stretch from Yeera Bluff to the confluence with Jimmawurrada Creek) produced over the study area which was used as a supporting tool for the GDE interpretation and ground-truthing process.

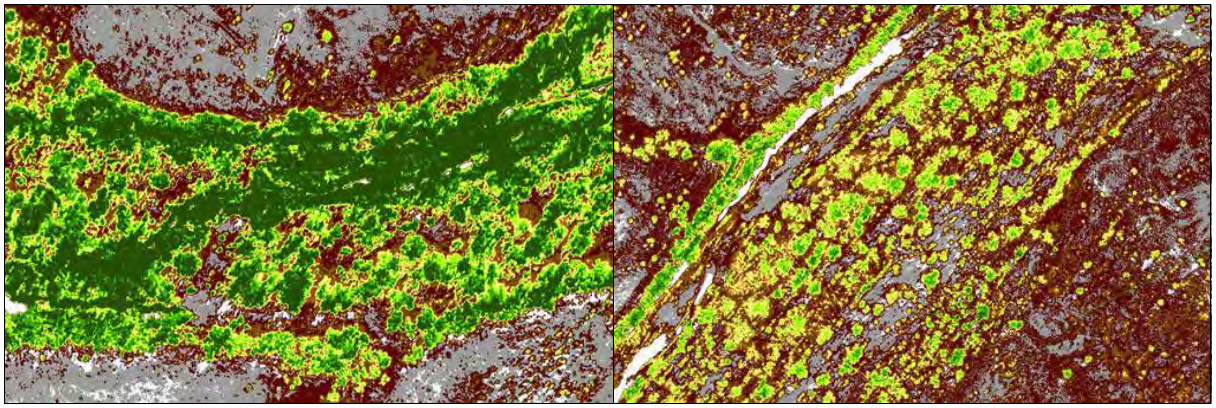

Plate 3-1: Samples of NDVI image showing a high density NDVI (vegetation cover) signature on the left and a sparse cover NDVI signature on the right

Historical aerial photography and true colour DMSI was also visually assessed to identify and digitally map areas of anomalously dense vegetation and consistently formed canopy cover which might identify the spatial location of OPV or more mesic FPV. As part of this process; an alternative set of digital polygons were produced which represented the pure shrubland communities, and separately all the open woodland and above treed riparian communities.

Polygons digitised from both NDVI images, DMSI and historical aerial photography were uploaded to a GPS, along with other relevant environmental layers such a 50k hydrology and historical vegetation mapping.

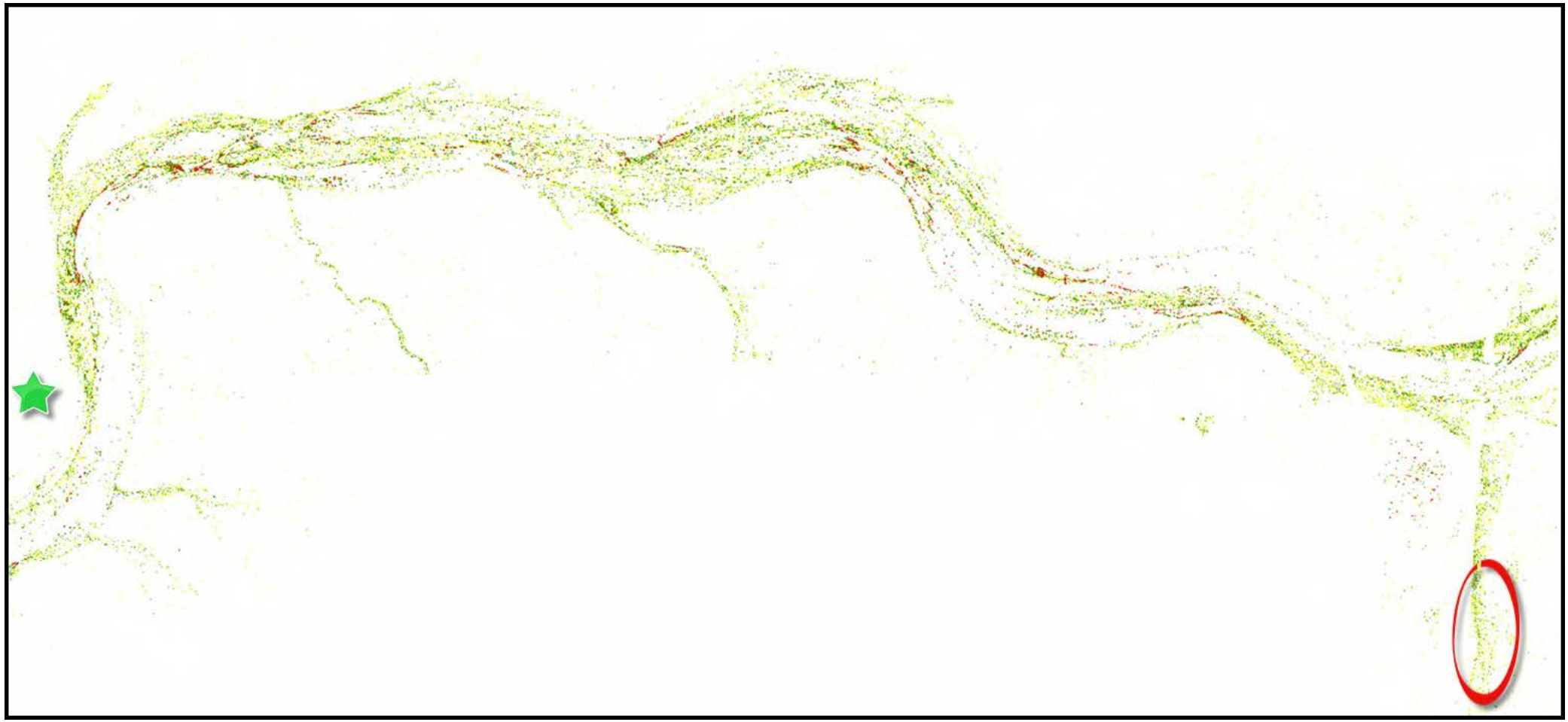

Plate 3-2: Example of the summarised NDVI imagery produced as a ground truthing tool for use when surveying the Robe River (between Yeera Bluff (position indicated by green star) and Jimmawurrada Creek (identified by red circle))

3.1.3 Ground-truthing and Mapping Refinement Field Work

A field data collection framework was devised to focus on the following key tasks within the Robe River study area:

- Traverse the entire width of the gravel bed and incised channel profile (while periodically intersecting the inner portion of the adjacent terrace features) and key high-flow channels to gain an understanding of the ecology and distribution of significant riparian communities present within their boundaries. In addition; gaining an overarching awareness of the variability, morphology and spatial distribution of the different creek profiles and associated substrates present throughout;
- Ground-truthing of all relevant identified dense vegetation signatures and anomalous NDVI signatures to confirm the presence/absence of phreatophytic species (namely *Melaleuca argentea*, and to a lesser extent useful GDE indicator species such as *Eucalyptus camaldulensis, Acacia ampliceps, Sesbania formosa*, Cyperaceae spp., etc.) and associated communities, and
- Record specific data about the spatial boundaries/distribution of OPV, and the size and age structure (and spatial boundaries) of *Melaleuca argentea* populations encountered throughout.

Within the relevant section of the Robe River; the incised channel width is variable but generally observed to be in the order of 300 to 1,000 m wide, and likely inundated by 3-5 year ARI (Average Recurrence Interval) stream flow events. Due to the surrounding topography of the relevant stretch of the Robe River, the surrounding terrace/floodplain zone is relatively narrow for the most part due to the wide gravel bed zone effectively incorporating a significant proportion of the river floodplain.

It was anticipated that these key tasks would be carried out by directing field traverses and associated survey effort in a way which ultimately was a guided by the interaction of four key drivers to traverse pattern:

1. Firstly; it was determined that typical vegetation distribution patterns were likely to be aligned in a linear fashion parallel to the direction of primary/secondary and minor flow channels. A traverse pattern which intersected perpendicular to these perceived boundaries was deemed most effective at ground-truthing digitised vegetation polygons and collecting the most representative spatial dataset for the fine scale extrapolation of vegetation boundaries. Therefore a zig-zag style traverse pattern was determined the best technique to use when traversing the creek.
2. The second process was the use of the NDVI image and desktop NDVI, DMSI and aerial photo signature mapping to influence the surveyor's fine scale travers pattern decisions. Essentially this relates to the process of aiming successive zig-zag traverses across the creek in a manner which will intersect digitised vegetation patches of most relevance to mapping GDE presence. This process of successive aiming is primarily driven by the use of the desktop mapping tools previously described or by visual cues described below in point 3.
3. The density, height and distribution of the vegetation present would determine that not every part of the creek could be viewed and assessed for the presence of OPV. To reduce the chance of missing such communities the direction and path of successive meanders would also be influenced by the visual cues to these communities which were gathered each time the surveyor moved through sections of the creek which allowed clear view of vegetation over longer distances.
4. The final driver to traverse pattern was the observed patterns in the morphology and variability of the creek profile. Such patterns and characteristics significantly influence the associated distribution patterns of phreatophytic vegetation, and can therefore be interpreted in field to predict the ongoing distribution of such vegetation. In certain river sections;

interpretation of these morphological patterns (in concert with desktop mapping) gave additional confidence that certain zones of the creek were devoid of OPV, thus allowing much smaller wavelength zig-zag traverse patterns to be employed. This in turn meant that lateral traverse distances were typically much smaller allowing a much greater degree of focus on the most relevant river bed zones.

The resultant traverse pattern and data capture array realised in the field is presented in Figures 3-1 to 3-8 as track logs and data points recorded via GPS. Throughout this traverse pattern; the following types of data were recorded at the resultant array of waypoints recorded within the study area.

- "Structurally Present" or "Structurally Absent" *Melaleuca argentea* populations – "Structurally Present" equating to a cover/abundance considered as comprising a dominant/co-dominant structural component of the stratum which it occupies, and not generally representing a cover/abundance below 1-2 %. "Structurally Absent" represents either not detected within the vicinity of the record whatsoever or only present as an associated species. For the purpose of this work, and more generally; associated species are defined as those species not comprising a dominant structural component of vegetation and typically not representing a cover/abundance above 1-2 %.
- The presence of *M. argentea* if only present as an associated species. In these cases records were generally prefixed with an "N" cover/abundance so that its cumulative distribution could be considered spatially.
- The intersected boundary locations of riparian communities where *M. argentea* populations are deemed "Structurally Present" (i.e. OPV).
- The cover/abundance *M. argentea* populations recorded as a "Structurally Present" (i.e. representing a dominant/co-dominant member of the vegetation).
- The position (and where able to be easily conveyed; the dimensions) of any sizeable "patches", "strips", or "thin strips" of riparian vegetation where *M. argentea* was considered "Structurally Present". In most cases, where appropriate, the close alignment/association of such "patches" with bodies of water or clear channels was noted in the data recorded.
- The size class (as a proxy of age) range of any recorded *M. argentea* populations and any spatial boundary points which are relevant to the recorded size-class range – In all cases the recordings were for the population either in the vicinity of the recorder ("internal" record) or throughout the area delineated by the relevant recorded spatial boundary points ("boundary" record). These size classes were inferred based on a visual assessment of the average trunk diameter, or the average range of trunk diameters present throughout the relevant population in sight. The size class/range determined at data points was allocated to populations via the use of terms which represented the various size classes used. In many cases (where appropriate – i.e. the size structure showed minimal variability) an average size class was recorded (such as Young), and in other areas where size structure was more variable a range was given (i.e. Young to Semi-Mature-minus). The size class terms used were:
  - 'Mature' (M);
  - 'Semi Mature Plus' (SM+);
  - 'Semi Mature' (SM);
  - 'Semi Mature Minus' (SM-);
  - and 'Young' (Y).

  The definition of each of these size classes and the representative terms used in the field are presented in Table 3-1.

- Mapping notes – general notes on vegetation or mesic species present at point locations. This often involved assigning vegetation to pre-determined associations/sub-associations or previously identified and mapped riparian communities/units.
- Photo points – points where multiple photographs (minimum 4) were taken of the vegetation surrounding the record. These were used to gather a quick database of vegetation information across the study area. This data is particularly relevant in areas of more benign (from a GDE perspective) vegetation where detailed information was not required, but for which high resolution photos help to significantly increase the accuracy of the entire vegetation model produced.

The above data collection framework was used to collect data in the field over two field trips conducted by Rio Tinto Botanist Jeremy Naaykens and with the assistance of RTIO Environment staff Hanouska Bishop and Caitlin O'Neil. The first field trip focused on the downstream half of the study area and was conducted from the 18th to the 23rd of December 2016. The second field trip focussed on the upstream section and was conducted from the 14th to the 20th of January 2017.

Table 3-1: Definitions for the stem size classes used to classify the average trunk diameter (or range of trunk diameters) of *Meleleuca argentea* populations encountered in the field, and allocate these populations to a perceived age class (or age class range) and an infered degree of permanency.

Stem Size classes (as a proxy for age)	***Melaleuca argentea* individuals/populations which were visually estimated to possess:**	**Vegetation which was generally dominated by individuals/populations of this size (but not larger) were generally inferred to :**
M - Mature trees	Trunk diameter(s) at knee to waist height in the **Range of 50cm and above**	Represent areas where bed and subsurface conditions are likely to have consistently supported *M. argentea* communities for a relatively long period of time within the relevant section of river bed. For this reason, their presence in this location was considered to be stable and therefore of higher significance when considering potential for impact.
SM(+) - Semi Mature plus	Trunk diameter(s) at knee to waist height in the **Range of 30-45cm**	Represent areas where bed and subsurface conditions have somewhat consistently supported *M. argentea* communities within the relevant section of river bed. However, in such areas, conditions may have only become suitable for *M. argentea* to proliferate in the last 10 years or more.
SM - Semi Mature	Trunk diameter(s) at knee to waist height in the **Range of 20-30cm**	Represent areas where bed and subsurface conditions are either only moderately variable or have more recently become suitable to support *M. argentea* communities within the relevant section of river bed. Communities dominated by this size class are often fringing secondary channels within the main river bed and appear to be more influenced by surface water regimes than increasingly mature *M. argentea* communities.
SM(-) - Semi Mature minus	Trunk diameter(s) at knee to waist height in the **Range of 10-20cm**	Represent areas where bed and subsurface conditions are likely to either be quite variable, or have changed in recent to very recent times, such that *M. argentea* populations are now supported. Communities possessing a dominance of *M. argentea* individuals in this size class are most likely to represent areas which are currently only able to support more transient populations of this species.
Y - Young	Trunk diameter(s) at knee to waist height in the **Range of less than 10cm**	Represent areas where bed and subsurface conditions are likely to either be too variable, or have changed in very recent times, such that *M. argentea* populations are now supported. Communities possessing a dominance of *M. argentea* individuals in this size class are most likely to represent areas which are currently only able to support more transient populations of this species. For this reason the significance attributed to their presence (when considering potential for impact) is heavily reduced due to their likelihood of being absent more often than not.

Note: *M. argentea* populations were allocated to size classes in the field based on visual estimates of trunk diameter and as such there is some potential for inaccuracy. In all cases the recordings were a range estimate for the entire population in view of the recorder. In many cases (where appropriate – i.e. the size structure showed minimal variability) an average size class was recorded (such as Young), and in other areas where the size structure was more variable a range was given (i.e. Young **to** Semi-Mature-minus). Diameter estimates are based on the diameter at knee to waist height of the observer, as the branching habit of individuals in the younger size classes make it impractical to estimate diameter at breast height – a more commonly used standard for tree diameter measurements.

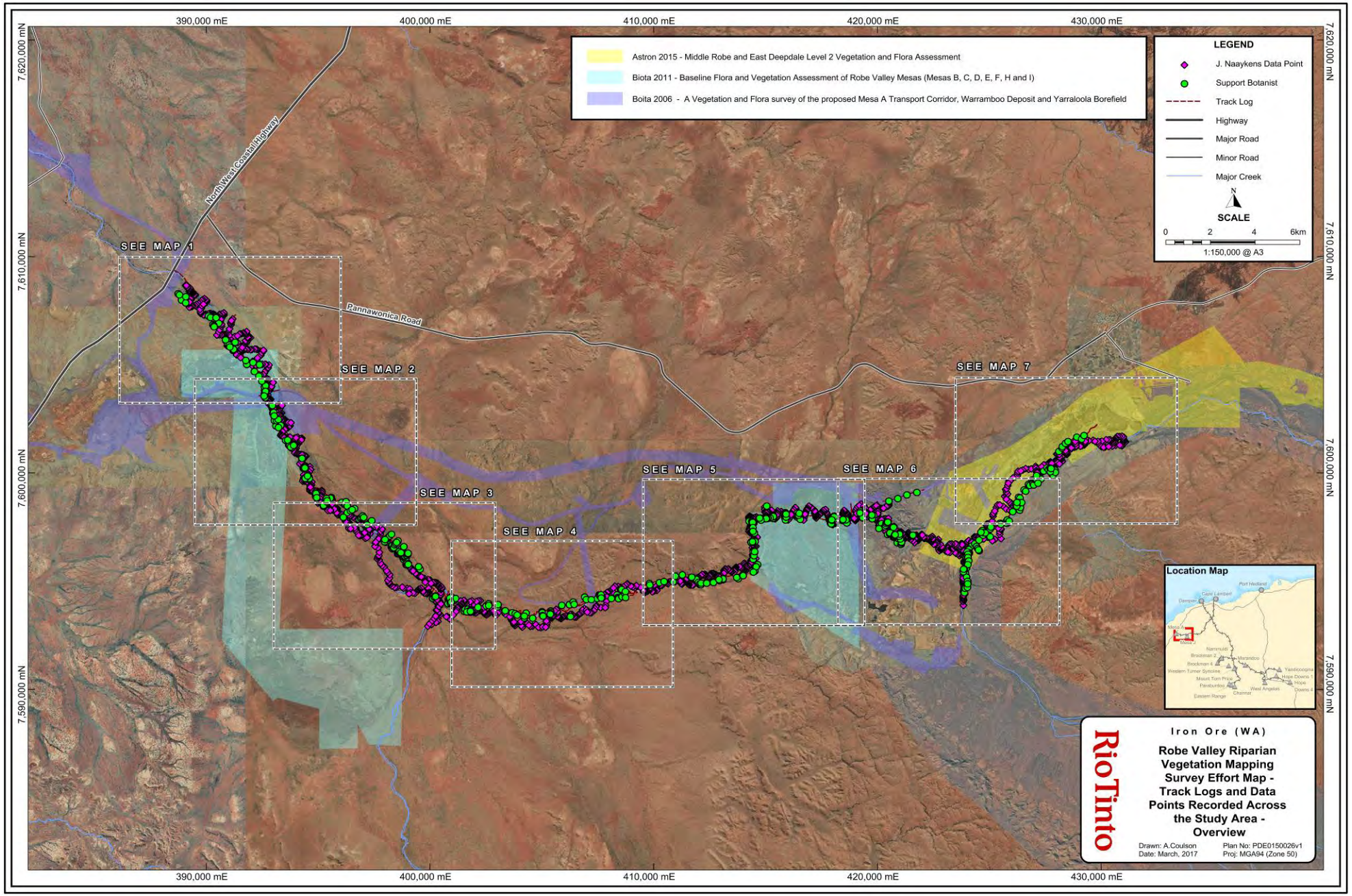

Figure 3-1: Overview of survey effort maps 1 to 7. Maps 1 -7 depict the survey effort conducted within the study area by showing the track logs and data points collected throughout using a GPS. This map also shows the most relevant previous riparian vegetation mapping surveys conducted across the study area.

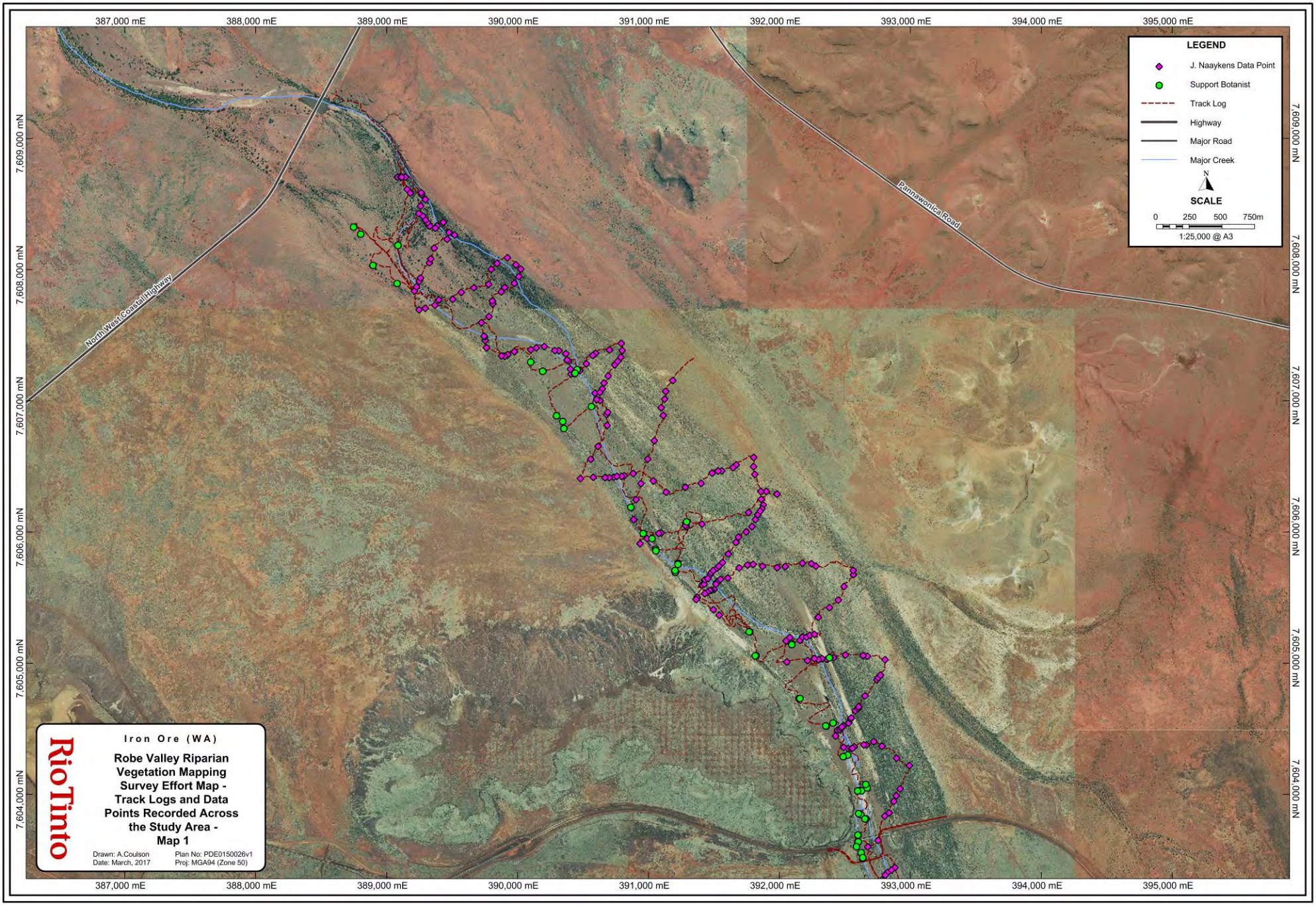

Figure 3-2: Survey effort Map 1 of 7

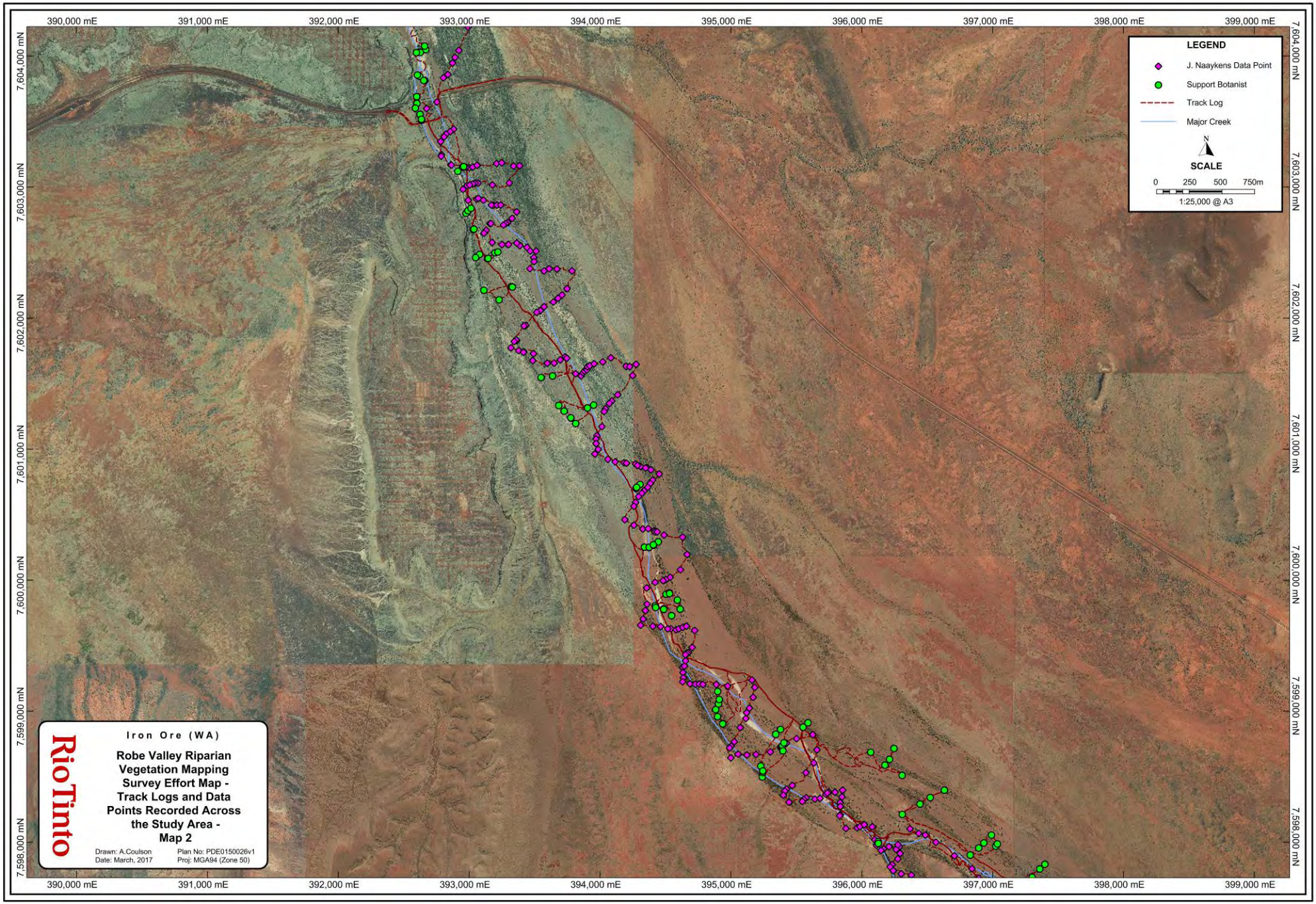

Figure 3-3: Survey effort Map 2 of 7

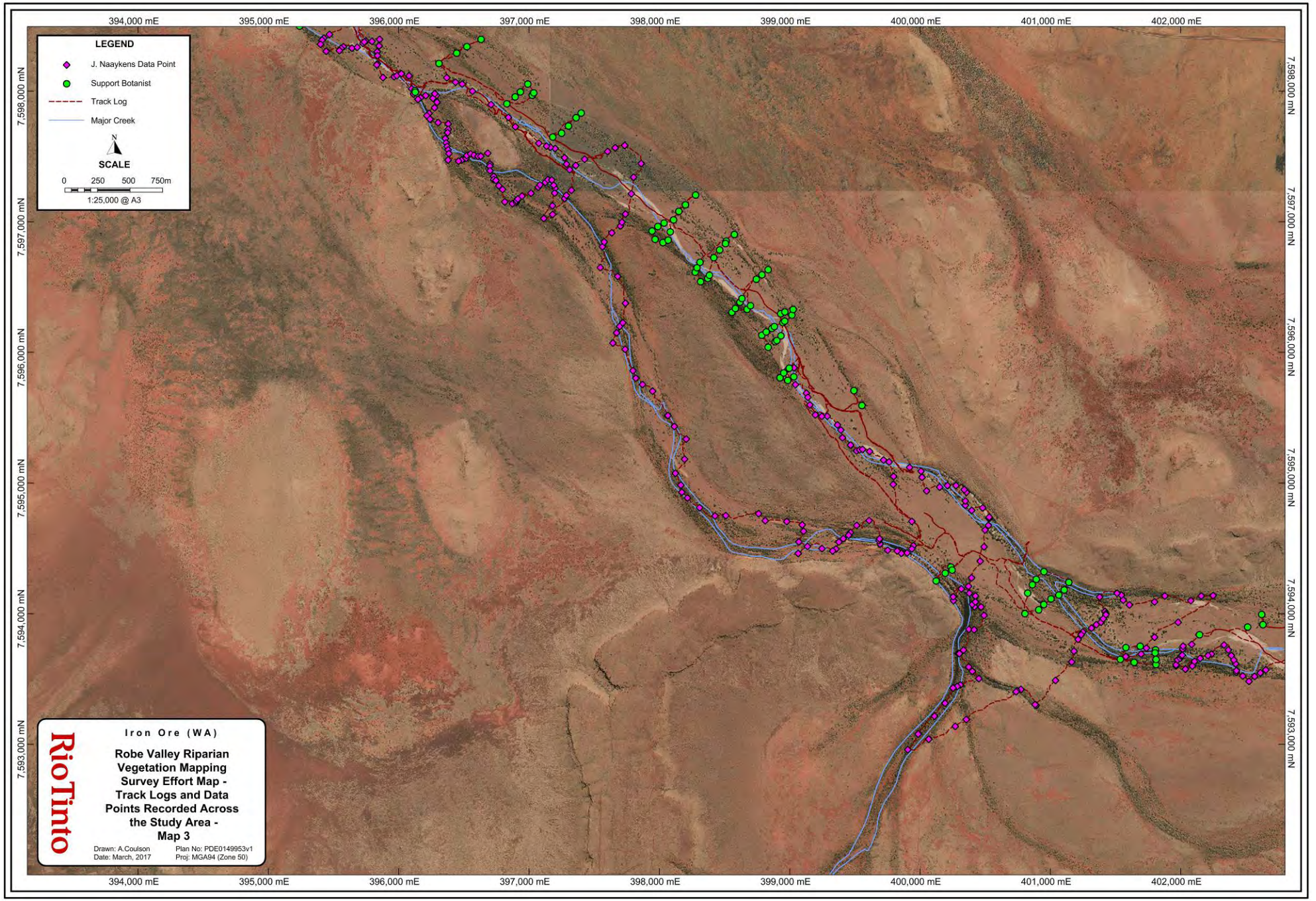

Figure 3-4: Survey effort map 3 of 7

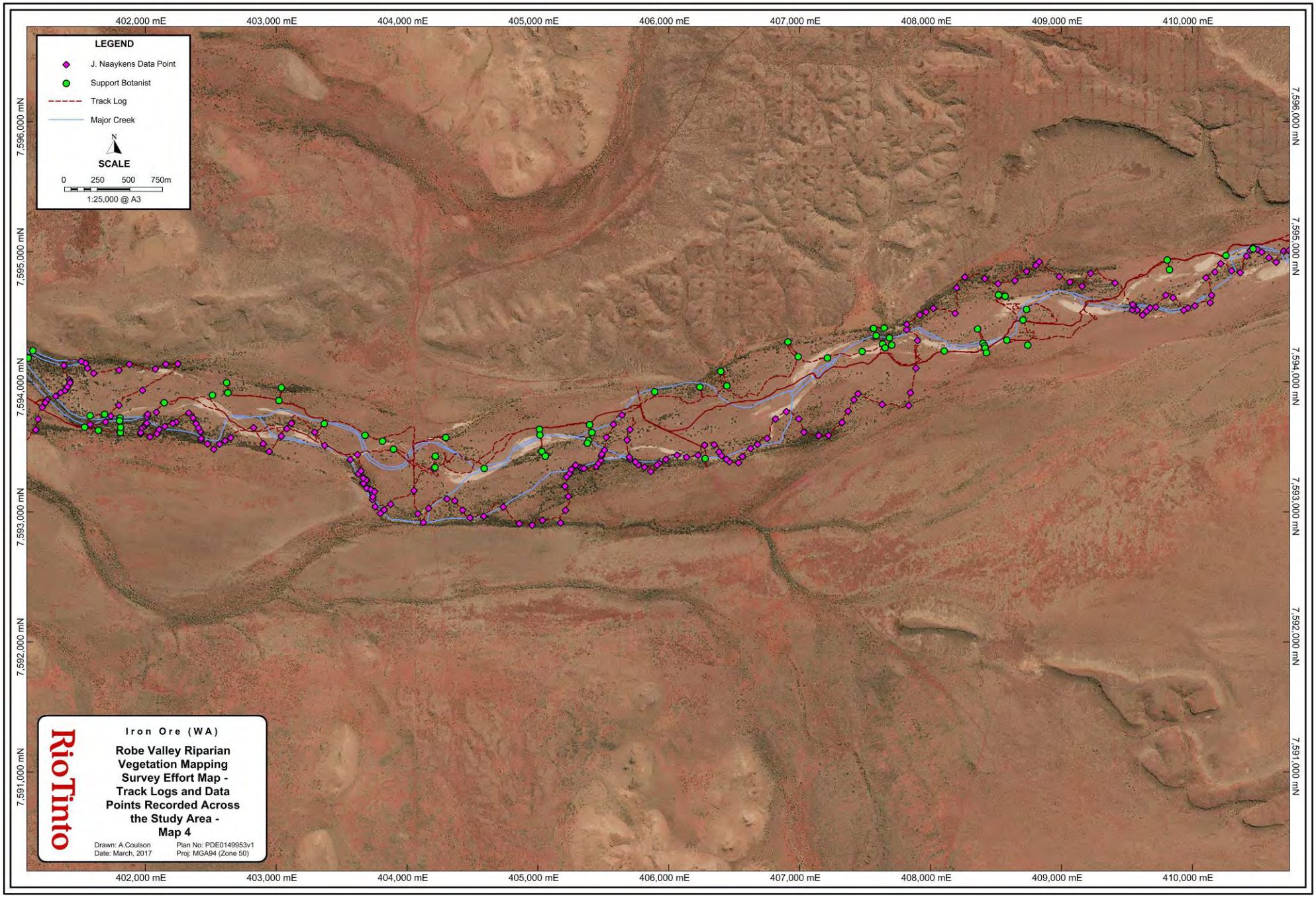

Figure 3-5: Survey effort Map 4 of 7

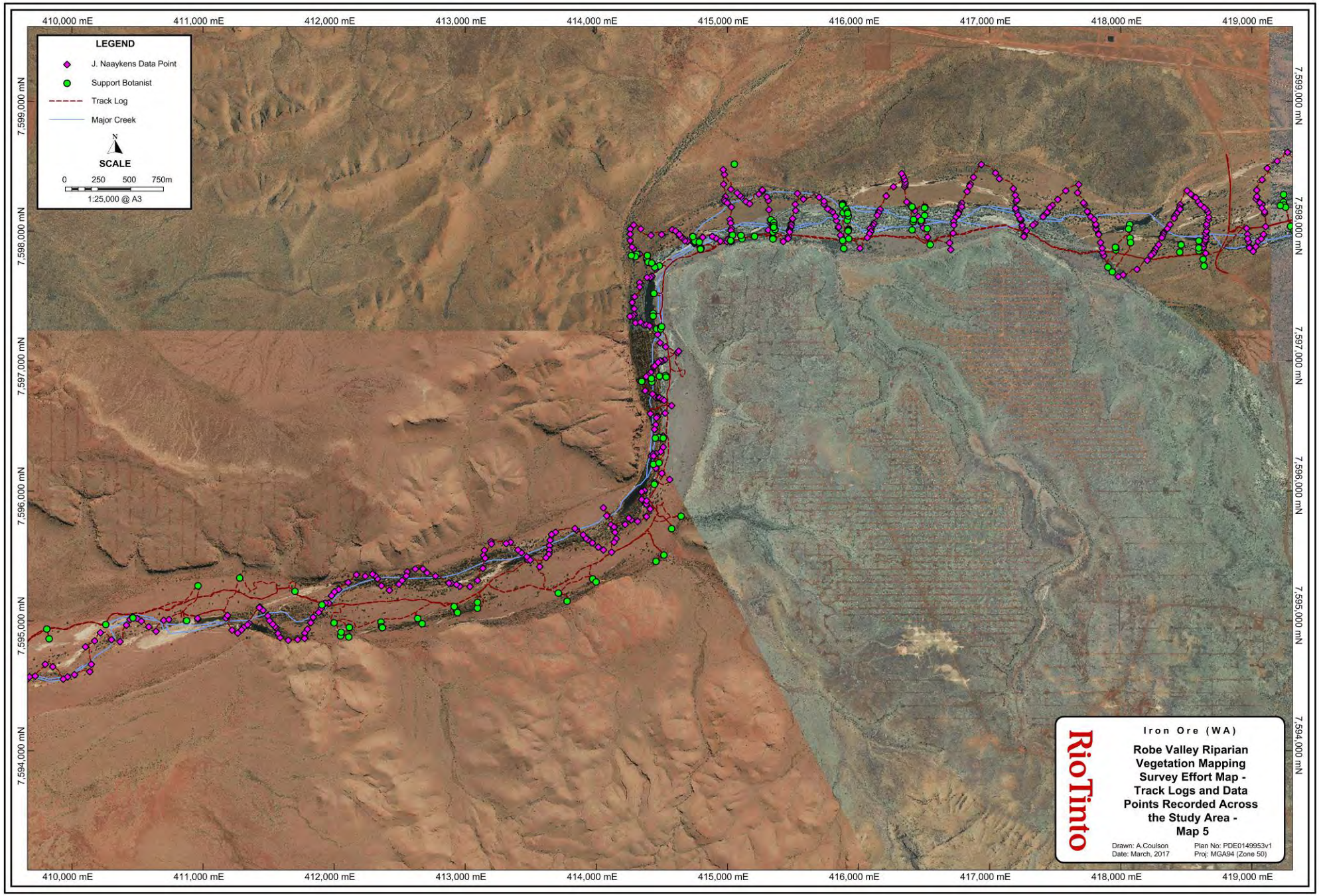

Figure 3-6: Survey effort Map 5 of 7

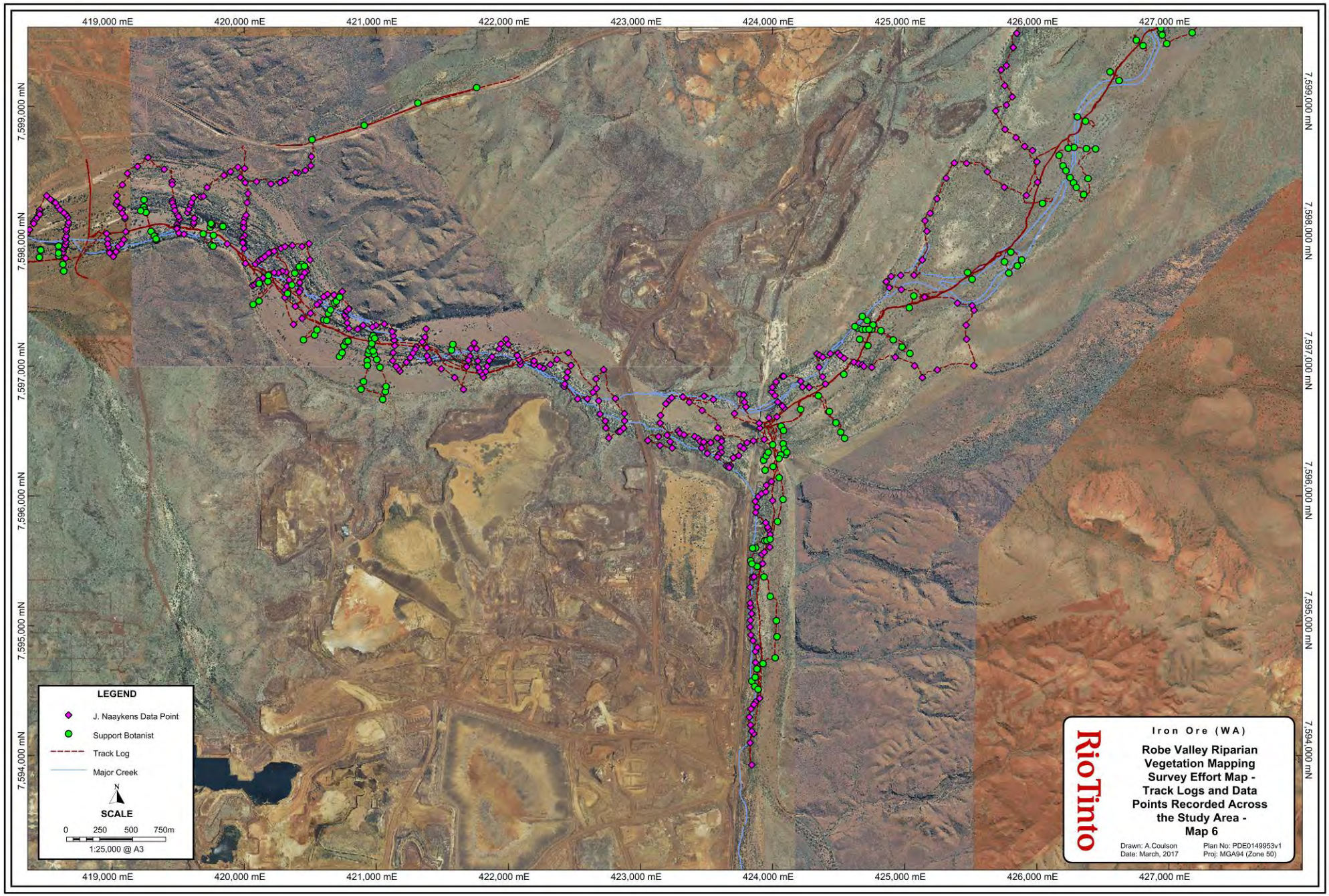

Figure 3-7: Survey effort Map 6 of 7

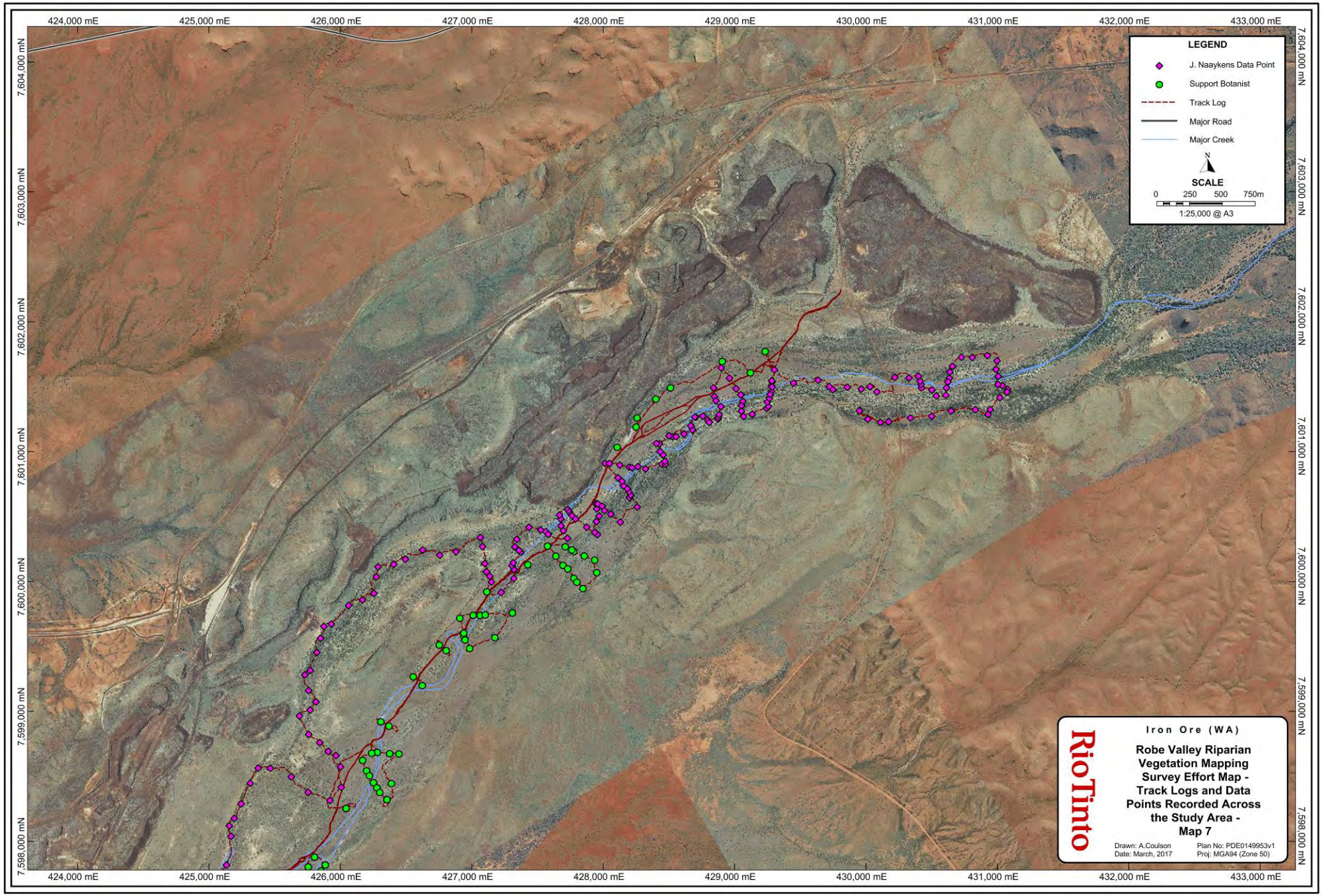

Figure 3-8: Survey effort Map 7 of 7

3.1.4 Post Field Work Vegetation Mapping

Classification and mapping of OPV communities across the study area

Following field acquisition, data was entered within Microsoft Excel and uploaded to a GIS (Mapinfo Pro, Encom Discovery 2011). This GIS data was initially analysed to gain a broad scale understanding of the distribution of OPV within the study area. Once general distribution patterns were established and considered in relation to the location of different river reaches, adjacent topographical features and broad patterns of river morphology, all data relating to OPV were used to identify and classify 6 different OPV community types across the study area;

1. a "Mature" *Melaleuca argentea* (**MA**) dominated closed forest.
2. a "Mature" MA dominated open forest.
3. a variable "Mature" (to "Semi-mature") woodland co-dominated by MA and *E. camaldulensis*
4. a variable "Young" to "Semi-mature" low woodland (to tall shrubland) of MA and *Eucalyptus* pp.
5. a "Young" shrubland (to open shrubland) of MA *and E. camaldulensis* saplings
6. a "Young" (to "Semi-mature") low open forest of *MA* (low trees to saplings).

These six communities were split on their structural and compositional characteristics and by their degree of "Maturity" (inferred from recorded size class ranges). Therefore; the inferred degree of structural/compositional stability and inherent significance is able to be reasonably attributed to each. Using the complete OPV dataset and commonly accepted data point correlation and extrapolation techniques, the spatial boundaries of all OPV communities encountered in the study were mapped at a fine scale. Correlation and extrapolation techniques generally involve the correlation of vegetation data with aerial photo signatures and the subsequent extrapolation of that data across the extent of the relevant aerial signature. These polygons were mapped to represent areas where the cover/abundance of *M. argentea* was deemed to comprise a significant component of the resident community's structure and therefore represent a co-dominant/dominant structural component as opposed to merely an associated species.

Factors used in the process of allocating various patches of OPV encountered in the field to one of the six OPV communities included the following.

1. the variability/range of the inferred age structure recorded (inferred based on trunk size classes) within a mapped vegetation patch.
2. the maximum inferred *M. argentea* size for each representative vegetation patch.
3. the general structure and composition (particularly the presence absence of key mesic indicator species) of the vegetation within which the *M. argentea* populations occurred.
4. the distribution of each community in relation to key morphological features of the river (e.g. fringing pools, fringing scoured channels, outer banks, high flow channels etc.).

Once all occurrences of these OPV communities were mapped; for the purpose of presentation within this study, certain communities were amalgamated to produce a simpler complete vegetation model. Of the 6 community types from the preceding list; the 6th was combined with the 3rd type, and the 5th combined with the 4th type. The "Young" (to "Semi-mature") low open forest of MA (Type 6) was combined with the variable mature woodland (Type 3) due to its generally close spatial association with mature communities alongside large relatively permanent pools. Amalgamation of this community with the other more transient and less significant "Young to Semi-Mature" structured communities is considered incongruent from sensitivity, significance and spatial standpoints, despite the some similarities in age and physical structure.

The amalgamation of types 4 and 5 was an obviously complimentary choice and determined sound from all relevant standpoints.

Mapping FPV communities present within the study area

Following the OPV mapping process; the remaining wooded riparian associations (generally representing FPV) co-occurring with and often surrounding the OPV were refined based on targeted mapping notes, photo points, and interpretation of community and species specific aerial photo signatures.

The key task of this final mapping component was to establish, and spatially delineate FPV communities with a tree strata either dominated by *Eucalyptus camaldulensis* or co-dominated by *E. camaldulensis* and *E. victrix* (FPV), but which does not contain *Melaleuca argentea* as a co-dominant species. *Eucalyptus camaldulensis* is widely considered to be the more groundwater dependent of the riparian eucalypts which commonly occur in the study area. While *Eucalyptus victrix* is generally considered to be a facultative phreatophytic species, it is also recognised that this species is less reliant on groundwater access than *E. camaldulensis*, and more easily able to survive solely on vadose soil water sources. For this reason, mapping the distribution of *E. camaldulensis* (outside of OPV) is an important secondary step in the process of mapping varying degrees of community related groundwater dependence.

E. camaldulensis distribution mapping essentially either requires regular field notes on the presence/absence and abundance of *E. camaldulensis* in the field, or relies on some presence absence field data to help enable accurate interpretation of species specific aerial photo signatures. Within the Robe River; it was noted that canopy and stem related visual cues which often allow relatively confident differentiation between these two species were not clearly aiding this differentiation process during the field survey. For this reason, aerial photo interpretation was the key tool used for mapping the distribution of *E. camaldulensis*, and *E. victrix* in this study. This process was aided significantly by the use of recent high resolution (0.5 m) true colour DMSI imagery. High resolution 4-band aerial imagery enabled individuals/populations of *Eucalyptus camaldulensis* to be identified on GIS and therefore accurately mapped as either representing dominant or co-dominant vegetation communities. In order of relative usefulness in the Robe river locality; Individuals or groups of *Eucalyptus camaldulensis* within the riparian environment were distinguished on aerial photography from *E. victrix* on the basis of:

1. the generally darker green canopy colour signature of *E. camaldulensis*;
2. the generally denser canopy cover signature of *E. camaldulensis*;
3. the generally dissimilar branch signature of *E. camaldulensis* canopy architecture; and
4. the generally larger (spatial extent) canopy footprint of *E. camaldulensis*.

The available aerial photography was considered to be of a quality suitable for the application of the above described visual assessment and was found to be robust when ground-truthed using field data. Some more obvious and presentable examples of the aerial signature of *E. camaldulensis* trees from Weeli Wolli Creek are provided below in Plate 3-3. The examples presented in Plate 3-3 were generally chosen due to their location on an open floodplain, where canopy density is reduced and as such surrounding canopy species don't inhibit the display of the above described characters, thus making them easier for the reader to appreciate/visualise. Plate 3-4 shows examples of key eucalypt aerial signatures from the Robe River

All vegetation types mapped as part of this study, were described using Aplins' (1979) framework for "Vegetation Structural Classes" (Specht 1970). This framework is presented in Appendix 1, along with vegetation condition scale used in this study (Trudgen 1988). As such all communities (**Table 4-1**)

established as part of this study are generally considered to represent sub-associations. Community descriptions were created by identifying dominants (where present) for all relevant strata available, rather than restricted to the three traditional strata, such that they represent relatively detailed vegetation descriptions, approximately equivalent to level 5 mapping within the National Vegetation Information System (**NVIS**) (DoE 2014b).

Given the Stage 1 status of this study; some vegetation types mapped and described as part of this study are potentially more accurately classified as associations, or are lacking some of the structural/compositional differentiation which comes from sampling over multiple phases (as part of a detailed survey (EPA 2016b)). Furthermore; some of the non-core riparian communities of the high-flow and terrace riparian habitats are yet to be properly described and delineated throughout the study area. Given the focus of this study is on delineating groundwater dependent ecosystems the reduced level of detail provided for such communities is considered relatively inconsequential and of low significance when considering potential impacts.

Plate 3-3: Aerial photos showing examples of *Eucalyptus camaldulensis* canopies (inside orange polygon) on high resolution aerial photography (Weeli Wolli Creek)

Note: Beyond the more obvious shrub features, the majority of the remaining eucalypt canopies present in these plates are considered to be *E. victrix* as indicated by the relatively obvious white branch and trunk colouration, open branching habit and lighter foliage colour.

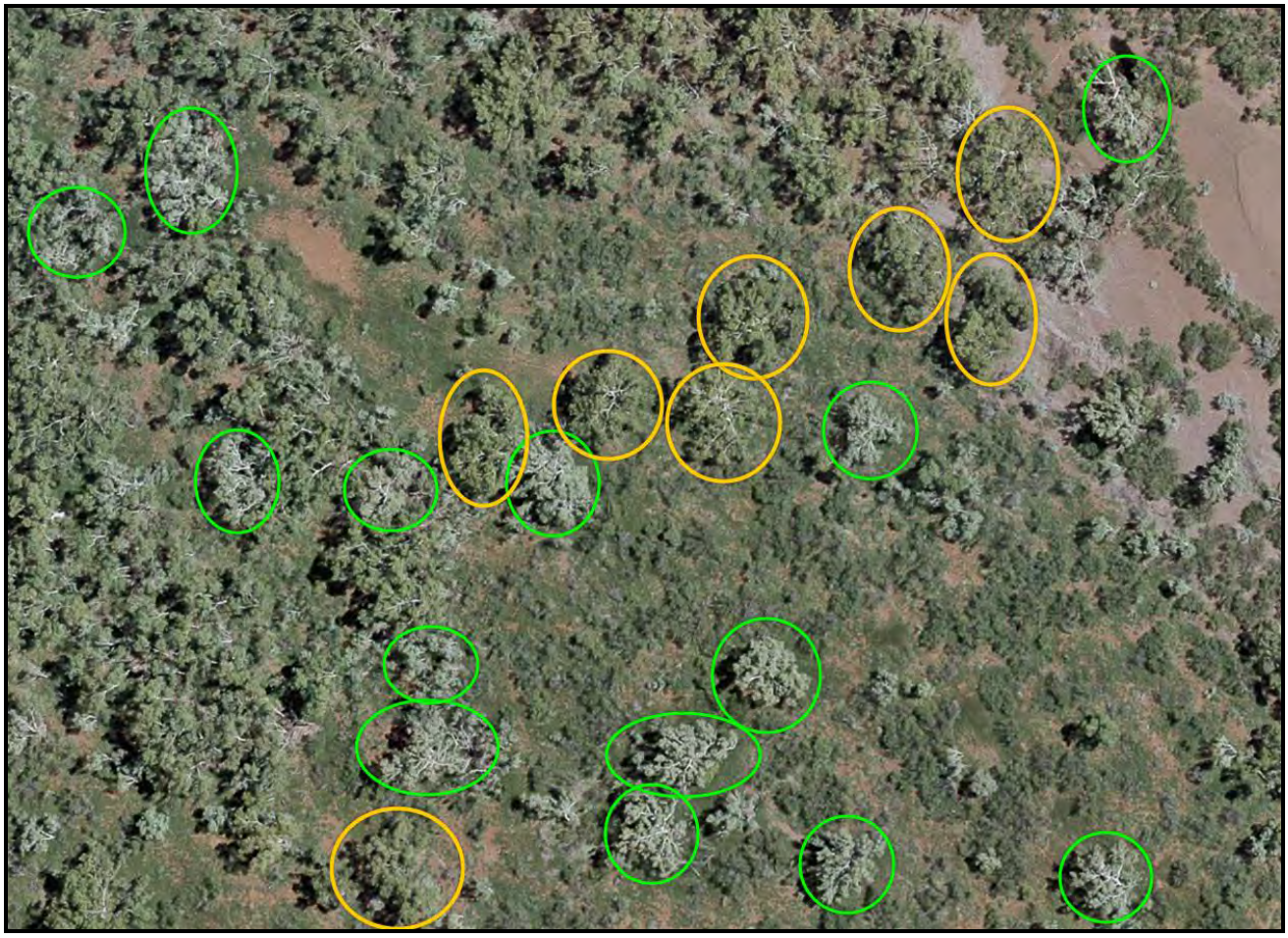

Plate 3-4: Aerial photos showing examples of Eucalyptus camaldulensis canopies (inside orange polygons), and E. victrix (inside green polygons), on high resolution aerial photography within the Robe River (April 2017)

3.2 SIGNIFICANCE FRAMEWORK USED TO ASSESS THE LOCAL SIGNIFICANCE OF RIPARIAN COMMUNITES MAPPED WITHIN THE STUDY AREA

For the purpose of incorporating a sense of "quantification" to the process of attributing significance to riparian communities within the study area, the following "framework for Significance" was developed in Rio Tinto 2015 and adapted in this study as a means of providing a more systematic qualitative assessment of significance:

Key steps for considering the relevant factors/attributes are:

1. Part one - consider the number and magnitude of ecological values associated with or provided by a biological feature.
2. Part two - determine the distribution and therefore degree to which it is restricted in the environment, the degree of representation (the degree to which a vegetation unit is represented by other communities outside of the study area), and potential rarity of this feature within local, sub-regional, and regional scales.
3. Part three – consider the condition of the biological feature, and its inherent resilience to perturbation.

Once determined, the combined consideration of parts one and two result in the determination of an initial significance rating. The inherent sensitivity or resilience of a feature to perturbation will tend to increase or decrease the likelihood of impact, as well as the consequences of the impact. In addition, the current condition of the feature at the time of consideration will have an influence on its significance. In order to incorporate sensitivity/resilience and locally known potential anthropogenic impacts into the resultant

significance, it is proposed that for this study, a final "Resultant Local Significance rating" will be determined via part three of the framework and used to attribute an alternative and more locally measured significance to the biological features being assessed.

In addition to the considering physical and biological condition of a feature; this final significance will incorporate some consideration of the inherent risks and potential consequences of development on this feature into the attributed resultant significance. The result of this framework is that ultimately the final resultant local Significance will in turn provide a more measured guidance to management and mitigation as development is undertaken or continued.

3.3 LIMITATIONS OF THIS STUDY

Overarching

- For the most part the study area was easily accessed.
- Base flow in the Robe River was anecdotally much reduced preceding (for at least 1-2 years prior) and at the time of the first survey. Rainfall/seasonal conditions and flowering/fruiting conditions were sub-optimal. However because the GDE focus of this study determined that key interests surrounded the distribution of perennial species this was not generally a limiting factor. Instead the sub-optimal seasonal conditions allowed relatively unrestricted vehicular access and traverse patterns to be conducted throughout the river bed. In addition; the unusually low water levels enabled collection of information on the spatial distribution of low to moderate degrees of hydrological stress within obligate phreatophytes across the study area.
- The vast majority of the field work required for the Robe River riparian vegetation mapping project was successfully completed and reported upon herein. However; some of the planned outer reaches of Robe River and Jimmawarrada Creek remain to be assessed with the methodology adopted in this study. Only those information requirements needed in the short term have been completed and included in this Stage 1 report. This includes the complete differentiation and mapping of some of the Floodplain/Terrace communities which lie in the outer riparian zones of the Robe River. Further to this; a 25 cm pixel aerial photo was requested for the complete study area in October of 2016, but at the time of production of this report had not yet been flown and processed due to mechanical breakdowns and weather limitations. Given the species specific, and community specific identification advantages of this orthophoto, it was planned to be used as an important tool in this project for providing the highest confidence mapping of OPV and FPV communities within the study area. This aerial photo is planned to be used once all additional field work is complete and the entire dataset can be validated using this tool as part of Stage 2.

Desktop and Field Data Acquisition Tools

- Size classes attributed to *M. argentea* populations are a visual estimate and potentially inaccurate in some cases.
- As previously experienced limitations in the correlation between NDVI cover anomalies and OPV were again apparent for the mature OPV woodland communities. This essentially determined that such communities (mainly the C1A and C1b vegetation type) were much harder to distinguish at a desktop level from that of more common mature *Eucalyptus* spp. FPV communities. In these instances; true colour aerial photo signatures and relatively comprehensive creek coverage was relied upon to minimise false negative recordings.

Ground Truthing and Vegetation Mapping Field Work

- The amount of standing water in the creek at the time of survey only restricted movement across creek in a few situations; consequently ground truthing traverse patterns were not hindered.

- Not all species of interest were in optimal condition at the time of the survey. However this did not significantly hinder the acquisition of field data and as mentioned above, for obligate phreatophytic species this enabled the collection of additional useful data. For the most part key eucalypt species were not regularly fruiting/flowering at the time of survey. This did hinder quick differentiation between riparian Eucalypts, however, given that the study area was >60 km in length, it was not feasible to differentiate between these species often enough in the field to provide meaningful differentiation at the scale of the mapping produced. As a result high resolution aerial photo signatures of *E. camaldulensis* and *E. victrix* was inevitably the key tool for mapping the distribution patterns of these two key riparian eucalypt species. However; some field data for ground-truthing aerial photo signatures was required, and where fruit was not available the following technique was used.
- Where riparian eucalypt fruit/flowers were not available, hand lenses were used to determine the identification of the resident eucalypts within a number of representative patches of vegetation via leaf anatomy. *E. camaldulensis* typically possesses true oil glands within the endoplasmic reticulum of its leaves, whereas *E. victrix* does not. Combined with the distinctive differences in lateral vein architecture of the two species (broad/sparse and wavy in *E. camaldulensis*, and tight/uniform and straight in *E. victrix*) ID's were considered accurate in all occasions rather than potentially inaccurate in certain conditions without hand lens techniques.
- Flora and vegetation data collected as part of this study came from a single phase of work and as such were not seasonally sampled.

Post Field Work Vegetation Mapping Process

- Data quantity and resolution was more than adequate for the scope of the targeted assessment.
- Coverage was more than adequate for the scope of the targeted assessment.

Mapping errors have been significantly minimised through extensive ground-truthing and 4-band aerial photo interpretations. The degree of ground-truthing effort conducted for the included groundwater dependent communities, and particularly the OPV communities, is such that the mapping is considered to be significantly more accurate than vegetation mapping typically undertaken within riparian areas.

4 RESULTS

4.1 VEGETATION MAPPING

Table 4-1 below presents the resultant vegetation types described as part of the GDE focused vegetation mapping process. A list of the associated species recorded in each is included in Appendix 2. Representative photos of the riparian vegetation types mapped as part of this study are presented in Appendix 3. For each vegetation type mapped, multiple photos are provided in Appendix 3 to provide some indication of the degree of variation which was observed in each. In an effort to provide a more simplified vegetation model which facilitates easier and broader comprehension of the distribution of groundwater dependent and mesic riparian communities within the study area, a number of the vegetation types presented in Table 4-1 were strategically amalgamated to produce the following riparian vegetation summary maps presented in Figures 4-1 to 4-4. Within Table 4-1, a column has been added to delineate which of the detailed vegetation types were amalgamated to form the summary map vegetation types presented in Figures 4-1 to 4-4. These figures are essentially for the purpose of viewing the distribution of potentially GDV at a larger scale and therefore over larger swathes of the river. These maps should be used when a simpler, broader scale perspective of riparian vegetation within the Robe River is preferred. Maps presenting the resultant vegetation mapping for the complete suite of Stage 1 vegetation types (i.e. without amalgamation of similar communities) are presented in Figures 4-5 to 4-13. These figures present the full degree of mapping detail resulting from stage 1 of the riparian mapping project within the Robe River. As a result Figures 4-5 to 4-13 are most appropriate when considering the distribution and extent of riparian vegetation at the finer scale.

4.1.1 Vegetation Coding

As detailed in the methods, the same coding regime as Rio Tinto (2015) was attributed to vegetation types identified in this study. To help equate the resultant vegetation types to the most recent and relevant local vegetation mapping in the sub-region, the equivalent Astron (2015/2016) veg code for each vegetation type in this study is provided in Table 4-1. The original codes and the hierarchy of significance which they were defined to convey in Rio Tinto (2015) have been maintained as much as possible while still allowing them to reflect the compositional findings and resultant vegetation structure identified in the study area. The most important differences between the coding of these two studies, while minor, relate to the C1AA end of the coding spectrum (communities with an overstorey dominated by obligate phreatophytes) and to the C4-C6 (differing shrublands) end of the coding spectrum. In addition; codes relating to *E. camaldulensis* dominated woodlands/open-forests were required to be integrated due to their delineation in this study and absence in Rio Tinto (2015).

4.2 GROUNDWATER DEPENDENT VEGETATION COMMUNITIES MAPPED

As part of the vegetation mapping process six key types of groundwater dependent vegetation were identified. Listed in order of relative hydrological sensitivity, these are:

1. OPV-A: Vegetation dominated by mature Obligate Phreatophytes

2. OPV-B: Vegetation co-dominated by mature Obligate Phreatophytes

3. OPV-C: Vegetation co-dominated by immature Obligate Phreatophytes
4. FPV-A: Vegetation dominated by *Eucalyptus camaldulensis* (the most hydrologically sensitive Local Facultative Phreatophyte) and at times supporting *Sesbania formosa*
5. FPV-B: Vegetation co-dominated by *Eucalyptus camaldulensis*
6. FPV-C: Vegetation dominated by *Eucalyptus victrix* (the second most hydrologically sensitive local Facultative phreatophyte)

These GDE types are generally relevant to the local Pilbara environment; however the structural concepts and physiological scales which they describe can be applied more widely. It should be noted that the applied differentiation (i.e. A, B, and C) within each accepted hydrological strategy (i.e. Obligate, Facultative etc.) is not widely known or accepted. However; the varying degrees of groundwater availability inferred by the degrees of phreatophyte structural dominance (and maturity) which they intend to classify, are entirely relevant and a useful way of classifying groundwater dependence.

Table 4-1: Vegetation descriptions and GDE summary info for all riparian vegetation types mapped in the study area.

Veg Code	GDE / Community Summary Info	GDE Type	Vegetation Description	Distribution	Condition	Equivalent Astron 2015 and 2016 Code
PO	Minimal Vegetation	Pool - GDE	**Tree Strata: N/A** **Shrub Strata: N/A** **Lower Strata:** Fringed by variable Sedgeland to open sedgeland of *Typha domingensis*, Cyperaceae spp., *Schoenoplectus* spp., *Schoenus* spp., along with *Stemodia grossa* and other small mesic shrubs	Uncommon but Scattered along the low flow channel and often spatially correlated with topographic pinch points along the river channel	Good to Poor	N/A
C1AAa	Mature MA dominated Closed Forest	OPV	**Tree Strata:** *Melaleuca argentea* closed forest **Shrub Strata:** *Petalostylis labicheoides*, *Acacia trachycarpa*, *Melaleuca glomerata* and *Acacia ampliceps* scattered shrubs **Lower Strata:** *Cyperus vaginatus* open sedgeland over *Stemodia grossa* scattered to low open shrubland, amongst scattered pools.	Scattered along low points in the river bed, where groundwater appeared shallow, often up against steep massive bank formations	Excellent to Very Good	Similar to EcMaCvCspp (Astron 2015) or MaEcCv (Astron 2016)
C1AAb	Mature MA dominated Open Forest	OPV	**Tree Strata:** *Melaleuca argentea* (plus scattered *Eucalyptus camaldulensis*) open forest (to closed forest in places). **Shrub Strata:** *Petalostylis labicheoides*, *Acacia trachycarpa*, and *Acacia ampliceps* scattered shrubs (to open shrubland in places) **Lower Strata:** *Cyperus vaginatus* very open sedgeland (to open sedgeland) over *Stemodia grossa* scattered low shrubs	Scattered along low points in the river bed, and near mesa features where groundwater appeared shallow	Excellent to Very Good	MaEcCv (Astron 2016) or Similar to EcMaCvCspp (Astron 2015)

Veg Code	GDE / Community Summary Info	GDE Type	Vegetation Description	Distribution	Condition	Equivalent Astron 2015 and 2016 Code
C1A	Mature MA and EC dominated Open forest to Low Woodland	OPV	**Tree Strata:** *Melaleuca argentea* & *Eucalyptus camaldulensis* subsp. *refulgens* (plus scattered *Sesbania formosa*) Low open forest (to woodland in places) **Shrub Strata:** *Melaleuca argentea*, *Petalostylis labicheoides*, *Acacia trachycarpa*, *Acacia ampliceps* and *Melaleuca glomerata* open shrubland (to shrubland in places) **Lower Strata:** Scattered sedges/shrubs of *Cyperus vaginatus*, *Stemodia grossa* and at times; **Cenchrus ciliaris*, **Cenchrus setiger*, **Setaria verticillata* very open tussock grassland	Consistently fringing low flow channels or scattered around permanent water features where groundwater appeared shallow	Excellent to Very Good	EcMaCvCspp (Astron 2015) or MaEcCv (Astron 2016)
C1b	Semi-Mature MA and EC dominated Low Woodland	OPV	**Tree Strata:** *Melaleuca argentea*, *Eucalyptus camaldulensis* subsp. *refulgens* variable low woodland (to low open woodland) (also includes low open forests of *M. argentea* & *E. camaldulensis* saplings fringing pools **Shrub Strata:** *Melaleuca argentea*, *Petalostylis labicheoides*, *Acacia trachycarpa*, and *Melaleuca glomerata* variable open shrubland to shrubland **Lower Strata:** *Cyperus vaginatus* scattered sedges, over *Stemodia grossa* scattered low shrubs.	Scattered along low flow or secondary channels of the main river bed, including some high flow channels	Excellent to Very Good	Similar to EcMaCvCspp (Astron 2015) or similar to MaEcCv (Astron 2016)
C2AA	Large Mesic EC dominated Open Forest representations	FPV-A	**Tree Strata:** *Eucalyptus camaldulensis* subsp. *refulgens* open forest (to low open forest with scattered *Eucalyptus victrix* and at times *Sesbania formosa*) **Shrub Strata:** *Petalostylis labicheoides*, *Acacia trachycarpa*, *Melaleuca glomerata* and *Acacia ampliceps* tall shrubland (to tall open shrubland in places) **Lower Strata:** *Cyperus vaginatus* scattered sedges and in places **Cenchrus ciliaris*, **Cenchrus setiger* (**Setaria verticillata*) very open tussock grassland	Scattered along secondary channels and banks of the main river bed, including some high flow channels	Very Good to Good	Similar to EcCv (Astron 2015) or EcEvAtrApyPlTw (Astron 2016)

Veg Code	GDE / Community Summary Info	GDE Type	Vegetation Description	Distribution	Condition	Equivalent Astron 2015 and 2016 Code
C2A	EC dominated Open Forest	FPV-A	**Tree Strata:** *Eucalyptus camaldulensis* subsp. *refulgens* open forest (to low open forest with scattered *Eucalyptus victrix* and at times *Sesbania formosa*) **Shrub Strata:** *Petalostylis labicheoides*, *Acacia trachycarpa*, *Melaleuca glomerata* and *Acacia ampliceps* tall shrubland (to tall open shrubland in places) **Lower Strata:** *Cyperus vaginatus* scattered sedges and in places **Cenchrus ciliaris*, **Cenchrus setiger*, **Setaria verticillata* very open tussock grassland	Consistently Scattered along low flow channels, secondary channels and banks of the main river bed	Very Good to Good	Similar to EcCv (Astron 2015) or EcEvAtrApyPlTw (Astron 2016)
C2B	EC & EV co-dominated Open Forest	FPV-B	**Tree Strata:** *Eucalyptus camaldulensis* subsp. *refulgens*, *E. victrix* open forest (to woodland in places) **Shrub Strata:** *Acacia trachycarpa*, *Petalostylis labicheoides* and *Melaleuca glomerata* tall open shrubland (to tall shrubland in places) **Lower Strata:** **Cenchrus ciliaris*, **Cenchrus setiger* (**Setaria verticillata*) very open (to open) tussock grassland with scattered sedges of *Cyperus vaginatus*	Scattered throughout the bed, but often along secondary channels and banks of the main river bed, including high flow channels.	Good to Poor	Similar to EcEvCspp (Astron 2015) or EcEvAtrApyPlTw (Astron 2016)
C2A-B	EC dominated Woodlands	FPV-A	**Tree Strata:** *Eucalyptus camaldulensis* subsp. *refulgens* woodland (to open forest in places) **Shrub Strata:** *Acacia trachycarpa*, *Petalostylis labicheoides* (*Acacia pyrifolia*, *Gossypium robinsonii*) tall open shrubland (plus *Melaleuca glomerata* in some areas) **Lower Strata:** **Cenchrus ciliaris*, **Cenchrus setiger* very open (to open) tussock grassland (plus scattered *Cyperus vaginatus* and *Stemodia grossa* and at times very open hummock grassland of *Triodia epactia* & *T. wiseana*)	Scattered throughout the bed, but often along secondary channels and banks of the main river bed, including high flow channels	Good	EcCv (Astron 2015) or EcEvAtrApyPlTw (Astron 2016)

Veg Code	GDE / Community Summary Info	GDE Type	Vegetation Description	Distribution	Condition	Equivalent Astron 2015 and 2016 Code
C2B-B	EC & EV co-dominated Woodland	FPV-B	**Tree Strata:** *Eucalyptus camaldulensis* subsp. *refulgens*, *Eucalyptus victrix* woodland (to low woodland) **Shrub Strata:** *Acacia trachycarpa*, *Petalostylis labicheoides* (*Acacia pyrifolia*, *Gossypium robinsonii*) tall open shrubland (plus *Melaleuca glomerata* in some areas) **Lower Strata:** **Cenchrus ciliaris*, **Cenchrus setiger* very open (to open) tussock grassland (plus scattered *Cyperus vaginatus* and *Stemodia grossa* and at times very open hummock grassland of *Triodia epactia* & *T. wiseana*)	Scattered throughout the bed, often along secondary channels and banks of the main river bed, including tributaries & high flow channels	Good to Poor	EcEvCspp (Astron 2015) or EcEvAtrApyPlTw (Astron 2016)
C2C	EV Dominated Woodland	FPV-C	**Tree Strata:** *Eucalyptus victrix* woodland (to low woodland with scattered *E. camaldulensis*) **Shrub Strata:** *Acacia trachycarpa*, *Petalostylis labicheoides* (*Acacia pyrifolia*) tall open shrubland (to scattered tall shrubs in places) **Lower Strata:** **Cenchrus ciliaris*, **Cenchrus setiger* very open (to open) tussock grassland (and at times very open hummock grassland of *Triodia epactia* & *T. wiseana*)	Scattered throughout the bed, often along secondary channels and banks of the main river bed, including tributaries & high flow channels	Good to Poor	EvMgCv (Astron 2015) or EvAtrTwCspp (Astron 2016)
C3A	EC & EV co-dominated Open woodland	FPV-B	**Tree Strata:** *Eucalyptus camaldulensis* subsp. *refulgens*, *Eucalyptus victrix* open woodland (to scattered trees in places) **Shrub Strata:** *Acacia trachycarpa*, *Petalostylis labicheoides* (*Acacia pyrifolia*) tall shrubland (to tall open shrubland) **Lower Strata:** Gravel beds at times colonised by **Cenchrus ciliaris*, **Cenchrus setiger* very open (to open) tussock grassland (at times including a very open hummock grassland of *Triodia epactia* & *T. wiseana*)	Scattered throughout the drier, often elevated sections of the main river bed, and associated tributaries	Good to Poor	EcEvCspp (Astron 2015) or similar to EcEvAtrApyPlTw (Astron 2016)

Veg Code	GDE / Community Summary Info	GDE Type	Vegetation Description	Distribution	Condition	Equivalent Astron 2015 and 2016 Code
C3B	EV Dominated Open Woodland	FPV-C	**Tree Strata:** *Eucalyptus victrix* low open woodland (to scattered trees in places) **Shrub Strata:** *Acacia trachycarpa*, *Petalostylis labicheoides* (*Acacia pyrifolia*) tall shrubland (to tall open shrubland) **Lower Strata:** Gravel beds at times colonised by **Cenchrus ciliaris*, **Cenchrus setiger* very open (to open) tussock grassland (at times including a very open hummock grassland of *Triodia epactia* & *T. wiseana*)	Scattered throughout the drier, often elevated sections of the main river bed, and associated tributaries.	Good	EvMgCv (Astron 2015) or EvAtrTwCspp (Astron 2016)
C4	Shrublands	Vadophytic	**Tree Strata:** N/A **Shrub Strata:** *Acacia trachycarpa*, *Petalostylis labicheoides* (*Acacia pyrifolia*) tall shrubland (to tall open shrubland) **Lower Strata:** Gravel beds generally dominated by scattered mixed grasses and herbs; but at times colonised by **Cenchrus ciliaris*, **C. setiger* very open (to open) tussock grassland and *Triodia epactia* very open hummock grassland	Scattered throughout the main river bed and terraces; often associated with periodically scoured bed formations	Good to Very Good	Similar to AtrEs & AtTeCc (Astron 2015) or AtrPl (Astron 2016)
C5	Beds with minimal vegetation	Vadophytic	**Tree Strata:** Expansive open gravel beds with isolated trees **Shrub Strata:** Isolated to scattered tall shrubs of *Acacia trachycarpa*, *Petalostylis labicheoides* **Lower Strata:** Variable; Scattered herbs of *Euphorbia schultzii*	Scour zones present throughout river bed, in low flow channels and preferential flow zones where scouring is high.	Excellent	AtrEs (Astron 2015) or Es (Astron 2016*)

Veg Code	GDE / Community Summary Info	GDE Type	Vegetation Description	Distribution	Condition	Equivalent Astron 2015 and 2016 Code
C6	Shrublands	Vadophytic / Xerophytic	**Tree Strata:** N/A **Shrub Strata:** Variable; Tall shrubland (to tall open shrubland) of *Acacia trachycarpa*, *A. pyrifolia* & *Petalostylis labicheoides* (dominating riparian fringes); *A. bivenosa*, *A. inaequilatera*, *A. synchronicia* & *A. ancistrocarpa* with scattered *Corymbia hamersleyana* low trees (dominating terraces) **Lower Strata:** Variable grasslands: **Cenchrus ciliaris*, **Cenchrus setiger* open tussock grassland and *Triodia epactia* (*T. wiseana*) very open hummock grassland (fringing riparian zones); *T. wiseana* (*T. epactia*) open hummock grassland (on terraces)	Distributed throughout the river terrace and high flow channel zones.	Good to Very Good	Similar to AtTeCc & ChAsppTwTe (Astron 2015) or ChAsppGOrGsppPlSsTeTw & ChPlAbGOrTw (Astron 2016)

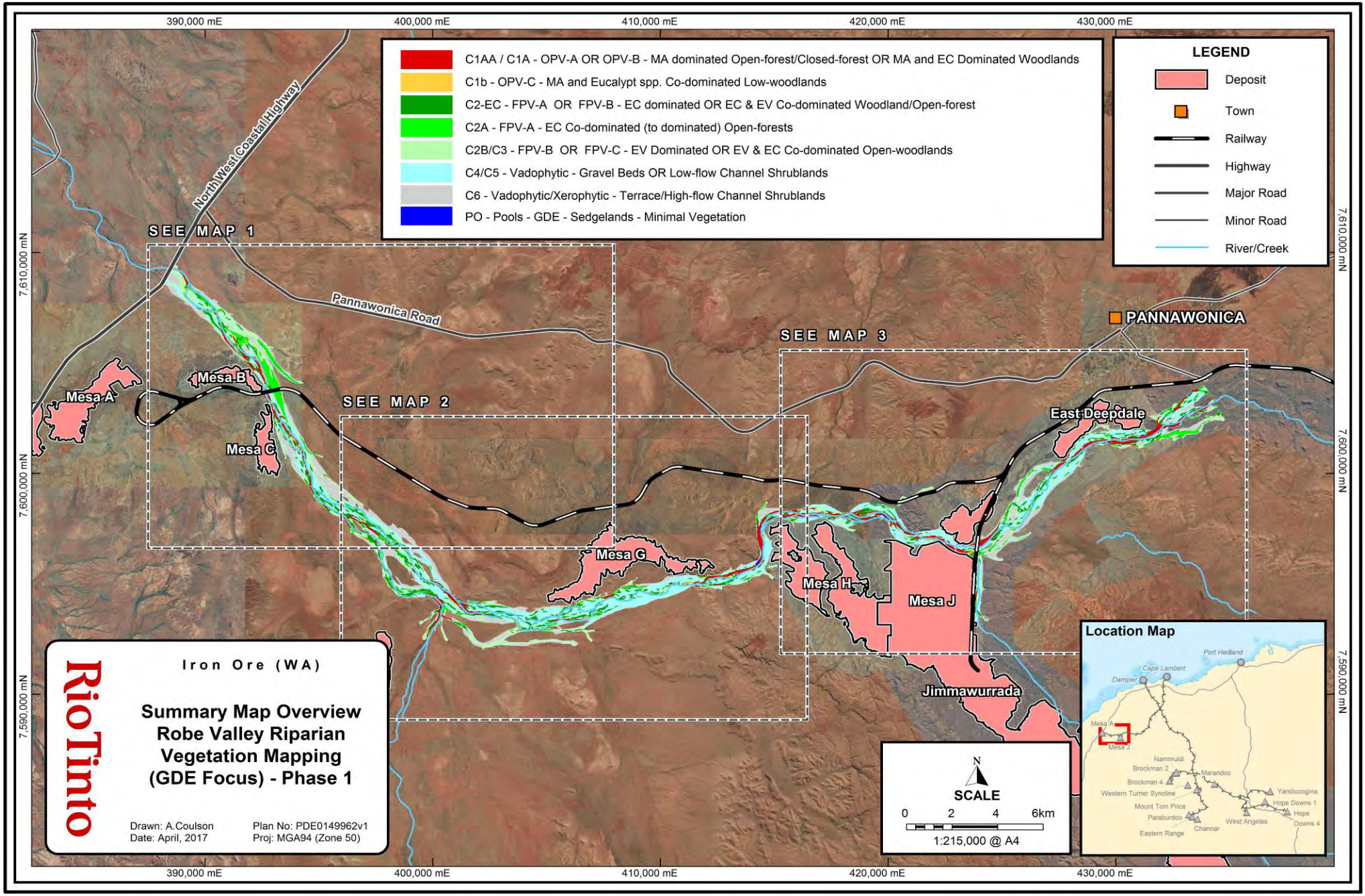

Figure 4-1: Overview map showing the layout of the 3 Riparian Vegetation Summary Maps

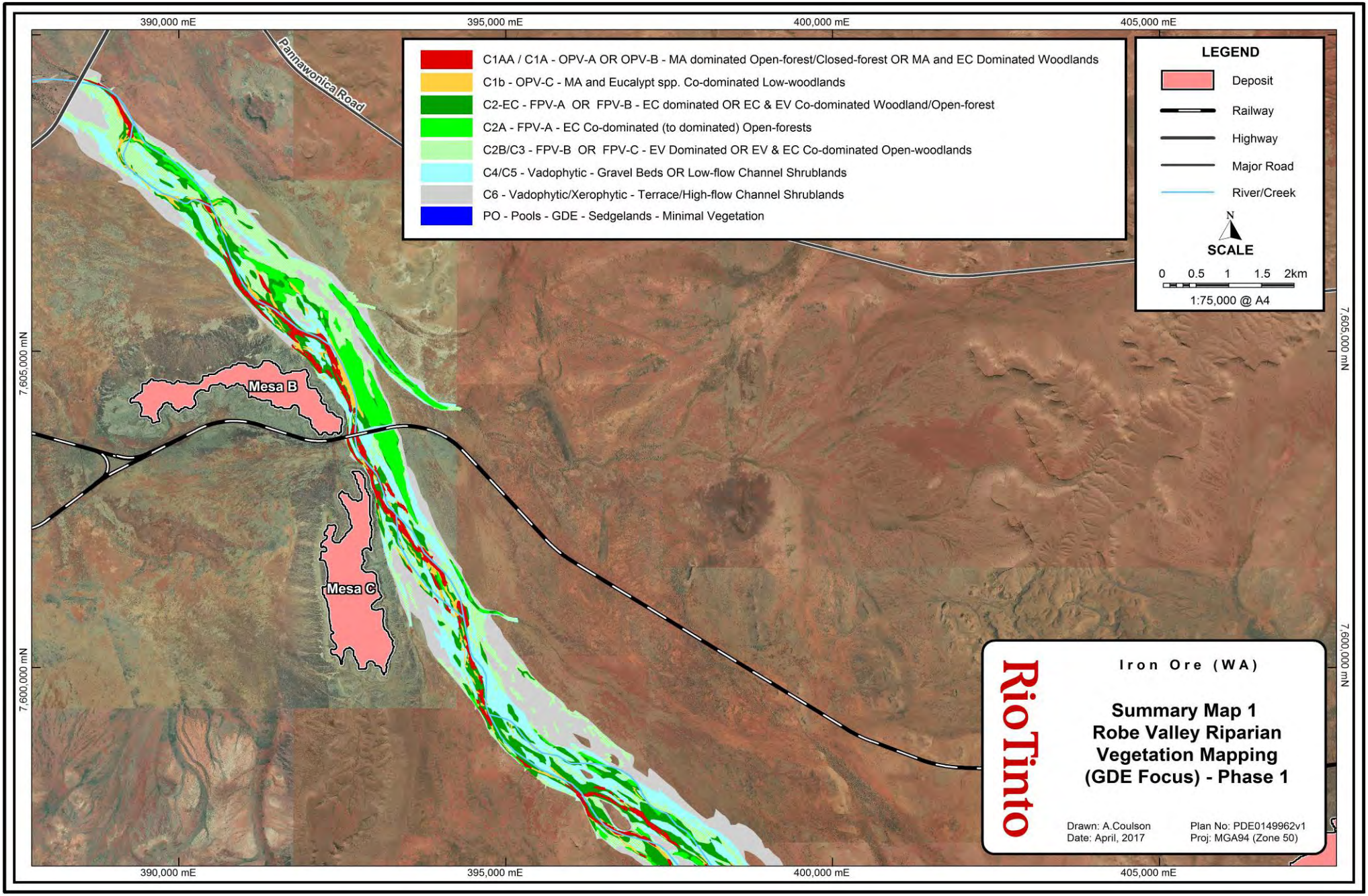

Figure 4-2: Robe Valley Riparian Vegetation summary; Map 1 of 3

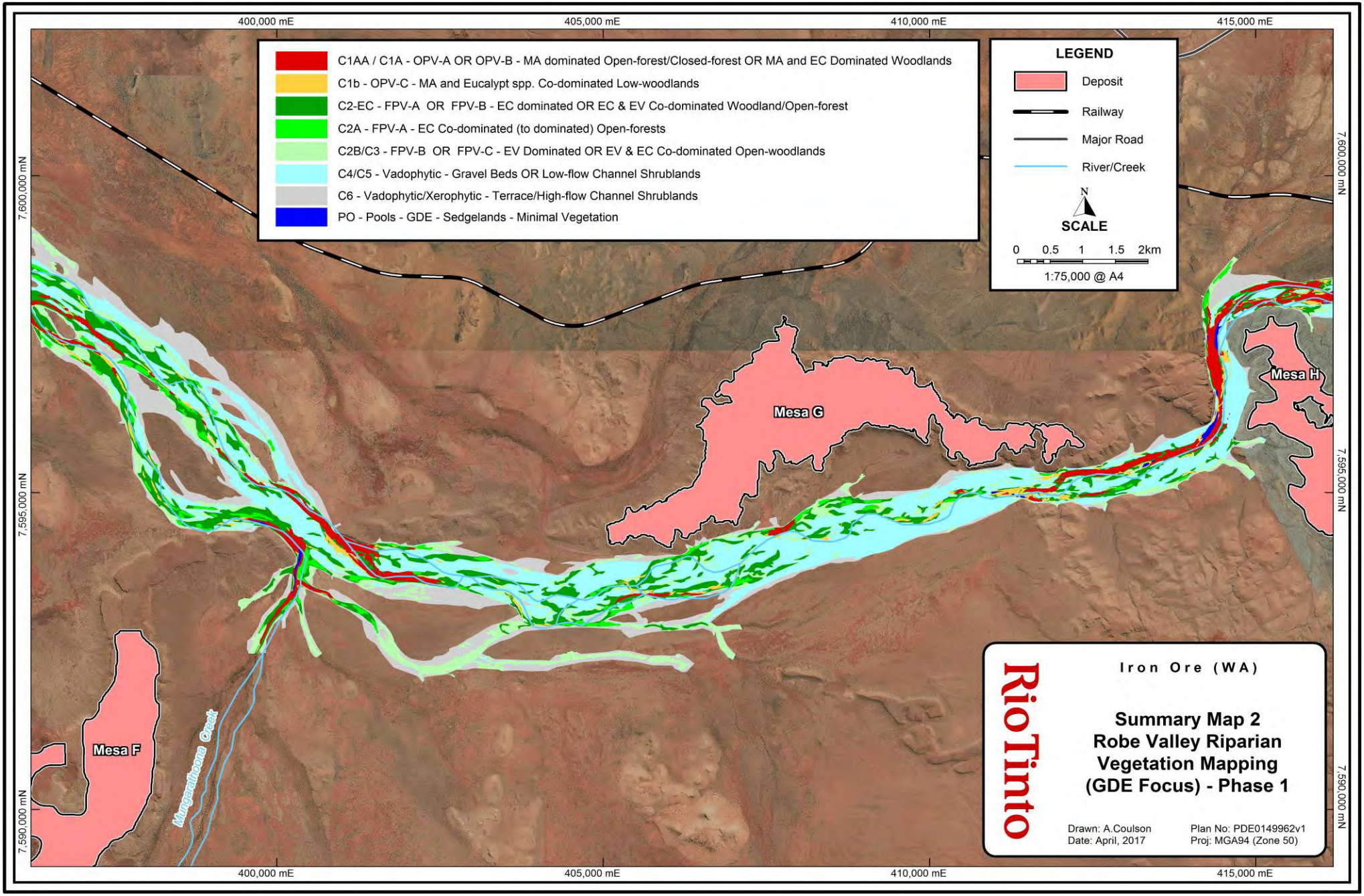

Figure 4-3: Robe Valley Riparian Vegetation summary; Map 2 of 3

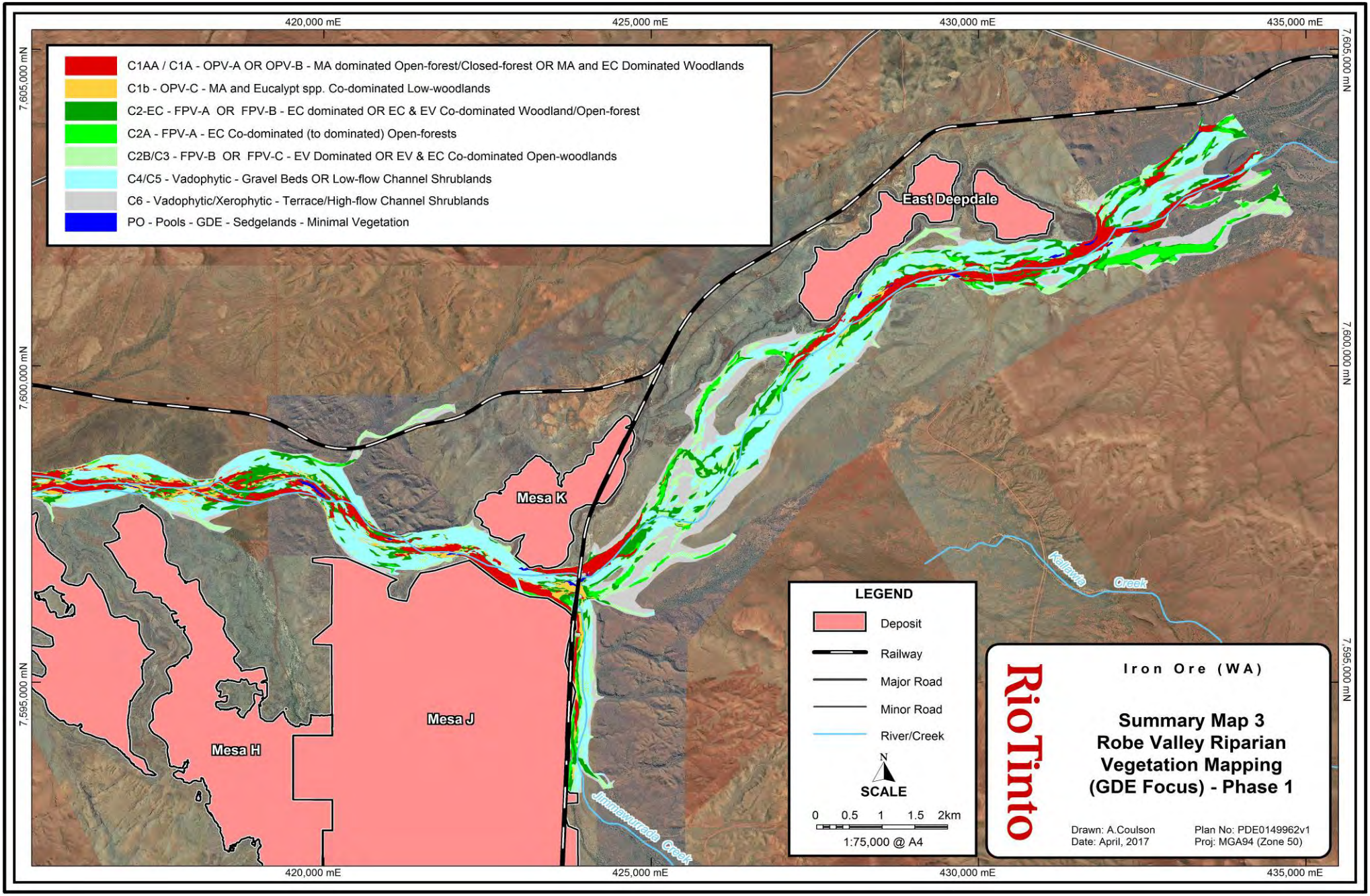

Figure 4-4: Robe Valley Riparian Vegetation summary; Map 3 of 3

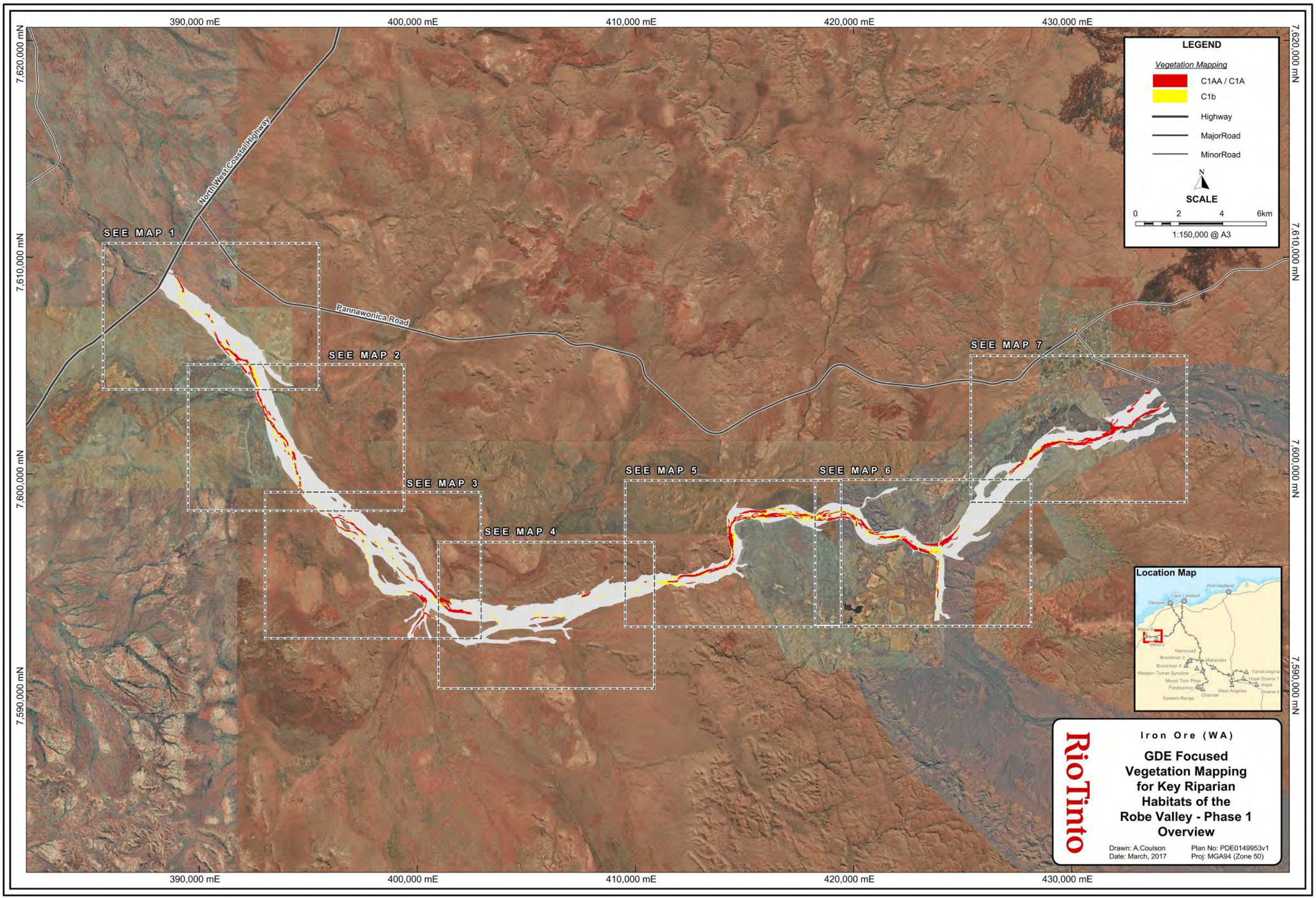

Figure 4-5: **Overview map showing the layout of the 7 maps showing the results of the Robe River riparian vegetation mapping project.**

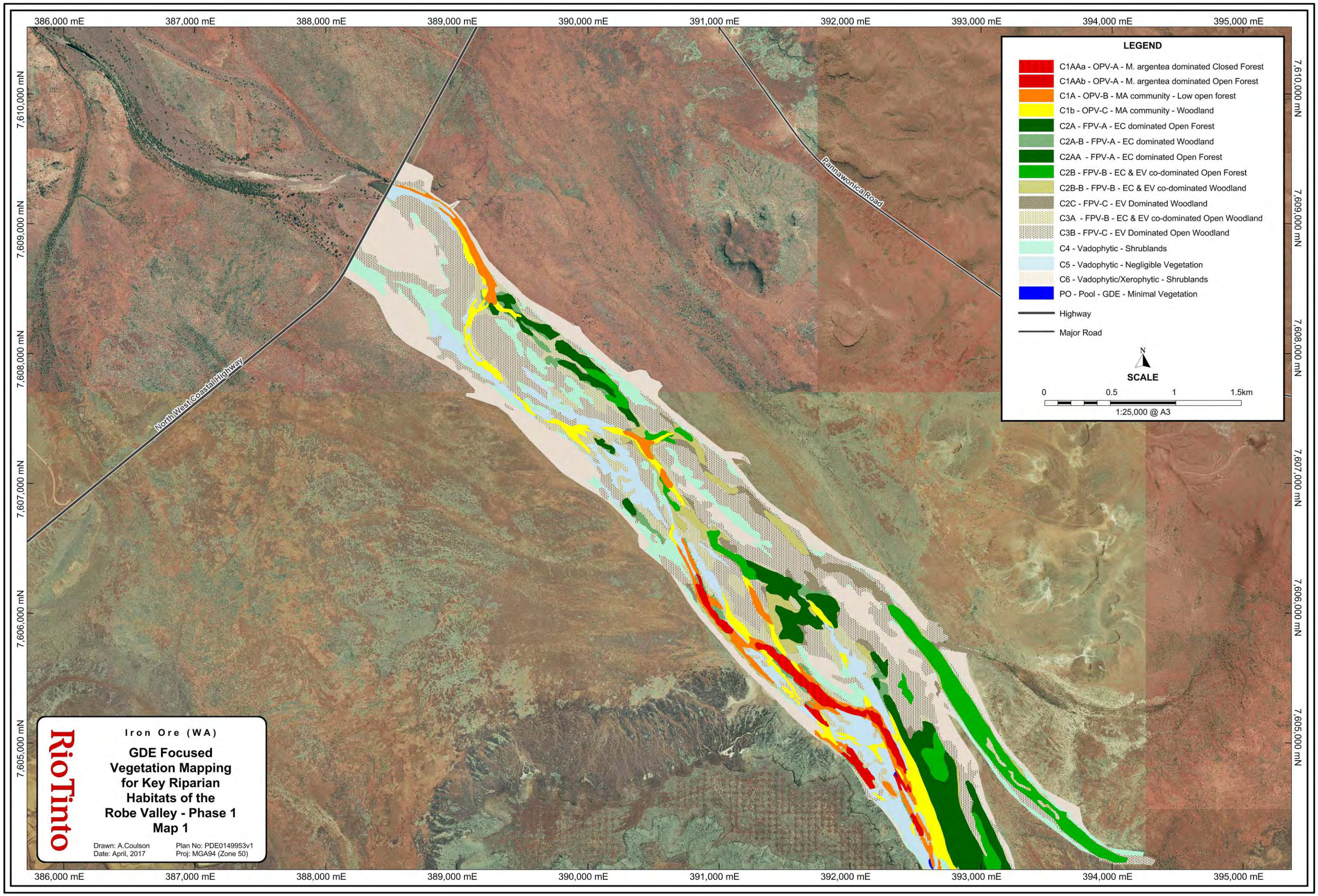

Figure 4-6: **Results of the Robe River riparian vegetation mapping project; Map 1 of 7**

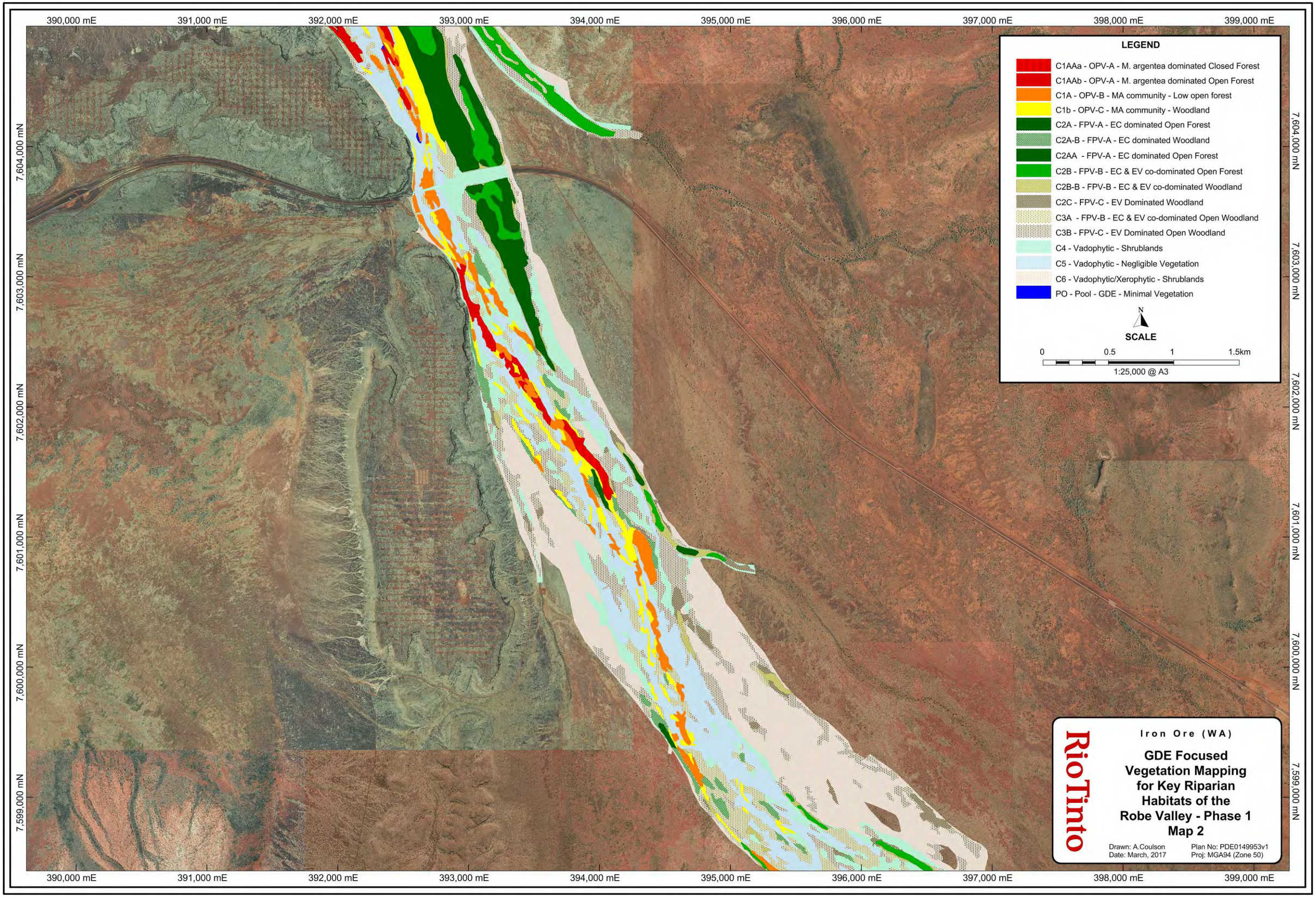

Figure 4-7: **Results of the Robe River riparian vegetation mapping project; Map 2 of 7**

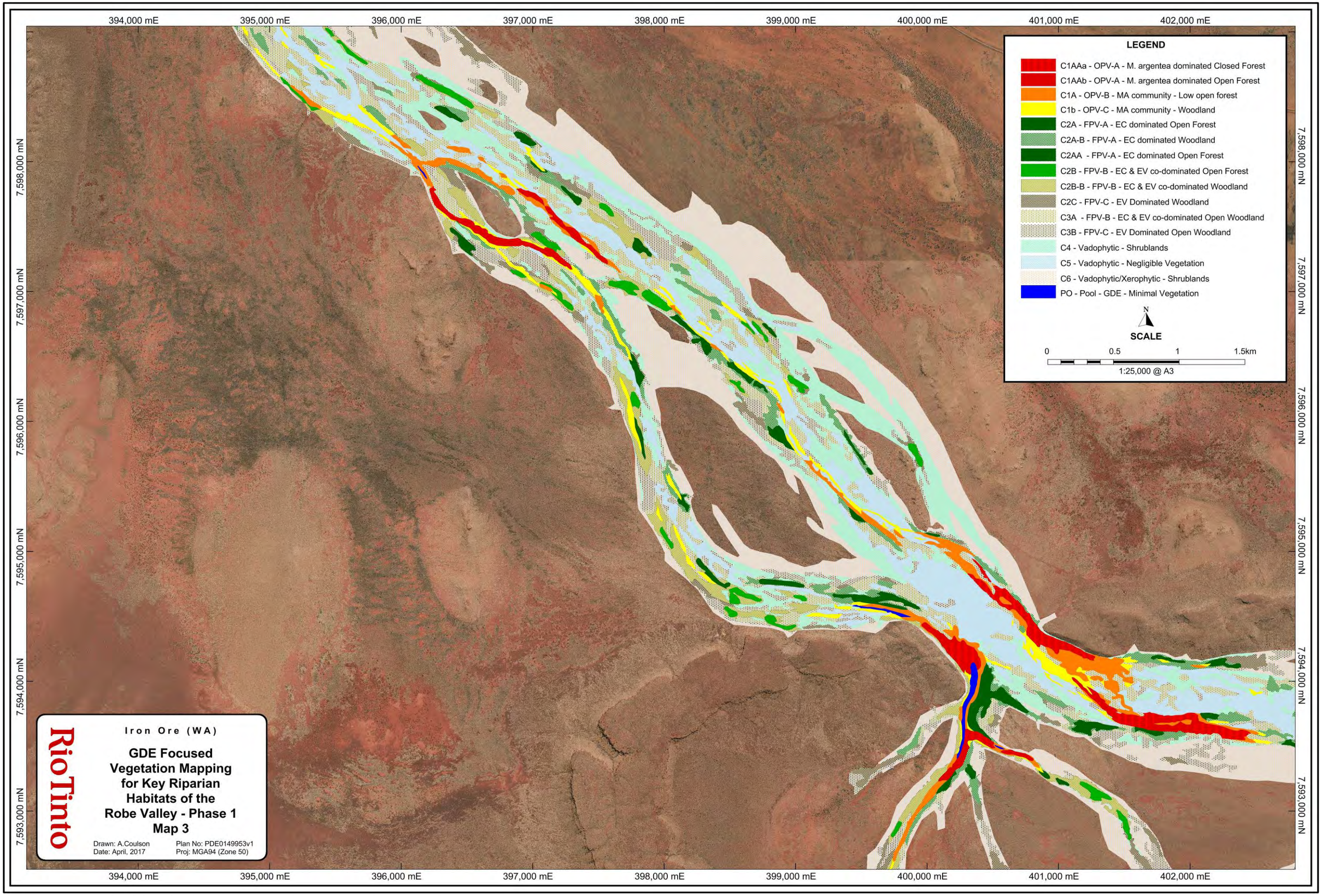

Figure 4-8: **Results of the Robe River riparian vegetation mapping project; Map 3 of 7**

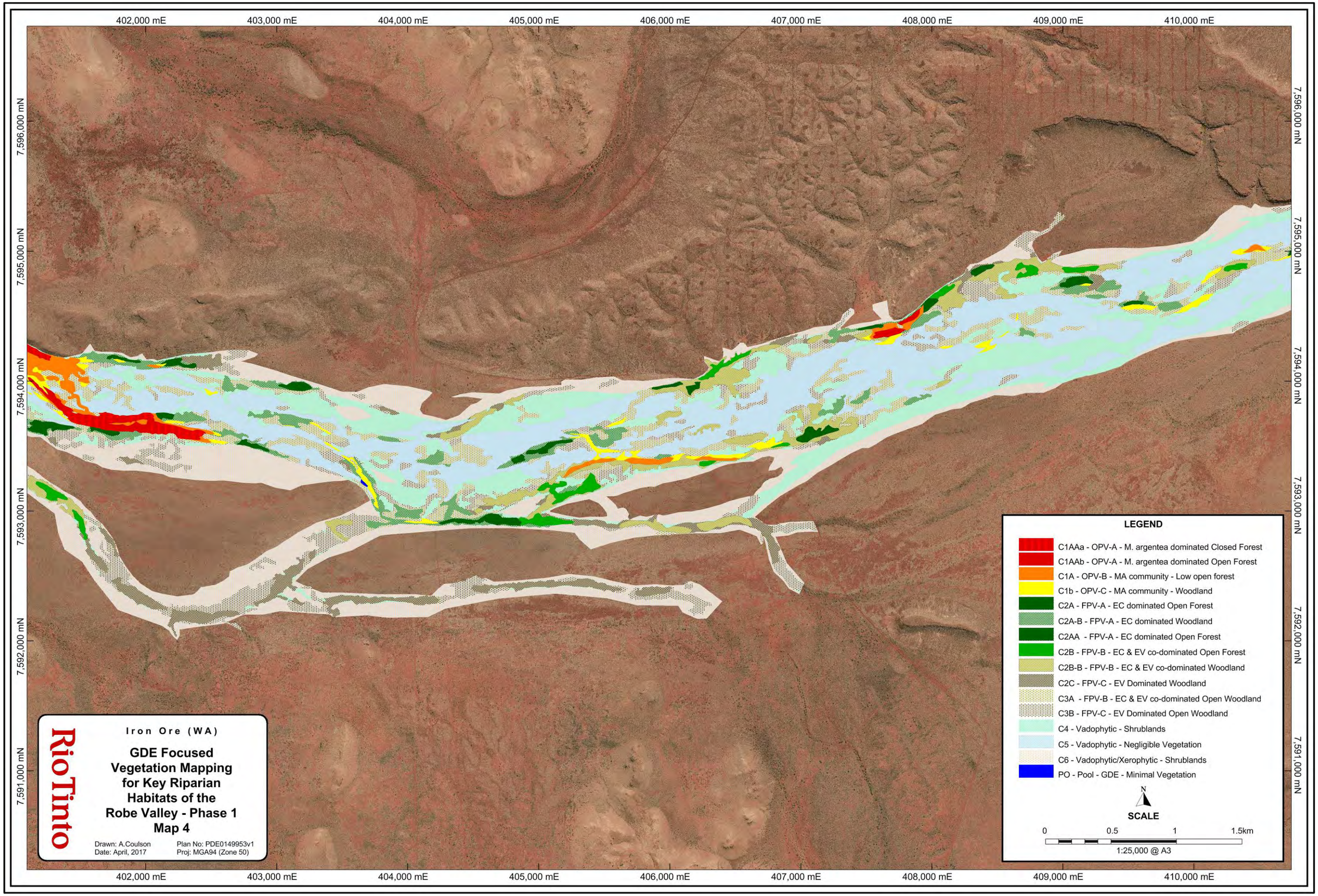

Figure 4-9: **Results of the Robe River riparian vegetation mapping project; Map 4 of 7**

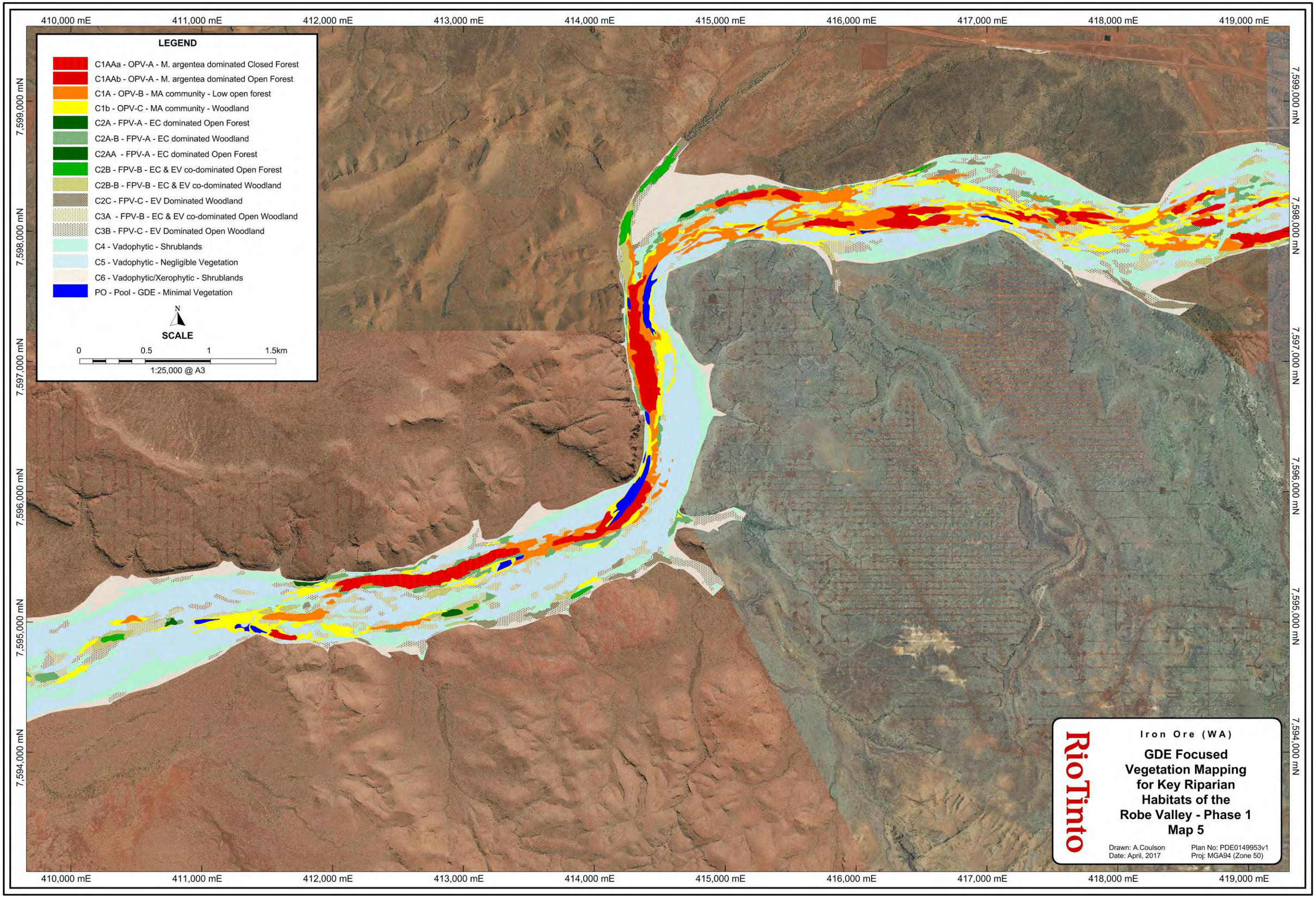

Figure 4-10: **Results of the Robe River riparian vegetation mapping project; Map 5 of 7**

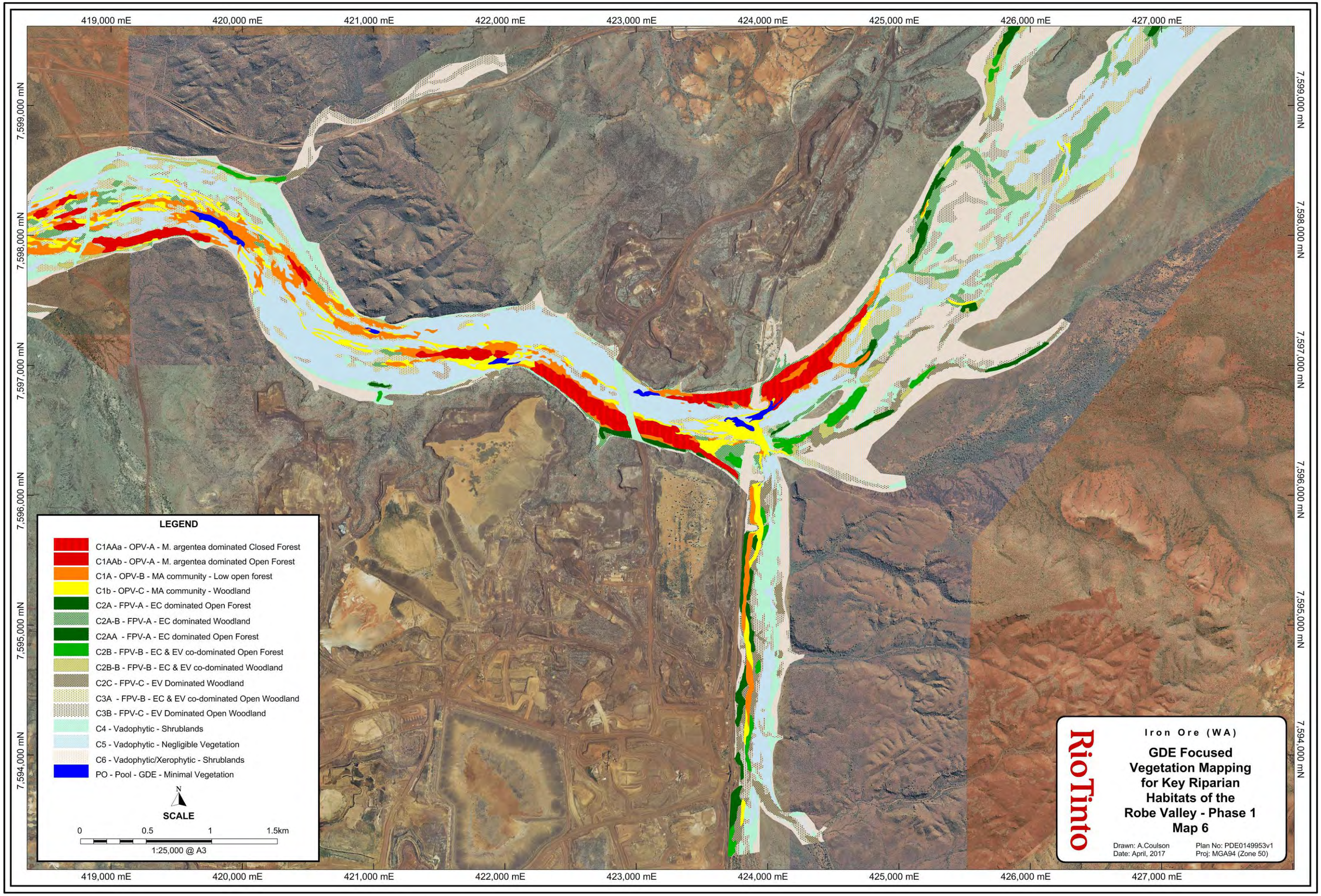

Figure 4-11: Results of the Robe River riparian vegetation mapping project; Map 6 of 7

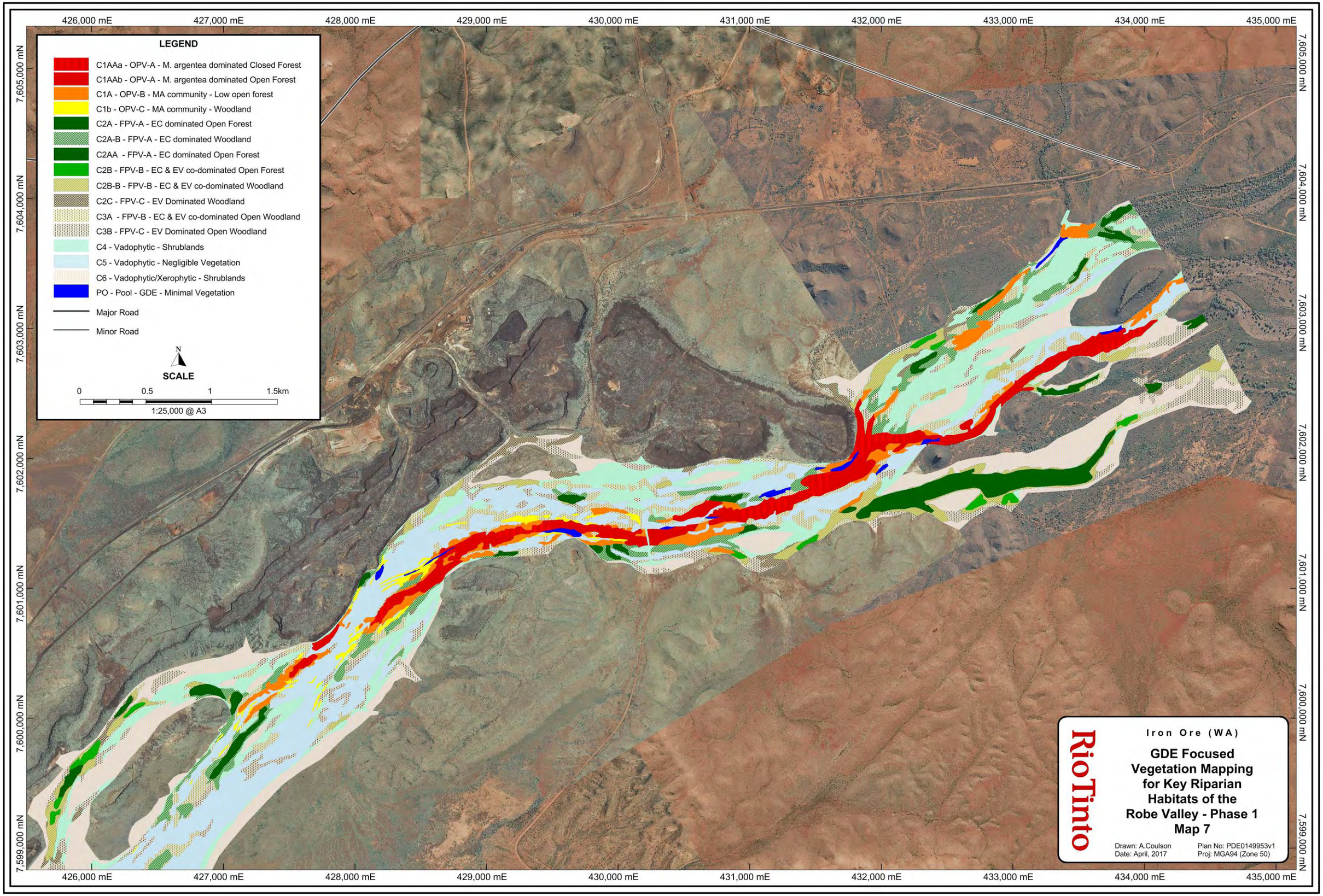

Figure 4-12: **Results of the Robe River riparian vegetation mapping project; Map 7 of 7**

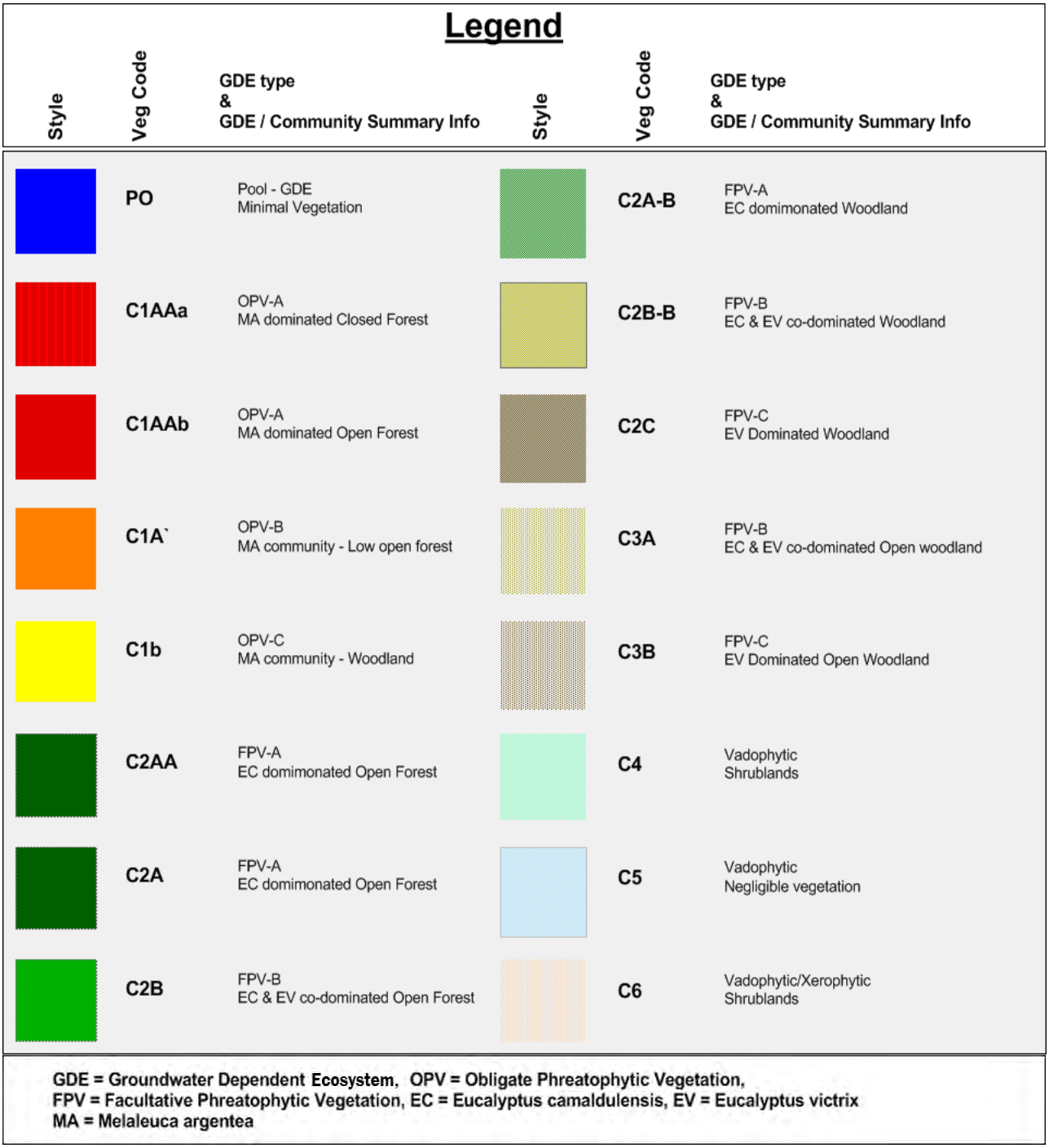

Figure 4-13: Detailed Legend for Figures 4-6 to 4-12.

4.3 SIGNIFICANCE OF THE RIPARIAN VEGETATION COMMUNITIES IN THE STUDY AREA

The extremely large distances traversed during the field survey enabled a relatively comprehensive understanding of the structure, composition and distribution of riparian communities throughout the study area. Through this process a thorough appreciation of the ecological values and significance held by vegetation communities within the Robe River was also attained. From this combined experience a number of communities of note, significance or elevated hydrological sensitivity were identified.

The permanent and semi-permanent pools of the Robe River are considered to be a restricted landform and habitat; in particular those with high species diversity and low disturbance from weed invasion, trampling and grazing. At the time of survey; the river was exceptionally dry and the remaining relatively permanent pools had been subject to greater than normal trampling and disturbance pressure from cattle. Vegetation surrounding these pools was typically dominated by dense *Melaleuca argentea* open forests, accompanied by scattered (and at times co-dominant) *Eucalyptus camaldulensis* subsp. *refulgens* over mixed sedge, grass and herbaceous species, and is described by vegetation associations C1AAa, C1AAb & C1A. This landform and associated vegetation often occurred on the edges of the Robe River, often close to breakaways and rock walls, where either adjacent (often porous) lithologies help maintain shallow water tables, or shallow water tables were coinciding with the main low-flow channel of the river. Patches of closed *Melaleuca argentea* forest (C1AAa) were often in association with such landforms. At the time of the survey; the more significant of these communities, namely the C1AAa & C1AAb vegetation types, were relatively dry, so the understorey appeared relatively devoid of the accompanying mesic species diversity thought to be normally supported.

The C1AAb and C1A communities were the most widespread of the more significant riparian OPV communities, with the C1AA vegetation types generally occurring where shallow water tables supported a wider more expansive lateral extent to the resident OPV communities. In areas where the zone of suitable conditions for OPV was much narrower and such vegetation was often more tightly restricted to low flow channel banks, the C1A community was common and relatively dominant.

Quite extensive, and relatively significant representations of the C1AA OPV vegetation types were mapped and noted to occur adjacent to and upstream of the East Deepdale deposits, adjacent to Yeera Bluff, immediately upstream and downstream of the confluence with Jimmawurrada creek, immediately upstream of the eastern tip of Mesa G, immediately upstream and downstream of the confluence with Mungarathoona creek (multiple occurrences), and immediately downstream of Mesa B. These areas were significant owing to the density and maturity of their canopies, the associated mesic species diversity, supported faunal assemblages, and mesic community diversity occupying the fringing ecotones (as a result of decreasing water availability).

The results of the field work and vegetation mapping exercise were used to contribute to an assessment of the significance of each of the communities mapped to occur within the study area. The significance value attributed to each community is derived from consideration of the factors deemed to be relevant when considering vegetation significance, and which are presented in Section 2.3. To do this in a relatively systematic qualitative manner the significance values attributed within this study followed a local significance framework developed in Rio Tinto 2015, adapted within this study and presented in Section 3.2.

This Framework incorporates an assessment of the ecological values provided, the distribution or degree to which it is represented in the environment (local, sub-regional, regional), the condition, and the sensitivity to change of each community mapped within the study area.

The resultant local significance framework attributed to each riparian vegetation unit is initially assigned to one of the following significance ratings (Table 4-3).

Table 4-2: Ten tier "Significance Rating" scale adapted for this study

(1) Very High	(2) Moderate
(3) High+	(4) Minor-Moderate
(5) High	(6) Minor +
(7) Moderate-High	(8) Minor
(9) Moderate+	(10) Low

It should be noted that this scale assumes the most common and widespread of the vegetation-types/habitats within a study area are considered to fall outside this scale such that the Low rating is attributed to vegetation of slightly elevated significance when compared to the remaining "common" vegetation units.

The results of the significance assessment are presented in Table 4-3 below. It should be noted that Table 4-3 does not provide an indication of conservation significance, rather provides a relative ranking in the locality for the context of this study.

Table 4-3: Significance ratings attributed to each community mapped in the study area and the associated factors contributing to assigned significance ratings.

Veg code	Broad Vegetation Type	GDE classification	Associated Ecological Values	Distribution/Representation/Rarity within the Pilbara Region.	Initial Local Significance	Condition	Sensitivity to relevant impacts	Resultant Local Significance Rating
C1AAa	Mature Melaleuca argentea dominated Closed Forest	OPV-A	Mature mesic Forest habitat, with a canopy dominated by Obligate Phreatophytes. Perennial groundwater availability, with scattered perennial pools also associated. High mesic flora species diversity. Cryptic and Conservation significant fauna habitat (likely to include the Pilbara olive python (POP), Northern Quoll (NQ), and potentially the Ghost Bat and Pilbara Leaf Nosed Bat (PLNB).	**Locally and Sub-regionally restricted and relatively rare/uncommon.** The rocky rangeland river variant of this community is genuinely uncommon and restricted within the Hamersley sub-region. Larger areal extent representations of this community are substantially restricted in the Hamersley sub-region. The unique substrates and adjacent rocky habitats which potentially support this community make it relatively unique when compared to riverine representations occurring in the wider Pilbara Bioregion **Potentially significant from Biological and cultural standpoints.** The representations present in the study area are at times relatively large and possess relatively wide lateral extents within the River Channel. Some degree of impact has already been suffered by these communities due to the construction of mining related infrastructure and minimal degrees of surplus water discharge.	**High**	**Excellent to Very Good**	**Very High**	**High (+)**
C1AAb	Mature Melaleuca argentea dominated Open Forest	OPV-A	Cryptic and conservation significant flora species habitat (e.g. Livistona alfredii). High subsurface aquatic invertebrate diversity. High local avifauna and bat species diversity. Some reduced value from direct impacts (e.g. rail line footings) and cumulative impact. Some vegetation augmentation from surplus water discharge (mainly in the Mesa J vicinity). Unique representation of a relatively upland positioned River System of the Pilbara.					
C1A	Mature M. argentea and *Eucalyptus camaldulensis* dominated Open Forest to Low Woodland	OPV-B	Relatively mature mesic woodland habitat Perennial groundwater availability, with some scattered semi-permanent pools also associated. Above average to High mesic flora species diversity. Cryptic and Conservation significant fauna habitat (likely to include the POP, NQ, and potentially the Ghost Bat, and PLNB). Cryptic and conservation significant flora species habitat (e.g. Livistona alfredii). High subsurface aquatic invertebrate diversity.	**Locally and somewhat Sub-regionally restricted and significant** The rocky rangeland river variant of this community is uncommon and relatively restricted within the Hamersley sub-region. Larger areal extent representations of this community are restricted in the Hamersley sub-region. The unique substrates and adjacent rocky habitats which potentially support this community make it relatively unique when compared to riverine representations occurring in the wider Pilbara Bioregion	**Moderate-high**	**Excellent to Very Good**	**High**	**High**

Veg code	Broad Vegetation Type	GDE classification	Associated Ecological Values	Distribution/Representation/Rarity within the Pilbara Region.	Initial Local Significance	Condition	Sensitivity to relevant impacts	Resultant Local Significance Rating
C1A (continued)			High local avifauna and bat species diversity. Some reduced value from direct and indirect impacts. Some reduced value from direct impacts (e.g. tracks & rail line footings) and cumulative impact. Some vegetation augmentation from surplus water discharge (mainly in the Mesa J vicinity). Above average representation of the Major Creeklines of the Pilbara Ecosystem at Risk. Potential for elevated sedge diversity, and possibly including or conservation significant species.	**Potentially significant from Biological and cultural standpoints.** The representations present in the study area are at times relatively large and possess relatively wide lateral extents within the River Channel. Some degree of impact has already been suffered by these communities due to the construction of mining related infrastructure and minimal degrees of surplus water discharge.				
PO	Minimal Vegetation	Pool - GDE	Perennial water availability Above average mesic flora species diversity; particularly sedge and emergent macrophyte species Cryptic and Conservation significant fauna habitat (likely to include the POP, NQ, and potentially the Ghost Bat, and PNLB), particularly migratory bird species. Cryptic flora species habitat. Elevated sedge diversity, and possibly including cryptic and conservation significant sedge species grasses and herbs. High subsurface aquatic invertebrate diversity. High local avifauna diversity and important refuge habitat. High local and sub-regional aquatic fauna diversity (particularly fish assemblages). Some reduced value from direct impacts. supports highly productive algal communities linked to productivity of surrounding ecosystems.	**Locally to Sub-regionally restricted** **Habitat is considered significant from Both Biological, Cultural and Social standpoints** **The representations mapped and present in the study area are all considered relatively Permanent (to Semi-permanent) and at times relatively substantial in size.**	**Moderate-High**	**Good to Poor**	**High**	**High**
C1b	Young to Semi-Mature Melaleuca argentea and Eucalyptus camaldulensis dominated Low Woodland	OPV-C	Young to semi-mature mesic woodland habitat At least semi-permanent to permanent groundwater availability, with surface water expressions not uncommon. Relatively High mesic flora species diversity. At times relevant as cryptic and Conservation significant fauna habitat (potential to include the POP, NQ, and potentially the Ghost Bat, and PLNB). Cryptic flora species habitat, and some potential as habitat for conservation significant flora (e.g. Livistona alfredii). High subsurface aquatic invertebrate diversity.	**Locally restricted and somewhat uncommon** The rocky rangeland river variant of this community is somewhat uncommon and relatively restricted within the Hamersley sub-region. Larger areal extent representations of this community are restricted in the Hamersley sub-region. The unique substrates and adjacent rocky habitats which potentially support this community make it relatively unique when compared to riverine representations occurring in the wider Pilbara Bioregion.	**Moderate to High**	**Excellent to Very Good**	**Moderate to High** (Generally High, but due to likely transient nature; rating is reduced)	**Moderate** (At times: Moderate to High; due to close proximity to High sig'n communities)

Veg code	Broad Vegetation Type	GDE classification	Associated Ecological Values	Distribution/Representation/Rarity within the Pilbara Region.	Initial Local Significance	Condition	Sensitivity to relevant impacts	Resultant Local Significance Rating
C1b (continued)			Relatively High local avifauna and bat species diversity. Some reduced value from direct and indirect impacts. Some reduced value from direct impacts (e.g. tracks & rail line footings) and cumulative impact. Some reduced value due to the interpreted likely transient nature of this type of community within relevant zones of a Pilbara ephemeral river system.	The representations present in the study area are at times relatively large and possess relatively wide lateral extents within the river channel. Some degree of impact has already been suffered by these communities due to the construction of mining related infrastructure and minimal degrees of surplus water discharge.				
C2AA	Large Mesic Eucalyptus camaldulensis dominated Open Forest representations	FPV-A	Mature to Semi-Mature mesic open-forest habitat. Apparent; at least semi-permanent to permanent groundwater availability. Relatively high to Above average mesic flora species diversity. Cryptic and Mesic Fauna habitat (May include the POP). Cryptic flora species habitat. Potentially possesses Above average subsurface aquatic invertebrate diversity. Above average local avifauna diversity. Some reduced value from direct and cumulative impacts. May represent a higher risk GDE due to Mesic indicators. Above average to high quality representation of Riverine Eucalypt forests.	**This community represents the more mesic and Larger areal extent representations of the C2A community. Given the size, structure and composition of this community, it is considered to be Locally and potentially sub-regionally restricted.** The rocky rangeland creek variant of this community is somewhat uncommon within the Hamersley sub-region, and relatively restricted to Larger River and creek systems.	**Moderate (+)** (Moderate to High for largest representations)	**Very Good to Good** (at times poor due to moisture attracting grazing disturbance)	**Moderate to High**	**Moderate (+)**
C2A	Eucalyptus camaldulensis dominated Open Forest	FPV-A	Mature to Semi-Mature mesic open-forest habitat. Apparent; at least semi-permanent groundwater availability. Above average mesic flora species diversity. Cryptic and Mesic Fauna habitat (May include the POP). Cryptic flora species habitat. Above average subsurface aquatic invertebrate diversity. Above average local avifauna diversity. Some reduced value from direct and cumulative impacts. Above average representation of Riverine Eucalypt forests.	**Somewhat locally restricted but not uncommon** The rocky rangeland creek variant of this community is somewhat restricted within the Hamersley sub-region, but is not considered uncommon.	**Moderate**	**Very Good to Good**	**Moderate to high**	**Moderate**

Veg code	Broad Vegetation Type	GDE classification	Associated Ecological Values	Distribution/Representation/Rarity within the Pilbara Region.	Initial Local Significance	Condition	Sensitivity to relevant impacts	Resultant Local Significance Rating
C2B	Eucalyptus camaldulensis & Eucalyptus victrix co-dominated Open Forest	FPV-B	Mature somewhat mesic woodland/open-forest habitat.	**Somewhat locally restricted but not uncommon**	**Minor-Moderate**	**Very Good to Good** (+ regularly Poor)	**Moderate (+)**	**Moderate**
			Apparent; at least semi-permanent groundwater availability.	The rocky rangeland river variant of this community is somewhat restricted within the Hamersley sub-region, but is not considered uncommon.				
			Elevated mesic flora species diversity.					
			Cryptic and Mesic Fauna habitat (Some potential for Conservation significant fauna).					
			Cryptic flora species habitat (may include Stylidium Weeli Wolli).					
			Above average subsurface aquatic invertebrate diversity.					
			Elevated local avifauna diversity.					
			Some reduced value from direct and cumulative impacts, particularly grazing and grazing related weed infestation.					
			Average representation of Riverine Eucalypt forests.					
C2A-B	Eucalyptus camaldulensis dominated Woodlands	FPV-A	Mature somewhat mesic woodland habitat.	**Relatively common but somewhat restricted locally.**	**Minor-Moderate**	**Very Good to Good** (+ regularly Poor)	**Moderate**	**Minor-Moderate**
			Apparent; at least semi-permanent to permanent groundwater proximity.					
			Elevated mesic flora species diversity.					
			Cryptic and Mesic Fauna habitat (Some potential for Conservation significant fauna).					
			Cryptic flora species habitat (may include Stylidium Weeli Wolli).					
			Above average subsurface aquatic invertebrate diversity.					
			Elevated local avifauna diversity.					
			Some reduced value from direct and cumulative impacts, particularly grazing and grazing related weed infestation.					
			Average representation of Riverine Eucalypt Woodland.					
C2B-B	Eucalyptus camaldulensis & Eucalyptus victrix co-dominated Woodland	FPV-B	Mature somewhat mesic woodland habitat.	**Relatively common but somewhat restricted locally.**	**Minor (+)**	**Good to Poor**	**Moderate**	**Minor-Moderate**
			Apparent; at least semi-permanent to permanent groundwater proximity.					
			Elevated mesic flora species diversity.					
			Cryptic and Mesic Fauna habitat (Some potential for Conservation significant fauna).					
			Cryptic flora species habitat (may include Stylidium Weeli Wolli).					
			Above average subsurface aquatic invertebrate diversity.					
			Elevated local avifauna diversity.					
			Significantly reduced value from direct and cumulative impacts, particularly grazing and grazing related weed infestation.					
			Average representation of Riverine Eucalypt Woodland.					

Veg code	Broad Vegetation Type	GDE classification	Associated Ecological Values	Distribution/Representation/Rarity within the Pilbara Region.	Initial Local Significance	Condition	Sensitivity to relevant impacts	Resultant Local Significance Rating
C2C	Eucalyptus victrix dominated Woodland	FPV-C	Mature somewhat mesic woodland habitat. Generally ephemeral water availability, with indications that groundwater may be accessed but accessibility is moderately variable. Elevated to average Mesic flora species diversity. Mesic Fauna habitat. Elevated subsurface aquatic invertebrate diversity. Elevated local avifauna diversity. Significantly reduced value from direct and cumulative impacts, particularly grazing and grazing related weed infestation. Average representation of Riverine Eucalypt Woodland.	**Relatively common but somewhat restricted locally.**	**Minor**	**Good to Poor**	**Low-Moderate**	**Minor**
C3A	Eucalyptus camaldulensis & Eucalyptus victrix co-dominated Open Woodland	FPV-B	Mature somewhat mesic open woodland habitat. Apparent; at least regular to intermittent groundwater proximity. Elevated subsurface aquatic invertebrate diversity. Mesic flora species present. Mesic Fauna habitat. Elevated local avifauna diversity. Significantly reduced value from direct and cumulative impacts, particularly grazing and grazing related weed infestation. Average representation of Riverine Eucalypt Woodland.	**Relatively common but somewhat restricted locally.**	**Minor (+)**	**Good to Poor**	**Low (+)**	**Minor (+)**
C3B	Eucalyptus victrix dominated Open Woodland	FPV-C	Mature open woodland habitat. Generally ephemeral water availability, with indications that groundwater may be accessed but accessibility is highly variable. Mesic flora species present. Mesic Fauna habitat. Elevated subsurface aquatic invertebrate diversity. Elevated local avifauna diversity. Significantly reduced value from direct and cumulative impacts, particularly grazing and grazing related weed infestation. Average representation of Riverine Eucalypt Woodland.	**Common and not locally restricted**	**Minor**	**Good**	**Low (+)**	**Minor**

Veg code	Broad Vegetation Type	GDE classification	Associated Ecological Values	Distribution/Representation/Rarity within the Pilbara Region.	Initial Local Significance	Condition	Sensitivity to relevant impacts	Resultant Local Significance Rating
C4	River bed Shrublands	Vadophytic with isolated facultative phreatophytes	Riparian habitat with ephemeral water availability. Mesic Fauna habitat. Elevated to average subsurface aquatic invertebrate diversity. Elevated local avifauna diversity. Some to at times significantly reduced value from direct and cumulative impacts, particularly grazing and grazing related weed infestation. Some increased value from discharge enhancement.	**Relatively common but somewhat restricted.** This community is relatively common within the western half of the Hamersley sub-region, but riparian representations are restricted to larger creek/river systems.	**Minor**	**Very Good to Good** (& regularly Poor)	**Low**	**Minor**
C5	Scoured Beds with minimal vegetation	Vadophytic with isolated facultative phreatophytes	Ephemeral water availability. Mesic Fauna habitat. Potentially elevated subsurface aquatic invertebrate diversity. Some reduced value from direct impacts. High potential for reversion to pre-impact condition due to fluvial processes in effect. Large repository of coarse alluvial sediments important for aquatic invertebrate habitats.	**Minimal vegetation; habitat relatively common but somewhat restricted.**	**Low**	**Excellent to Very Good**		**Low**
C6	Floodplain Shrublands	Vadophytic / Xerophytic	Ephemeral water availability (Perennial in some areas at present). Slightly elevated mesic flora species diversity. Mesic Fauna habitat. Elevated local avifauna diversity. At times significantly reduced value from direct and cumulative impacts, particularly grazing and grazing related weed infestation.	**Common and not locally restricted**	**Low**	**Very Good to Good (and regularly Poor)**	**Very Low**	**Low**

4.4 GDE SENSITIVITY AND RISK MAPPING

For the purpose of mapping the spatial distribution of risk within the study area each community mapped was attributed a risk rating. This process firstly involved providing an interpretation of the degree of sensitivity (or vulnerability) to hydrological change held by each community. Secondly; using this degree of sensitivity/vulnerability; produce a rating of the risk that "measurable" impact/change to a community could result from a significant degree of hydrological change. A significant degree of hydrological change may be in multiple forms, including;

- a 2-3m drop in the average groundwater height within the alluvial's immediately adjacent to features of value;
- a discernible (statistically significant) reduction in catchment reporting to the river, and
- a physical obstruction to river flow significantly changing flow patterns.

A "measurable" impact is defined as detectable (beyond natural variability) changes to the health, composition and structure of riparian communities, brought about by changes to groundwater access. Natural impacts to vegetation as a result of changing water availability are common in arid riparian habitats of the Pilbara region. Such arid habitats exhibit extremes in climate and therefore local vegetation inherently possess numerous adaptive traits to facilitate their persistence. As a result, significant impacts are best defined as those changes which are able to be distinguished from the natural variability in effect at the locality. For this reason it is important to be able to distinguish anthropogenic impacts from the inherent degree of natural variation and associated riparian changes. This baseline (or natural) riparian vegetation change is generally restricted to changes in health and at times structure, but less often leading to vegetation compositional changes. As a result "measurable" impact is restricted to that level of riparian change which includes both health changes as well as at least one of either compositional (loss or addition of dominant species) or structural change in resident vegetation.

Conceptually, a significant degree of hydrological change may be best viewed as a magnitude equal to or greater than that hydrological variability experienced naturally at least every 1 to 2 decades. However at this stage, the magnitude of hydrological change, or the definition of a "measurable" impact is not the important factor. What is most important to understand is that an interpretation of sensitivity has been combined with additional influential environmental factors to attribute a risk rating. Thus; once the magnitude of potential hydrological change can be measured the risk rating can be used as a factor by which to multiply the magnitude of hydrological change to in–turn give an idea of the potential size of the resulting ecological perturbation.

To interpret this sensitivity and therefore attribute a final risk rating; the following factors were considered:

(1) Water use strategy (i.e. obligate phreatophyte, facultative, etc.) and associated groundwater dependence associated;
(2) Obligate phreatophyte age structure (maturity);
(3) Obligate phreatophyte structural dominance;
(4) Distribution within the bed profile;
(5) Vegetation cover (i.e. stand density);
(6) Proximity to surface water; and
(7) Inherent Significance; broadly as a measure of degree of restriction, and magnitude of associated values.

Once all of these factors were considered a risk rating was attributed, and this rating was attributed from a 10 tier scale of risk rating such that the following ratings presented in Table 4-4 were

available. In situations where, almost no risk was perceived to be present, a rating of Negligible was determined as the relevant rating to be attributed.

Table 4-4: Ten tier "Risk Rating" scale adapted for this study

(1) Very High	(2) Moderate
(3) High+	(4) Low-Moderate
(5) High	(6) Low+
(7) Moderate-High	(8) Low
(9) Moderate+	(10) Very Low

The final Residual risk ratings (similar to "Importance" ratings applied in SKM (2001) attributed to each community are presented in Table 4-5 The spatial risk mapping created from this risk assessment process is presented in Figures 4-14 to 4-17.

Table 4-5: Risk ratings attributed to each community mapped in the study area and the associated GDE classification and sensitivity rating associated with each.

Veg Code	Broad Vegetation Type (MA= Melaleuca argentea, EC= Eucalyptus camaldulensis, EV= Eucalyptus victrix)	GDE Classification	Initial sensitivity rating	Residual Risk (or importance) Attributed
C1AAa	Mature MA dominated Closed Forest	OPV-A	Very High	Very High
C1AAb	Mature MA dominated Open Forest	OPV-A	Very High	
C1A	Mature MA and EC dominated Open forest to Low Woodland	OPV-B	High to High (+)	High
PO	Minimal Vegetation	Pool - GDE	High	
C1b	MA and EC dominated Low Woodland	OPV-C	High	Moderate-High
C2AA	Large Mesic EC dominated Open Forest representations	FPV-A	Moderate to High	
C2A	EC dominated Open Forest	FPV-A	Moderate to High	Moderate (+)
C2B	EC & EV co-dominated Open Forest	FPV-B	Moderate (+)	
C2A-B	EC dominated Woodlands	FPV-A	Moderate	
C2B-B	EC & EV co-dominated Woodland	FPV-B	Moderate	Moderate
C2C	EV Dominated Woodland	FPV-C	Low to Moderate	Low-Moderate
C3A	EC & EV co-dominated Open Woodland	FPV-B	Low (+)	
C3B	EV Dominated Open Woodland	FPV-C	Low (+)	Low
C4	Shrublands	Vadophytic	Low	
C5	Beds with minimal vegetation	Vadophytic	Negligible	Very Low
C6	Shrublands	Vadophytic / Xerophytic	Very Low	

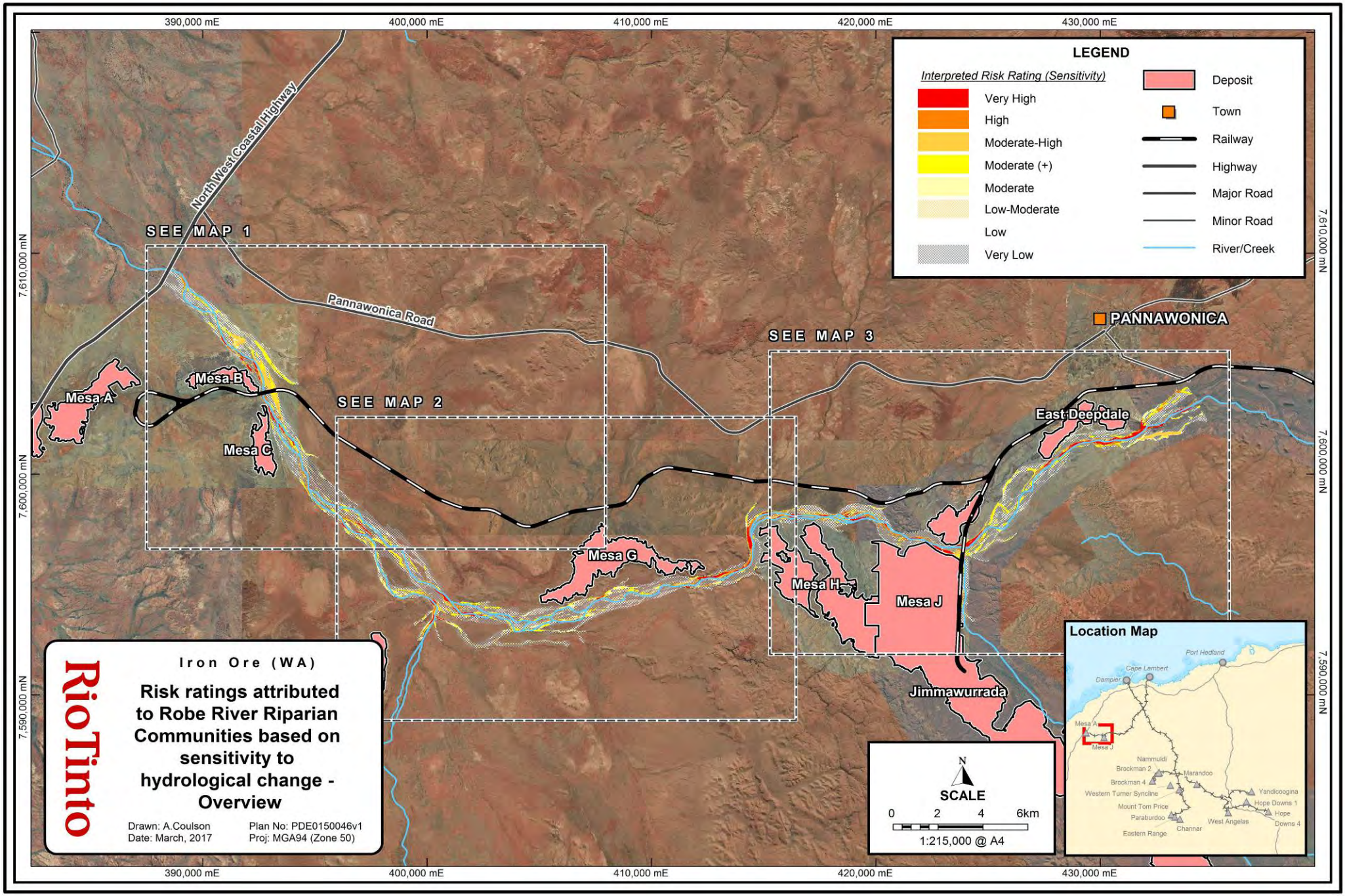

Figure 4-14: Risk mapping depicting the inherent "Sensitivity" of Robe River Riparian vegetation to hydrological change; Overview Map

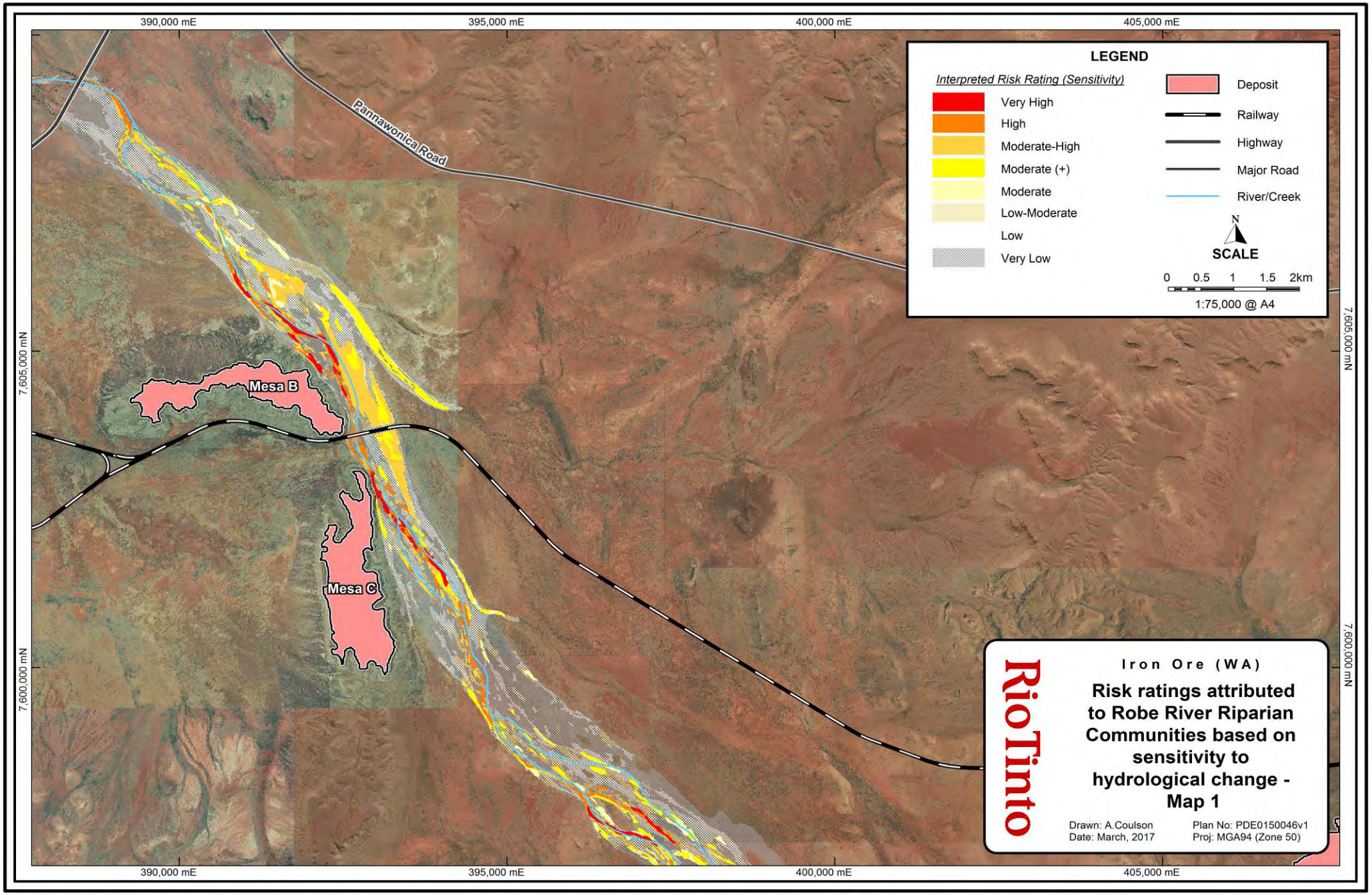

Figure 4-15: Risk mapping depicting the inherent "Sensitivity" of Robe River Riparian vegetation to hydrological change; Mesas B and C

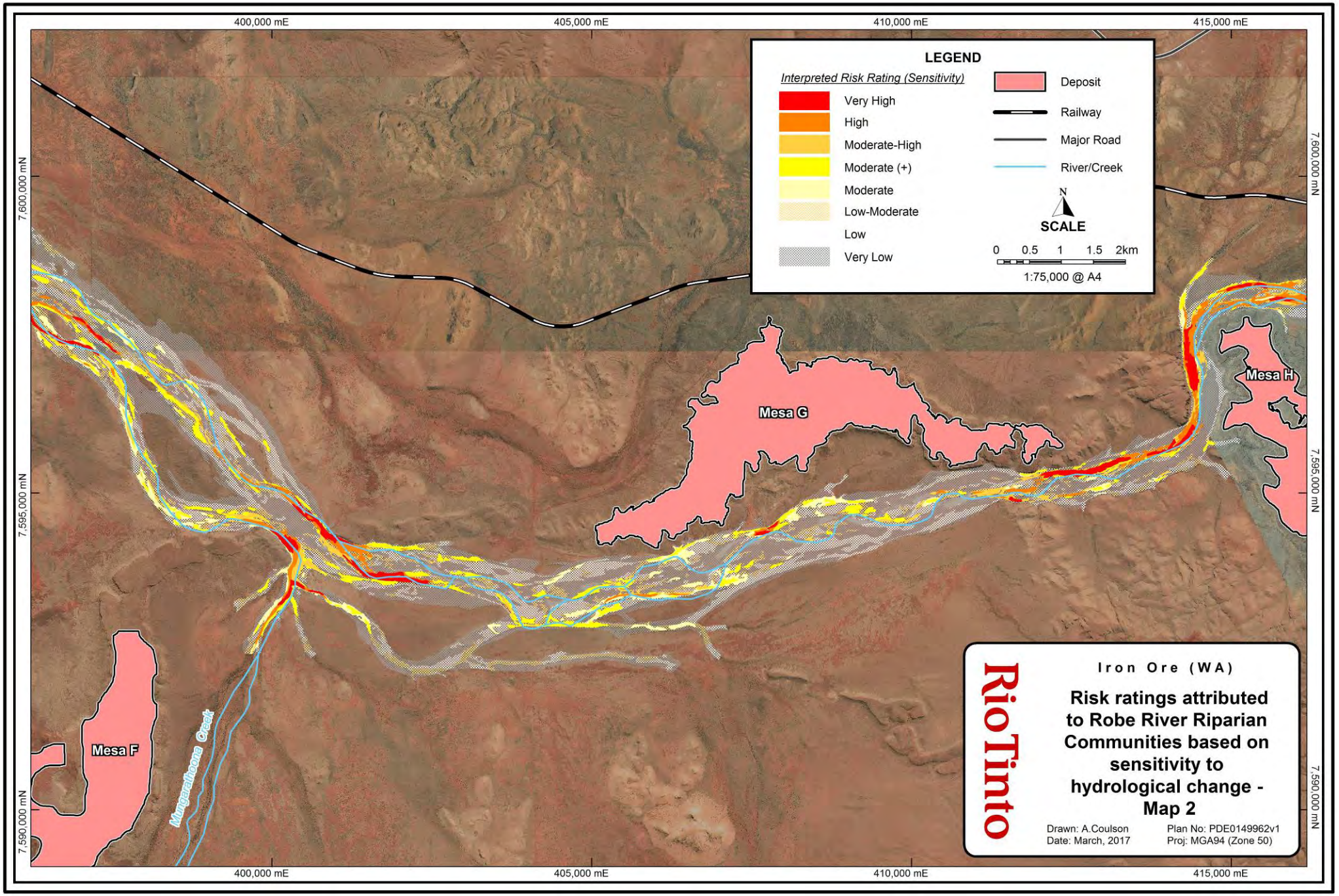

Figure 4-16: Risk mapping depicting the inherent "Sensitivity" of Robe River Riparian vegetation to hydrological change; Mesa F to H.

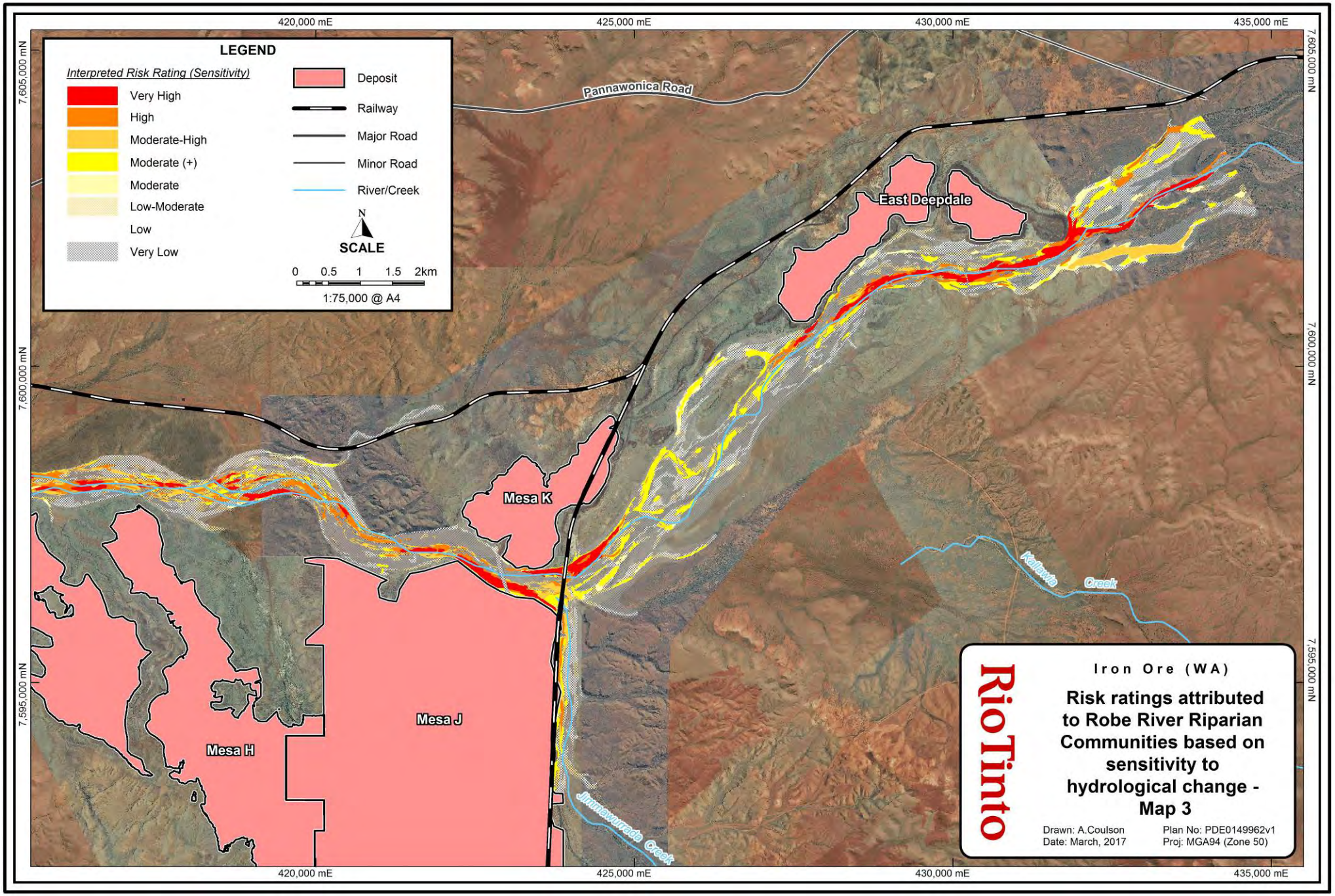

Figure 4-17: Risk mapping depicting the inherent "Sensitivity" of Robe River Riparian vegetation to hydrological change; Mesa H to East Deepdale.

5 DISCUSSION

Within the study area; in general, GDV in the form of OPV was relatively common and somewhat consistently longitudinally (i.e. parallel to the river flow) distributed throughout. Local OPV is sensitive to hydrological change and has therefore been categorised as a High Risk type of GDE (as defined by the 10 tier risk rating scale presented in Table 4-4), as it possesses a core dominant species which is obligately dependent on groundwater access.

With regard to the more mature types of OPV identified; distributions were less consistent longitudinally, but such communities were still relatively common throughout the study area. Lateral (i.e. perpendicular to the river flow) distribution patterns of OPV (particularly the distribution of reaches possessing multiple large and laterally broad OPV representations) within the river profile did show stronger spatial correlation to various topographical, drainage and geological features in the landscape. Such features include; large structurally controlled formations (e.g. mesas) in close proximity to the river, river sections strongly confined by outcropping formations with cliffs / bluffs, and confluences with major creek systems. The distribution of mature OPV with tree strata solely dominated by obligate phreatophytes (*Melaleuca argentea*), and represented by vegetation types C1AAa & C1AAb were also more restricted and strongly correlated with such features. This observed association was considered to indicate that through these areas, groundwater was likely shallow and consistently accessible such that these areas also supported surface water expressions and OPV of much broader lateral extent.

Experience with large riparian systems elsewhere in the Pilbara suggests strong correlation between the distribution of mature OPV and alluvial bed intersection/interactions with underlying porous lithologies such as channel iron deposits. Despite this, it is not yet clear what is driving the distribution of clustering among larger, broader, and structurally mature OPV representations within the Robe River. It is plausible that the distribution of such communities may be significantly influenced by these landscape features, but their degree of influence and interaction with other sub-surface and local to catchment scale hydrological factors is highly variable and relatively unknown.

Based on the results, it was noted that occurrences of the mature C1A OPV community were regularly distributed throughout the study area, even occurring in areas where large and obvious landscape features (Mesas etc., with potential to influence groundwater proximity) were relatively absent. This is thought to be important, as it potentially provides evidence supporting the concept that the Robe River is representative of a River Base-flow System (RBS) type of GDE (Clifton and Evans 2001, Boulton and Hancock 2006), where resident communities are likely supported by a degree of groundwater base-flow throughout the local alluvial aquifer. While RBSs are generally perceived to be represented by rivers with perennial to near perennial surface flows, they can also be represented by sub-surface flow which maintain intermittent pools such as those present on the Robe River. Based on DoW gauging at Yarraloola; periods of zero flow along the Robe River occur less than 25% of the time (Streamtec 2016). In addition to this; pool velocity measurements conducted regularly as part of the long term ecological research project on the Robe River (Dobbs & Davies 2009) show that low flows (throughput) are often maintained in a significant proportion of the permanent pools every year. Other local evidence for a relatively sustained sub-surface groundwater flow within certain zones of the Robe is evident within the results of work conducted by Dobbs & Davies (2009), and includes:

- Abnormally low dry season turbidity levels within monitored permanent pools of the Robe River, suggesting relatively consistent sub-surface throughput is potentially reducing sediment loads;

- Observed relatively high levels of algal productivity, and likely nutrient enrichment within local river pools (ecologia & Streamtec 1992);

- Similar elevated nitrogen levels recorded in defined "ramp up" and "ramp down" periods (i.e. increasingly wet or increasingly dry periods) suggest nitrogen levels are less linked to rainfall induced flows and more likely to be a result of hyporheic exchanges and resultant nitrogen subsidies;

- The highest (while still relatively consistent) nitrogen levels are recorded in the largest, potentially most groundwater influenced pools; which could suggest that elevated nitrogen levels are likely to be subsidised by groundwater influx and associated hyporheic exchange processes (however may also be influenced by grazing inputs) .

- Monitored permanent pools commonly recorded as having a small flow velocity at 0.6m depth during dry season monitoring rounds thus indicating common throughput (i.e. supports the understanding that these are the result of base-flow).

Work conducted by Rio Tinto (2017) as part of the H3 Hydrogeological assessments for Mesa C and Mesa H, while not yet definitive, also indicates that base-flow through the alluvial aquifers is likely to have a significant influence on groundwater levels in the Robe River channel. This conclusion is also supported by work conducted by WRM (2016) and Aquaterra (2005).

In general, it is likely that GDEs which rely on river base-flow, have the potential to support more extensive OPV than GDEs that rely on more static type aquifers. Furthermore it is plausible that through continuing inputs; base-flow type GDEs are likely to be more resilient to the influence of changes experienced in "reach" to "local" scale aquifers due to "catchment" and "landscape" scale aquifer influences which are also being exerted on the base-flow delivered at the local and reach scales. Work by (Boulton and Hancock 2006) exploring the functional dependency of river base-flow systems on groundwater at the channel reach, catchment and landscape (regional) scales outlines how this upper catchment scale influence has the potential to minimise or even offset the influence of local scale changes.

In two key sections of the study area, the distribution of OPV showed sharp reductions in abundance, and at times only supported small scatterings of immature, more transient OPV (broadly represented by the C1b vegetation type). These two sections are located within the river reaches broadly running parallel and adjacent to Mesa G, and the reach located between the K and East Deepdale Mesas. For these reaches it is thought that sub-surface alluvial material depths and a reduced influence of sub-surface lithology is likely maintaining deeper groundwater and reduced water accessibility to biota. Importantly, the maintenance of at least minimal amounts of OPV in these reaches also potentially supports the inference that the system is likely base-flow driven.

As detailed above, there is evidence to suggest that rather that possessing more static primarily geomorphologically driven groundwater formations under the Robe River, the groundwater levels below are likely to also be significantly influenced by a catchment scale base-flow of groundwater.

Based on the results of the "H3 Hydrogeological Risk Assessment" for Mesa H (Rio Tinto 2017); the Robe River is considered an ephemeral river, which carries a significant underflow in its alluvial bed. In combination with the evidence sourced from work by Dobbs & Davies (2009), this suggests that; at least the vast majority of the river which falls within the current study area is likely to represent a river base flow type GDE which supports significant amounts of terrestrial GDV.

With the Robe River considered as likely to represent a river base flow type system; it is considered that the abundance and distribution of GDV mapped to occur within this system is largely dependent on the interaction of this base-flow and associated catchment scale inputs with local hydrogeology. Furthermore given the likely influence of base-flow; the influence of dewatering of adjacent local-scale aquifers (in some cases not considered to possess basement hydraulic connectivity with river alluvials) on groundwater proximity within the river channel, may be minimal or at least significantly reduced. However there are a number of unknowns; particularly in relation to basement hydraulic connectivity with alluvial's, and to a lesser degree in relation to the influence of base-flow.

6 CONCLUSIONS

With climatic influences broadly driving water levels in the Robe River to their lowest level in 26 years, and the potential for further anthropogenic changes to vegetation supported by the river a more holistic assessment of the significant riparian values of the Robe River was undertaken.

Broadly speaking the key aims of the study were to;

- Gather high confidence spatial data on the distribution structure, maturity/immaturity and temporal stability of resident OPVs (and to a lesser extent FPV) within the study area.

- Provide detailed mapping best positioned to assess significance and hydrological sensitivity of all potentially groundwater dependent vegetation throughout the study area (to support impact assessments and cumulative impact assessments)

- Provide spatial mapping of the interpreted risk associated with the significance and inherent sensitivity of these communities to potential hydrological change.

As a result of the degree of survey effort maintained throughout the study area, the field methodology employed, and the lack of significant limitations to the study outputs the study successfully achieved the key aims of the study. In addition, beyond the outputs presented herein; the level of detail recorded and the riparian knowledge accumulated through this study will directly continue to add significant additional value to the monitoring and management of significant riparian communities of the Robe Valley in the short to longer term. From these aims the following key learnings were made:

- GDEs in the form of OPV were relatively common and somewhat consistently longitudinally distributed throughout the study area.

- The more mature types of OPV (C1A vegetation type) were less consistent longitudinally, but still relatively common throughout the study area.

- Lateral distribution patterns of OPV, (particularly the distribution of reaches possessing multiple large and laterally broad representations) within the river profile, showed greater spatial correlation to geomorphological features in the landscape than longitudinal distributions.

- OPV with tree strata solely dominated by obligate phreatophytes (vegetation types C1AAa & C1AAb) and often more laterally broad in spatial extent; were relatively restricted and further correlated with larger geomorphological and geologically controlled features, demonstrating that in such areas, groundwater was quite shallow and consistently accessible.

From the resultant risk mapping produced as part of this study, it can inevitably be seen that the potential risk posed to GDEs in the study area by hydrological change in the alluvial aquifer is relatively extensive. However it is important to keep the risk mapping and attributed risk ratings in context. The risk attributed is not directly related to any proposed impacts related to current development proposal, but is rather a hypothetical risk if significant hydrological change were to eventuate for whatever reason. Furthermore; the Risk ratings were developed through a process of classifying dependence and inferred hydrological sensitivity on qualitative indicators (and some coarse quantitative indicators) of degrees of dependency on groundwater. In addition, it was recognised that the complexity of the natural environment determines that the potential for hydrological changes to be realised in the riparian zone is influenced by many overlapping factors. Factors which occur at the reach, catchment and regional scale, such that only a proportion of the predicted reach to local scale hydrological response may be realised.

While there is evidence to suggest that GDV present in the Robe River is to a degree likely supported by a sub-surface flow (consistent with a river base flow system), and as a result the influence of dewatering of smaller scale local aquifers, may be significantly reduced; at this stage there are still unknowns at a macro scale.

It is clear from the results of this study that a significant amount of groundwater dependent vegetation resides within the study area; importantly such communities are not restricted to those river reaches directly adjacent to mineral resources of the Robe Valley. In addition, there is a high potential that the influence of catchment scale base-flow has the ability to minimise low to moderate scale anthropogenic impacts on local hydrology/GDEs. Furthermore, in light of the magnitude of climatic influence inherently associated with and acting upon GDE's within arid Pilbara environments; the potential for broader scale anthropogenic impact on such communities is significantly reduced.

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8 APPENDICES

Appendix 1: Vegetation structure and condition scale used for vegetation description and mapping formulated within this study.

Vegetation Structure and Condition Scale

Vegetation Structural Classes*

Stratum	Canopy Cover (%)				
	70-100%	30-70%	10-30%	2-10%	<2%
Trees over 30 m	Tall closed forest	Tall open forest	Tall woodland	Tall open woodland	Scattered tall trees
Trees 10-30 m	Closed forest	Open forest	Woodland	Open woodland	Scattered trees
Trees under 10 m	Low closed forest	Low open forest	Low woodland	Low open woodland	Scattered low trees
Shrubs over 2 m	Tall closed scrub	Tall open scrub	Tall shrubland	Tall open shrubland	Scattered tall shrubs
Shrubs 1-2 m	Closed heath	Open heath	Shrubland	Open shrubland	Scattered shrubs
Shrubs under 1 m	Low closed heath	Low open heath	Low shrubland	Low open shrubland	Scattered low shrubs
Hummock grasses	Closed hummock grassland	Hummock grassland	Open hummock grassland	Very open hummock grassland	Scattered hummock grasses
Grasses, Sedges, Herbs	Closed tussock grassland / bunch grassland / sedgeland / herbland	Tussock grassland / bunch grassland / sedgeland / herbland	Open tussock grassland / bunch grassland / sedgeland / herbland	Very open tussock grassland / bunch grassland / sedgeland / herbland	Scattered tussock grasses / bunch grasses / sedges / herbs

* Based on Muir (1977), and Aplin's (1979) modification of the vegetation classification system of Specht (1970): Aplin T.E.H. (1979). The Flora. Chapter 3 In O'Brien, B.J. (ed.) (1979). *Environment and Science*. University of Western Australia Press; Muir B.G. (1977). Biological Survey of the Western Australian Wheatbelt. Part II: Vegetation and habitat of Bendering Reserve. *Records of the Western Australian Museum*, Suppl. No. 3; Specht R.L. (1970). Vegetation. In: *The Australian Environment*. 4th edn (Ed. G.W. Leeper). Melbourne.

Vegetation Condition Scale*

E = Excellent (=Pristine of BushForever) Pristine or nearly so; no obvious signs of damage caused by the activities of European man.
VG = Very Good (= Excellent of BushForever) Some relatively slight signs of damage caused by the activities of European man. For example, some signs of damage to tree trunks caused by repeated fire, the presence of some relatively non-aggressive weeds such as **Sonchus oleraceus* or **Cucumis* spp., or occasional vehicle tracks.
G = Good (= Very Good of BushForever) More obvious signs of damage caused by the activities of European man, including some obvious impact on the vegetation structure such as that caused by low levels of grazing or by selective logging. Weeds as above, possibly plus some more aggressive ones such as **Cenchrus* spp.
P = Poor (= Good of BushForever) Still retains basic vegetation structure or ability to regenerate to it after very obvious impacts of activities of European man, such as grazing, partial clearing (chaining) or frequent fires. Weeds as above, probably plus some more aggressive ones such as **Cenchrus* spp.
VP = Very Poor (= Degraded of BushForever) Severely impacted by grazing, very frequent fires, clearing or a combination of these activities. Scope for some regeneration but not to a state approaching good condition without intensive management. Usually with a number of weed species including very aggressive species such as **Prosopis* spp.
D = Completely Degraded (= Completely Degraded of BushForever) Areas that are completely or almost completely without native species in the structure of their vegetation; ie. areas that are cleared or 'parkland cleared' with their flora comprising weed or crop species with isolated native trees or shrubs.

* Based on Trudgen M.E. (1988). A Report on the Flora and Vegetation of the Port Kennedy Area. Unpublished report prepared for Bowman Bishaw and Associates, West Perth.

Appendix 2: Associated species recorded in each mapped vegetation type.

Veg Code	GDE / Community Summary Info	GDE Type	Associated Species	Equivalent Astron 2015 Code
PO	*Minimal Vegetation*	*OPV*	*Acacia ampliceps, Acacia trachycarpa, Achyranthes aspera, Aeschynomene indica, Alternanthera denticulata, Alternanthera nodiflora, Ammannia baccifera, Argemone ochroleuca* subsp. *Ochroleuca*, Boerhavia repleta, Cenchrus ciliaris*, Cenchrus setiger*, Centipeda minima* subsp. *macrocephala, Cleome viscosa, Clerodendrum tomentosum* var. *lanceolatum, Corchorus tridens, Crotalaria medicaginea* var. *neglecta, Cucumis melo, Cymbopogon ambiguus, Cynodon dactylon*, Cyperus bulbosus, Cyperus iria, Cyperus vaginatus, Eriachne benthamii, Eriachne flaccida, Eleocharis dulcis, Eleocharis geniculata, Eucalyptus camaldulensis, Euphorbia australis, Flueggea virosa subsp. melanthesoides, Gomphrena cunninghamii, Gossypium robinsonii, Helichrysum luteoalbum, Hybanthus aurantiacus, Ipomoea muelleri, Juncus kraussii, Lactuca serriola*, Lobelia arnhemiaca, Marsilea hirsuta, Melaleuca glomerata, Melaleuca argentea, Nicotiana occidentalis subsp. occidentalis, Passiflora foetida* var. *hispida*, Petalostylis labicheoides, Phyllanthus reticulatus, Pluchea rubelliflora, Portulaca oleracea, Ptilotus gomphrenoides, Rhynchosia minima, Rostellularia adscendens* var. *clementii, Schoenoplectus subulatus, Schenkia clementii, Sesbania cannabina, Setaria verticillata*, Sonchus oleraceus*, Sporobolus australasicus, Stemodia grossa, Trachymene oleracea* subsp. *Oleracea, Trianthema pilosum, Trianthema triquetrum, Typha domingensis, Utricularia australis, Vigna lanceolata* var. *lanceolata,* and *Zaleya galericulata.*	*N/A*
C1AAa	*Mature MA dominated Closed Forest*	*OPV-A*	*Abutilon sp. Dioicum (A.A. Mitchell PRP 1618), Acacia ampliceps, Acacia trachycarpa, Acacia tumida* var. *pilbarensis, Achyranthes aspera, Aerva javanica*, Aeschynomene indica, Alternanthera denticulata, Alternanthera nodiflora, Amaranthus cuspidifolius, Ammannia baccifera, Argemone ochroleuca* subsp. *Ochroleuca*, Boerhavia coccinea, Boerhavia repleta, Bulbostylis barbata, Capparis spinosa* var. *nummularia, Carissa lanceolata, Cenchrus ciliaris*, Cenchrus setiger*, Centipeda minima* subsp. *macrocephala, Cleome viscosa, Clerodendrum tomentosum* var. *lanceolatum, Corchorus tridens, Crotalaria medicaginea* var. *neglecta, Cucumis melo, Cucumis variabilis, Cymbopogon ambiguus, Cynodon dactylon*, Cyperus bulbosus, Cyperus iria, Cyperus vaginatus, Datura leichhardtii*, Echinochloa colona*, Eriachne benthamii, Eriachne flaccida, Euphorbia australis, Euphorbia hirta*, Ficus aculeata, Fimbristylis dichotoma, Flueggea virosa* subsp. *melanthesoides, Gomphrena cunninghamii, Gossypium robinsonii, Helichrysum luteoalbum, Hibiscus austrinus, Hybanthus aurantiacus, Ipomoea muelleri, Juncus kraussii, Lactuca serriola*, Lobelia arnhemiaca, Livistona alfredii, Malvastrum americanum*, Marsilea hirsuta, Melaleuca glomerata, Nicotiana occidentalis* subsp. *occidentalis, Passiflora foetida* var. *hispida*, Petalostylis labicheoides, Phoenix dactylifera*, Phyllanthus maderaspatensis, Phyllanthus reticulatus,* and *Pluchea rubelliflora, Portulaca oleracea, Ptilotus gomphrenoides, Rhynchosia minima, Rostellularia adscendens* var. *clementii,*	*Similar to EcMaCvCspp (Astron 2015) or MaEcCv (Astron 2016*)*

Veg Code	GDE / Community Summary Info	GDE Type	Associated Species	Equivalent Astron 2015 Code
			Schenkia clementii, Sesbania cannabina, Setaria verticillata, Solanum diversiflorum, Sonchus oleraceus*, Sporobolus australasicus, Stemodia grossa, Tinospora smilacina, Trachymene oleracea* subsp. *Oleracea, Trianthema pilosum, Trianthema triquetrum, Trichodesma zeylanicum var. zeylanicum, Typha domingensis, Vigna lanceolata var. lanceolata,* and *Zaleya galericulata.*	
C1AAb	*Mature MA dominated Open Forest*	*OPV-A*	*Acacia ampliceps, Acacia trachycarpa, Acacia tumida* var. *pilbarensis, Alternanthera nana, Amaranthus undulatus, Amaranthus cuspidifolius, Ammannia baccifera, Argemone ochroleuca* subsp. *ochroleuca*, Boerhavia coccinea, Capparis spinosa* var. *nummularia, Cenchrus ciliaris*, Centipeda minima* subsp. *macrocephala, Cleome viscosa, Clerodendrum tomentosum* var. *lanceolatum, Crotalaria medicaginea* var. *neglecta, Cucumis melo, Cucumis variabilis, Cymbopogon ambiguus, Cyperus bulbosus, Cyperus iria, Cyperus vaginatus, Cynodon dactylon*, Echinochloa colona*, Eriachne benthamii, Eriachne flaccida, Euphorbia australis, Ficus aculeata, Fimbristylis dichotoma, Flueggea virosa* subsp. *melanthesoides, Gomphrena cunninghamii, Cyperus vaginatus, Eucalyptus victrix, Goodenia lamprosperma, Gossypium robinsonii, Ipomoea muelleri, Juncus kraussii, Livistona alfredii, Notoleptopus decaisnei, Passiflora foetida* subsp. *hispida*, Petalostylis labicheoides, Phyllanthus reticulatus, Pluchea rubelliflora, Portulaca oleracea, Ptilotus gomphrenoides, Rhynchosia minima, Rhynchosia bungarensis, Rostellularia adscendens* var. *clementii, Schenkia clementii, Sesbania cannabina, Solanum diversiflorum, Sporobolus australasicus, Stemodia grossa, Tinospora smilacina, Sesbania formosa, Sonchus oleraceus*, Tephrosia rosea* var. *Fortescue Creeks (M.I.H. Brooker 2186), Vigna lanceolata, Waltheria indica,* and **Vachellia farnesiana.*	*MaEcCv (Astron 2016*) or Similar to EcMaCvCspp (Astron 2015)*
C1A	*Mature MA and EC dominated Open forest to Low Woodland*	*OPV-B*	*Acacia ampliceps, Acacia trachycarpa, Acacia tumida* var. *pilbarensis, Alternanthera nana, Amaranthus undulatus, Amaranthus cuspidifolius, Argemone ochroleuca* subsp. *ochroleuca*, Boerhavia coccinea, Capparis spinosa* var. *nummularia, Cenchrus ciliaris*, Centipeda minima* subsp. *macrocephala, Cleome viscosa, Clerodendrum tomentosum* var. *lanceolatum, Crotalaria medicaginea* var. *neglecta, Cucumis melo, Cymbopogon ambiguus, Cyperus iria, Cyperus vaginatus, Echinochloa colona*, Euphorbia australis, Gomphrena cunninghamii, Cyperus vaginatus, Eucalyptus victrix, Goodenia lamprosperma, Gossypium robinsonii, Ipomoea muelleri, Juncus kraussii, Notoleptopus decaisnei, Passiflora foetida* subsp. *hispida*, Petalostylis labicheoides, Pluchea rubelliflora, Ptilotus gomphrenoides, Rhynchosia minima, Schenkia clementii, Sesbania cannabina, Sesbania formosa, Sporobolus australasicus, Stemodia grossa, Tinospora smilacina, Sonchus oleraceus*, Tephrosia rosea* var. *Fortescue Creeks (M.I.H. Brooker 2186), Vigna lanceolata, Waltheria indica,* and **Vachellia farnesiana.*	*EcMaCvCspp (Astron 2015) or MaEcCv (Astron 2016*)*

Veg Code	GDE / Community Summary Info	GDE Type	Associated Species	Equivalent Astron 2015 Code
C1b	*MA and EC dominated Low Woodland*	*OPV-C*	*Acacia ampliceps, Acacia colei var. ileocarpa, Acacia trachycarpa, Acacia tumida* var. *pilbarensis, Alternanthera nana, Argemone ochroleuca* subsp. *ochroleuca*, Capparis spinosa* var. *nummularia, Cenchrus ciliaris*, Cleome viscosa, Clerodendrum tomentosum* var. *lanceolatum, Cucumis melo, Cymbopogon ambiguus, Cynodon dactylon*, Cyperus vaginatus, Echinochloa colona*, Eucalyptus victrix, Ficus aculeata, Flueggea virosa* subsp. *melanthesoides, Gossypium robinsonii, Ipomoea muelleri, Juncus kraussii, Passiflora foetida* subsp. *hispida*, Petalostylis labicheoides, Rhynchosia bungarensis, Sesbania formosa, Sesbania cannabina, Sonchus oleraceus*, Tephrosia rosea* var. *Fortescue Creeks (M.I.H. Brooker 2186) , Vachellia farnesiana*,* and *Vigna lanceolata.*	*Similar to EcMaCvCspp (Astron 2015) or similar to MaEcCv (Astron 2016*)*
C2AA	*Large Mesic EC dominated Open Forest representations*	*FPV-A*	*Acacia ampliceps, Acacia bivenosa, Acacia colei var. colei, Acacia trachycarpa, Acacia ancistrocarpa, Acacia maitlandii, Acacia pyrifolia* var. *pyrifolia, Acacia tumida* var. *pilbarensis, Argemone ochroleuca* var. *ochroleuca*, Cenchrus setiger*, Cenchrus ciliaris*, Cleome viscosa, Crotalaria medicaginea var. neglecta, Cucumis variabilis, Cucumis melo, Cyperus vaginatus, Eucalyptus victrix, Eulalia aurea, Euphorbia schultzii, Hybanthus aurantiacus, Ipomoea muelleri, Melaleuca glomerata, Melaleuca argentea, Petalostylis labicheoides, Phyllanthus maderaspatensis, Senna notabilis, Sesbania cannabina, Sesbania formosa, Stemodia grossa, Tephrosia rosea* var. *Fortescue creeks* (M.I.H. Brooker 2186), *Trachymene oleracea* subsp. *Oleracea, Triodia epactia, Typha domingensis, Vachellia farnesiana** and *Vigna lanceolata* var. *lanceolata.*	*Similar to EcCv (Astron 2015) or EcEvAtrApyPlTw (Astron 2016*)*
C2A	*EC dominated Open Forest*	*FPV-A*	*Acacia ampliceps, Acacia bivenosa, Acacia colei* var. *colei, Acacia trachycarpa, Acacia ancistrocarpa, Acacia trachycarpa, Argemone ochroleuca var. ochroleuca*, Cenchrus setiger*, Cenchrus ciliaris*, Cleome viscosa, Cucumis variabilis, Cyperus vaginatus, Eucalyptus victrix, Eulalia aurea, Euphorbia schultzii, Hybanthus aurantiacus, Melaleuca glomerata, Melaleuca argentea, Petalostylis labicheoides, Phyllanthus maderaspatensis, Sesbania formosa, Sesbania cannabina, Stemodia grossa, Trachymene oleracea* subsp. *Oleracea, Typha domingensis,* and *Vigna lanceolata* var. *lanceolata.*	*Similar to EcCv (Astron 2015) or EcEvAtrApyPlTw (Astron 2016*)*
C2B	EC & EV co-dominated Open Forest	FPV-B	*Acacia ampliceps, Acacia bivenosa, Acacia colei, Acacia trachycarpa, Acacia ancistrocarpa, Acacia pyrifolia* var. *pyrifolia, Cenchrus setiger*, Cenchrus ciliaris*, Cleome viscosa, Cyperus vaginatus, Eulalia aurea, Gossypium robinsonii, Indigofera colutea, Ipomoea muelleri, Melaleuca glomerata, Melaleuca argentea, Petalostylis labicheoides, Sesbania cannabina, Triodia epactia, Typha domingensis,* and *Vachellia farnesiana**	*Similar to EcEvCspp (Astron 2015) or EcEvAtrApyPlTw (Astron 2016*)*

Veg Code	GDE / Community Summary Info	GDE Type	Associated Species	Equivalent Astron 2015 Code
C2A-B	EC dominated Woodlands	FPV-A	*Acacia bivenosa, Acacia colei* var. *colei, Acacia trachycarpa, Acacia ancistrocarpa, Acacia trachycarpa, Argemone ochroleuca* var. *ochroleuca*, Cenchrus setiger*, Cenchrus ciliaris*, Cleome viscosa, Cucumis variabilis, Cyperus vaginatus, Eucalyptus victrix, Eulalia aurea, Euphorbia schultzii, Hybanthus aurantiacus, Melaleuca glomerata, Melaleuca argentea, Petalostylis labicheoides, Phyllanthus maderaspatensis, Sesbania cannabina, Stemodia grossa, Trachymene oleracea* subsp. *Oleracea, Typha domingensis,* and *Vigna lanceolata* var. *lanceolata.*	*EcCv (Astron 2015) or EcEvAtrApyPlTw (Astron 2016*)*
C2B-B	EC & EV co-dominated Woodland	FPV-B	*Acacia bivenosa, Acacia colei, Acacia trachycarpa, Acacia ancistrocarpa, Acacia pyrifolia* var. *pyrifolia, Cenchrus setiger*, Cenchrus ciliaris*, Cleome viscosa, Cyperus vaginatus, Cyperus vaginatus, Eulalia aurea, Gossypium robinsonii, Indigofera colutea, Ipomoea muelleri, Melaleuca argentea, Melaleuca glomerata, Petalostylis labicheoides, Sesbania cannabina, Triodia epactia, Typha domingensis,* and *Vachellia farnesiana**	*EcEvCspp (Astron 2015) or EcEvAtrApyPlTw (Astron 2016*)*
C2C	EV Dominated Woodland	FPV-C	*Acacia pyrifolia* var. *pyrifolia, Acacia bivenosa, Acacia maitlandii, Acacia pyrifolia* var. *pyrifolia, Acacia trachycarpa, Boerhavia coccinea, Cenchrus setiger*, Cenchrus ciliaris*, Cleome viscosa, Crotalaria medicaginea* var. *neglecta, Gossypium robinsonii, Hybanthus aurantiacus, Ipomoea muelleri, Rhynchosia minima, Senna notabilis, Stemodia grossa, Tephrosia rosea* var. *Fortescue creeks* (M.I.H. Brooker 2186)*, Triodia epactia, Triumfetta appendiculata, Vachellia farnesiana*,* and *Waltheria indica.*	*EvMgCv (Astron 2015) or EvAtrTwCspp (Astron 2016*)*
C3A	EC & EV co-dominated Open woodland	FPV-B	*Acacia bivenosa, Acacia colei, Acacia trachycarpa, Acacia ancistrocarpa, Acacia pyrifolia* var. *pyrifolia, Cenchrus setiger*, Cenchrus ciliaris*, Cleome viscosa, Cyperus vaginatus, Cyperus vaginatus, Eulalia aurea, Gossypium robinsonii, Indigofera colutea, Ipomoea muelleri, Melaleuca argentea, Melaleuca glomerata, Petalostylis labicheoides, Sesbania cannabina, Triodia epactia, Typha domingensis,* and *Vachellia farnesiana**	*EcEvCspp (Astron 2015) or similar to EcEvAtrApyPlTw (Astron 2016*)*
C3B	EV Dominated Open Woodland	FPV-C	*Acacia pyrifolia* var. *pyrifolia, Acacia bivenosa, Acacia maitlandii, Acacia pyrifolia* var. *pyrifolia, Acacia trachycarpa, Boerhavia coccinea, Cenchrus setiger*, Cenchrus ciliaris*, Cleome viscosa, Crotalaria medicaginea* var. *neglecta, Gossypium robinsonii, Hybanthus aurantiacus, Ipomoea muelleri, Rhynchosia minima, Senna notabilis, Stemodia grossa, Tephrosia rosea* var. *Fortescue creeks (M.I.H. Brooker 2186), Triodia epactia, Triumfetta appendiculata, Vachellia farnesiana*,* and *Waltheria indica*	*EvMgCv (Astron 2015) or EvAtrTwCspp (Astron 2016*)*

Veg Code	GDE / Community Summary Info	GDE Type	Associated Species	Equivalent Astron 2015 Code
C4	Shrublands	Vadophytic	*Acacia bivenosa, Acacia pyrifolia* var. *pyrifolia, Abutilon otocarpum, Acacia ancistrocarpa, Aerva javanica*, Argemone ochroleuca* subsp. *Ochroleuca*, Boerhavia coccinea, Cenchrus ciliaris*, Crotalaria cunninghamii, Eriachne pulchella* subsp. *dominii, Euphorbia schultzii, Gomphrena cunninghamii, Gossypium australe, Ipomoea muelleri, Notoleptopus decaisnei* var. *Orbicularis (A.B. Craig 428), Ptilotus astrolasius* var. *astrolasius, Ptilotus nobilis, Senna notabilis , Triodia epactia, Tephrosia rosea* var. *Fortescue Creeks (M.I.H Brooker 2186), Trachymene oleracea* subsp. *Oleracea,* and *Triodia wiseana.*	*Similar to AtrEs & AtTeCc (Astron 2015) or AtrPl (Astron 2016*)*
C5	Beds with minimal vegetation	Vadophytic	*Acacia trachycarpa, Argemone ochroleuca* subsp. *ochroleuca*, Boerhavia coccinea, Eriachne pulchella* subsp. *dominii, Gomphrena cunninghamii, Hybanthus aurantiacus, Ipomoea muelleri, Ipomoea muelleri, Ptilotus incanus, Ptilotus nobilis, Rhynchosia minima, Senna notabilis, Trichodesma zeylanicum* var. *zeylanicum,* and *Trachymene oleracea* subsp. *Oleracea.*	*AtrEs (Astron 2015) or Es (Astron 2016*)*
C6	Shrublands	Vadophytic / Xerophytic	*Acacia ancistrocarpa, Acacia bivenosa, Acacia inaequilatera, Acacia trachycarpa, Acacia tumida* var. *pilbarensis, Acacia colei* var. *ileocarpa, Acacia inaequilatera, Acacia maitlandii, Acacia monticola, Acacia pyrifolia* var. *pyrifolia, Acacia synchronicia, Acacia trachycarpa* x *tumida* var. *pilbarensis, Acacia tumida* var. *pilbarensis, Acacia wanyu, Abutilon otocarpum, Aerva javanica*, Boerhavia coccinea, Bonamia erecta, Cajanus cinereus, Cenchrus ciliaris*, Corchorus lasiocarpus* subsp. *parvus, Crotalaria cunninghamii, Cymbopogon ambiguous, Grevillea pyramidalis* subsp. *leucadendron, Gossypium australe, Gossypium robinsonii, Hybanthus aurantiacus, Indigofera monophylla, Jasminum didymum* subsp. *lineare, Malvastrum americanum*, Notoleptopus decaisnei* var. *Orbicularis* (A.B. Craig 428), *Pentalepis trichodesmoides, Rhynchosia minima, Senna artemisioides* subsp. *oligophylla, Senna notabilis,* and *Trichodesma zeylanicum* var. *zeylanicum.*	*Similar to AtTeCc & ChAsppTwTe (Astron 2015) or ChAsppGOrGsppPlSsTe Tw & ChPlAbGOrTw (Astron 2016*)*

Appendix 3: Representative photographs of the key riparian vegetation units mapped to occur within the study area

New Veg code	Vegetation Type and Description	Representative Photos
PO	Minimal Vegetation	

New Veg code	Vegetation Type and Description	Representative Photos

New Veg code	Vegetation Type and Description	Representative Photos
C1AAa	Mature MA dominated Closed Forest	

New Veg code	Vegetation Type and Description	Representative Photos

New Veg code	Vegetation Type and Description	Representative Photos
C1AAb	Mature MA dominated Open Forest	

New Veg code	Vegetation Type and Description	Representative Photos

New Veg code	Vegetation Type and Description	Representative Photos
C1A	Mature MA and EC dominated Open forest to Low Woodland	

New Veg code	Vegetation Type and Description	Representative Photos

New Veg code	Vegetation Type and Description	Representative Photos
C1b	MA and EC dominated Low Woodland	

New Veg code	Vegetation Type and Description	Representative Photos

New Veg code	Vegetation Type and Description	Representative Photos
C2AA	Large Mesic EC dominated Open Forest representations	

New Veg code	Vegetation Type and Description	Representative Photos
C2A	EC dominated Open Forest	

New Veg code	Vegetation Type and Description	Representative Photos

New Veg code	Vegetation Type and Description	Representative Photos
C2B	EC & EV co-dominated Open Forest	

New Veg code	Vegetation Type and Description	Representative Photos
C2A-B	EC dominated Woodlands	

New Veg code	Vegetation Type and Description	Representative Photos

New Veg code	Vegetation Type and Description	Representative Photos
C2B-B	EC & EV co-dominated Woodland	

New Veg code	Vegetation Type and Description	Representative Photos
C2C	EV Dominated Woodland	

New Veg code	Vegetation Type and Description	Representative Photos
C3A	EC & EV co-dominated Open woodland	

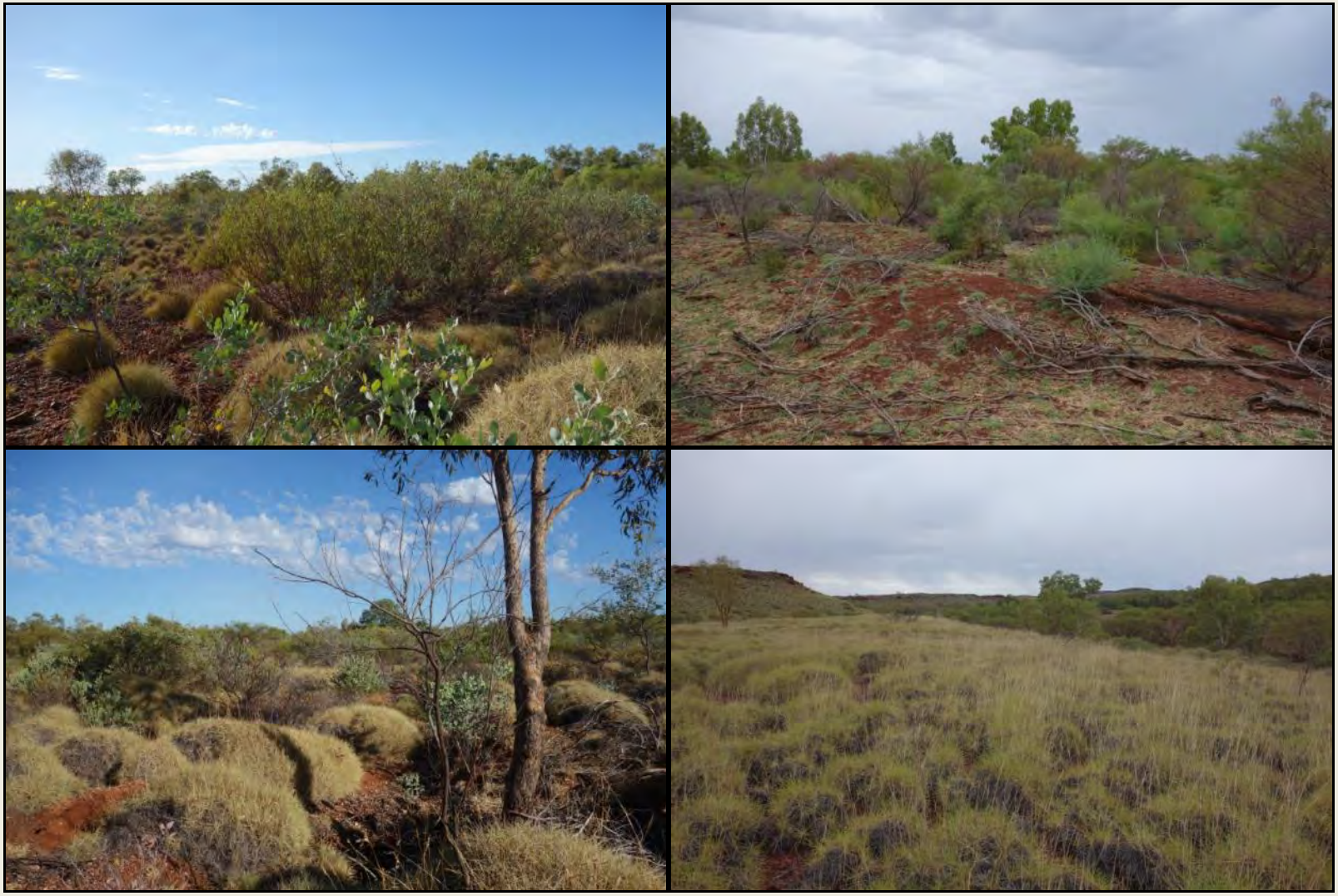
New Veg code	Vegetation Type and Description	Representative Photos

New Veg code	Vegetation Type and Description	Representative Photos
C3B	EV Dominated Open Woodland	

New Veg code	Vegetation Type and Description	Representative Photos
C4	Shrublands	

New Veg code	Vegetation Type and Description	Representative Photos
C5	Beds with minimal vegetation	

New Veg code	Vegetation Type and Description	Representative Photos
C6	Shrublands	

New Veg code	Vegetation Type and Description	Representative Photos
		

Addendum to; Assessment of Groundwater Dependent Vegetation distribution on the Robe River - Targeted Riparian Vegetation Survey – Stage 1:

Groundwater Dependent Vegetation distribution within Jimmawurrada Creek – Targeted Riparian Vegetation Survey

High confidence mapping of the distribution of Obligate and Facultative Phreatophytic Vegetation

May 2018

RTIO-HSE-0325951

Disclaimer and Limitation

This report has been prepared by Rio Tinto Iron Ore (Rio Tinto). Neither the report nor its contents may be referred to without the express approval of Rio Tinto, unless the report has been released for referral and assessment of proposals.

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1 INTRODUCTION

To provide information relevant to the proposed development of Mesa H, mapping of potentially groundwater dependent vegetation within the broader vicinity of Mesa H is required. In order to ensure that the mapping extended beyond the areas which may be affected by the proposal, the Riparian vegetation mapping work conducted along the Robe River was extended so as to cover approximately 21 km of Jimmawurrada Creek from its confluence with the Robe River.

The current report represents an addendum to the previous report "Assessment of Groundwater Dependent Vegetation Distribution on the Robe River, Targeted Riparian Vegetation Survey; Stage 1" (Rio Tinto 2017). The current report outlines additional details and results from the riparian vegetation mapping extended further along Jimmawurrada creek for the purpose of understanding any potential impacts which might occur due to potential groundwater level changes. Figure 1-1 shows the extent of the current study area and the boundaries of previous flora and vegetation surveys.

For all details relevant to the methodology and results not provided within this addendum, refer to Rio Tinto 2017 (Assessment of Groundwater Dependent Vegetation Distribution on the Robe River, Targeted Riparian Vegetation Survey; Stage 1).

The four key aims of this additional work are to:

1. Gather detailed and high confidence spatial information on the distribution of Groundwater Dependent Vegetation (**GDV**) along Jimmawurrada Creek, particularly those Obligate Phreatophytic Vegetation (**OPV**) communities.

2. Gather and incorporate information on the structure, age distribution, maturity and potential permanence/transience of resident OPV communities such that the resultant vegetation mapping is more strongly positioned to assess significance and groundwater dependence.

3. Describe and map all riparian communities throughout the study area, to a high level of detail, and in a manner prioritising the identification of all potentially groundwater dependent ecosystems and their distribution.

4. Based on the structure, maturity and distribution of mapped phreatophytic vegetation: provide an interpretation of the significance and inherent sensitivity of these communities to potential hydrological change in the form of interpreted risk mapping throughout the area of interest.

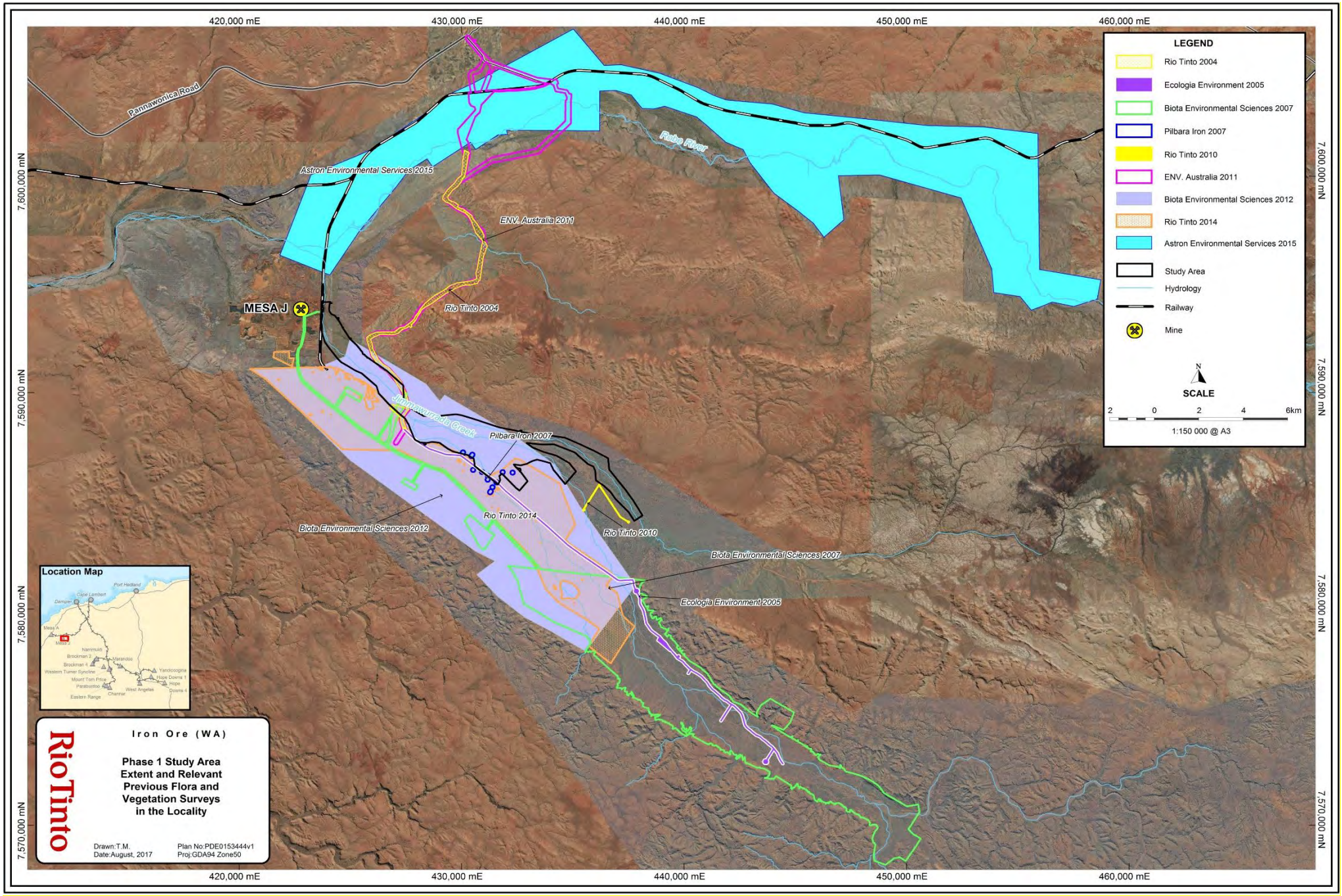


Figure 1-1: Extent of Jimmawurrada Creek covered by the Stage 1 Study Area; includes the study boundaries of key previous flora and vegetation surveys.

2 BACKGROUND

2.1 STUDY AREA

The study area focus of this addendum report incorporates an approximately 18 km stretch of Jimmawurrada Creek, which in combination with an approximate 3 km stretch covered by the main Robe River riparian report (Rio Tinto 2017a) provides an assessment of approximately 21 km of Jimmawurrada Creek (from the confluence with the Robe River). The stretch of Jimmawurrada Creek represented by the study area is wholly located within the Hamersley subregion of the Pilbara Bioregion (IBRA 7.1) (DoE 2014a).

The boundaries of this study area are presented in Figure 1-1 (and in more detail in Figure 3-1).

2.2 JIMMAWURRADA CREEK

Jimmawurrada Creek, and its adjoining member Bungaroo Creek, dissect a pair of broad, low-gradient valleys (forming the valley floor to rugged upland areas), which are prone to flooding after seasonal, tropical storms and cyclones. The creek valleys cut through the Buckland Hills and Mount Dempster areas, and are bounded to the south, and in some parts to the north by steep scarps, mostly formed of the resistant Dales Gorge member of the Brockman Iron formation (Rio Tinto 2011). The Bungaroo valley is approximately 0.5 km wide at the upstream end and 4 km wide where it confluences with Jimmawurrada Creek about 30 km downstream. The valley formed by Jimmawurrada Creek is approximately 9 km wide at the eastern end. Both valleys (particularly Bungaroo valley) contain numerous braided, dry creek beds that are prone to flooding during the wet season (Rio Tinto 2011).

The broader Bungaroo and Jimmawurrada Creek catchment provides approximately 1600 square kilometres of total catchment area. On its own, Jimmawurrada Creek has a catchment area of about 400 square kilometres, while the catchment for Bungaroo Creek is in the order of 1200 square kilometres.

2.3 PREVIOUS SURVEYS

A significant amount of survey work has been conducted in the Robe Valley locality since mining development began in the 1980's. Table 2-1 outlines the relevant flora and vegetation surveys which intersect Jimmawurrada Creek in the vicinity of the study area. The most relevant and recent studies have been conducted by Biota Environmental Sciences Pty Ltd (2012)(Table 2-1). This body of work has essentially sampled/surveyed a riparian environment which had already seen some degree of impact from pastoralism, groundwater drawdown and surplus dewater discharge from mining activities at Mesa J; and natural events (cyclones, flooding and fires). The survey boundaries of previous relevant flora and vegetation studies are presented in Figure 1-1 in relation to the boundary of the current study area.

Table 2-1: Summary of relevant vegetation and flora surveys intersecting the Jimmawurrada Creek study area.

Study (Reference)	Area Surveyed Within Study Area	Survey Description Survey Timing (Conditions for Plant Growth)	Available Data
Astron Environmental Services (2015): Middle Robe and East Deepdale Level 2 Vegetation and Flora Assessment.	11,816 ha	**Multiple-phase detailed survey;** Phase 1 conducted from the 15-27th of June 2015 (J. Atkinson D. Roocke K. McMaster, L. Vaughan), and Phase 2 was conducted from 21st (Sep) to 3rd of October 2015 (J. Atkinson and D. Roocke).	• Quadrats/relevés/mapping notes. • Conservation significant flora and weeds. • Floristic analysis • Vegetation mapping. • Vegetation condition assessment. • Species list.
Rio Tinto (2014): Flora, Vegetation and Fauna Habitat Assessment at Jimmawurrada; Native Vegetation Clearing Permit Supporting Report.	4,323 ha	**Single phase Reconnaissance survey;** Two surveys were conducted by Rio Tinto botanist (Emma Carroll) and assistance from Ciaran Gibson (Biota) (5-11th July 2013) and Ellie Ridley (Biota) (5-11th October 2013).	• Relevés/mapping notes. • Conservation significant flora and weeds. • Vegetation mapping. • Vegetation condition assessment. • Fauna habitat mapping. • Species list.
Biota Environmental Sciences (2012): Greater Bungaroo Flora and Vegetation Survey.	8,765 ha	**Multiple-phase detailed survey;** Phase 1 was conducted from the 20-30th of July 2009 (P. Anderson, R. Butler, P. Hoffman and Melinda Trudgen), Phase 2 from the 9-13th of June in 2011 (P. de Kock, J. Fairhead, C. Flaherty, P. Hoffman, E. Ridley and S. Venkatasamy).	• Quadrats/relevés/mapping notes. • Conservation significant flora and weeds. • Floristic analysis • Vegetation mapping. • Vegetation condition assessment. • Species list.
ENV Australia (2011): Bungaroo Alternate Powerline Routes Flora, Vegetation and Fauna Assessment.	863 ha	**Single Phase Reconnaissance Survey (NVCP level biological assessment);** Single survey conducted from the 17-20th May 2011 (K. McMaster, B. Watkins, L. Dadour, C. Webb).	• Quadrats/relevés/mapping notes. • Conservation significant flora and weeds. • Floristic analysis • Vegetation mapping. • Vegetation condition assessment. • Species list.
Rio Tinto (2010): A Flora and Vegetation Survey for Groundwater Investigations at Bungaroo.	4 ha	**Systematic Rare and Priority Flora Survey (Single Phase):** Single survey conducted on the 12th of January 2010 (Emil Thoma).	• Vegetation associations encountered • Conservation significant flora and weeds. • Vegetation condition assessment. • Species list.
Rio Tinto (2007): A Flora and Vegetation Survey; Lower Bungaroo Valley Proposed Drilling AR-07-01652	350 ha	**Systematic Rare and Priority Flora Survey (Single Phase):** Single survey conducted in August of 2007 (J. Fraser (Pilbara Iron) and R. Butler (Biota).	• Vegetation associations encountered • Conservation significant flora and weeds. • Vegetation condition assessment. • Species list.

Study (Reference)	Area Surveyed Within Study Area	Survey Description Survey Timing (Conditions for Plant Growth)	Available Data
Biota Environmental Sciences (2007): A Vegetation and Seasonal Flora Survey of the Bungaroo Trial Pit and Transport Corridor to Mesa J, near Pannawonica, and Sampling of the Broader Bungaroo Valley	550 ha	**Multiple-phase detailed survey;** Phase 1 conducted from the 8-20th of March 2005 (M. Maier, R. Orifici, B. Morgan), Phase 2 conducted from the 19-21st of July 2006 (M. Maier & R. Warner) and 7-16th of August 2006 (B. Morgan & R. Warner) plus additional Rare flora searches (A. Joder (Rio Tinto)) in June 2005.	• Quadrats/relevés/mapping notes. • Conservation significant flora and weeds. • Floristic analysis • Vegetation mapping. • Vegetation condition assessment. • Species list.
Ecologia Environment (2005): Road upgrade flora survey; Bungaroo valley	271 ha	**Systematic Rare and Priority Flora Survey (Single Phase):** 12-16th of May 2005	• Conservation significant flora and weeds. • Species list.
Rio Tinto (2004): Rare and Priority flora survey; Proposed road from Panna mine to Bungaroo.	863 ha	**Systematic Rare and Priority Flora Survey (Single Phase):** Single survey conducted from the 14-17th of August 2004 (Emil Thoma).	• Conservation significant flora and weeds. • Species list.

2.3.1 Resultant Vegetation Mapping

Previous vegetation mapping covering the study area has been completed at a resolution commensurate with the environmental impact assessment (**EIA**) objectives for which it was commissioned. Generally, flora and vegetation surveys conducted for the purpose of EIAs are commissioned with the aim of sampling and documenting all the values present. As a result, sampling effort is spread widely and the level of detail attained is typically proportionate to the size of the area, number of landforms present, and the extent of areas of elevated ecological value.

The Greater Bungaroo Flora and Vegetation Survey conducted by Biota (2012) represents the most detailed and extensive of the vegetation models previously created on Jimmawurrada Creek. This mapping provides an important platform for the current study; however the objectives of the current study determined that mapping with much greater spatial confidence and at a finer resolution was required. Improving the spatial confidence and detail of riparian vegetation mapping would help increase knowledge in the riparian zone and increase the understanding of the local environmental values (and their distribution), and hence increase the effectiveness of environmental management.

3 METHODOLOGY

3.1 RIPARIAN VEGETATION MAPPING WITH A FOCUS ON GDE CHARACTERISTICS AND DISTRIBUTION

To achieve the vegetation mapping aims of this study; a "Targeted Survey" was conducted as defined under the EPA Technical Guidance; Flora and Vegetation Surveys for Environmental Impact Assessment (EPA 2016b).

The survey work conducted for the Jimmawurrada component, involved 3.5 days field work for two Botanists from the 21-24th of May 2017. The field component was conducted by Jeremy Naaykens (Rio Tinto Botanical Specialist), and Pierre-Louis De-Kock (Botanist; Biota Environmental Sciences). This field work was combined with approximately 1 day of field work conducted within the first 3 km of Jimmawurrada Creek as part of the 2016/2017 Robe River mapping component.

The vegetation mapping conducted as part of this study focused on gathering high confidence and relatively detailed information on the distribution and characteristics of GDEs within Jimmawurrada Creek. This was achieved by primarily focusing on gathering information about the maturity and distribution of Obligate Phreatophytic Vegetation (**OPV**)[1]. A secondary data focus was placed on gathering information on the distribution of Facultative Phreatophytic Vegetation (**FPV**)[2]; particularly the distribution patterns exhibited by *Eucalyptus camaldulensis* (River Red Gums). The primary focus on OPV is motivated by the fact that this vegetation incorporates species possessing the highest degree of sensitivity to surface and groundwater hydrological changes, potentially associated with mining. However, in the case of Jimmawurrada Creek, OPV communities were largely absent once away from the hydrological influence of the Robe River.

The field methodology used in the Jimmawurrada Creek Targeted Riparian Survey essentially followed the methodology outlined in Rio Tinto (2017a) (the Robe River component). However the methodology used did differ slightly due to the general absence of communities dominated/co-dominated by *Melaleuca argentea*. As a result the data collected in relation to OPV was very minimal, and instead individuals of this species were way-pointed when sighted, and the focus shifted to making sure *M. argentea* populations were not missed and collecting data on the distribution and abundance of other more intermediate mesic indicator species.

In addition to changes in focus, the much smaller width and significantly reduced spatial complexity of Groundwater Dependent Ecosystems (**GDEs**) along Jimmawurrada creek meant that lateral traverses were of reduced importance, and were therefore conducted less frequently.

The vegetation mapping process and the resultant field survey effort attributed to the study area was conducted on riparian units occurring within the major riparian habitats of the study area. As part of this process, a high degree of survey effort was afforded to the riparian units in the main incised channel zone of the creek compared to the outer fringing communities and the terrace and floodplain habitats. Mapping of the outer riparian habitats of a significant proportion the study area had already

[1] This label is addressed in Rio Tinto (2018b), and is not an accepted label, but is applied to help delineate between vegetation units dominated/co-dominated by one or more obligate phreatophytes.

[2] This label is addressed in Rio Tinto (2018b), and is not an accepted label, but is applied to help delineate between vegetation units dominated/co-dominated by one or more facultative phreatophytes.

been conducted by Biota (2012), and so mapping in these low risk areas (from a GDE sense) relied upon this previous mapping to increase the degree of community validation applied.

With respect to data collection methods; this survey noted the adequate amount of Quadrat/Relevé based data collection which has previously been conducted within various parts of the study area. This survey also observed that mapping traverses had previously been used to a lesser extent than quadrat/relevé based techniques in the riparian zone of the study area. Coupled with the GDE focus of the study, it was concluded that the degree of information on the associated floristic composition of riparian communities already captured within the Bungaroo valley area was sufficient to meet the objectives of this study. Mapping traverses were, therefore, considered to be the most effective method for targeted vegetation mapping in this study. Mapping traverses, generally comprise walking through the target area and regularly taking notes, photographic records, and spatial information on the apparent vegetation associations/sub-associations present, and the location and pattern of boundaries which separate them.

It should be noted that vegetation mapping is essentially a model, such that the spatial validity of boundaries and the vegetation associations depicted to lie within those boundaries, is only true a portion of the time. In general, the proportion of time which the model is correct is directly correlated to the amount of ground-truthing which is done per unit area of the model, and the scale of the community descriptions created. The third influencing factor is generally considered to be the complexity of environmental factors influencing vegetation ecology, but for the surveyor, this is an uncontrolled factor and is therefore not generally considered in detail.

For the vegetation mapping model presented as a part of this study, a key aim was to provide a high degree of accuracy in relation to the spatial location and distribution of resident OPV and FPV communities. As a result, the degree of ground-truthing effort conducted within the core riparian zone (particularly the incised channel zone) was high, such that the mapping is considered to be significantly more accurate than typical quadrat/relevé dominated sampling methodology and subsequent vegetation mapping undertaken in typical flora and vegetation surveys within WA.

All vegetation types mapped as part of this study, were described using Aplins' (1979) framework for "Vegetation Structural Classes" (Specht 1970). This framework is presented in Appendix 1, along with vegetation condition scale used in this study (Trudgen 1988). As such all communities (**Table 4-1**) established as part of this study are generally considered to represent sub-associations (equivalent to the NVIS classification). Community descriptions were created by identifying dominants (where present) for all relevant strata available, rather than restricted to the three traditional strata, such that they represent relatively detailed vegetation descriptions, approximately equivalent to level 5 mapping within the National Vegetation Information System (**NVIS**) (DoE 2014b).

Given the Stage 1 status of this study; some vegetation types mapped and described as part of this study are potentially more accurately classified as associations, or are lacking some of the structural/compositional differentiation which comes from sampling over multiple phases (as part of a detailed survey (EPA 2016b)). Furthermore; some of the non-core riparian communities of the high-flow and terrace riparian habitats are yet to be properly described and delineated throughout the study area. Given the focus of this study is on delineating groundwater dependent ecosystems the reduced level of detail provided for such communities is considered relatively inconsequential and of low significance when considering potential impacts.

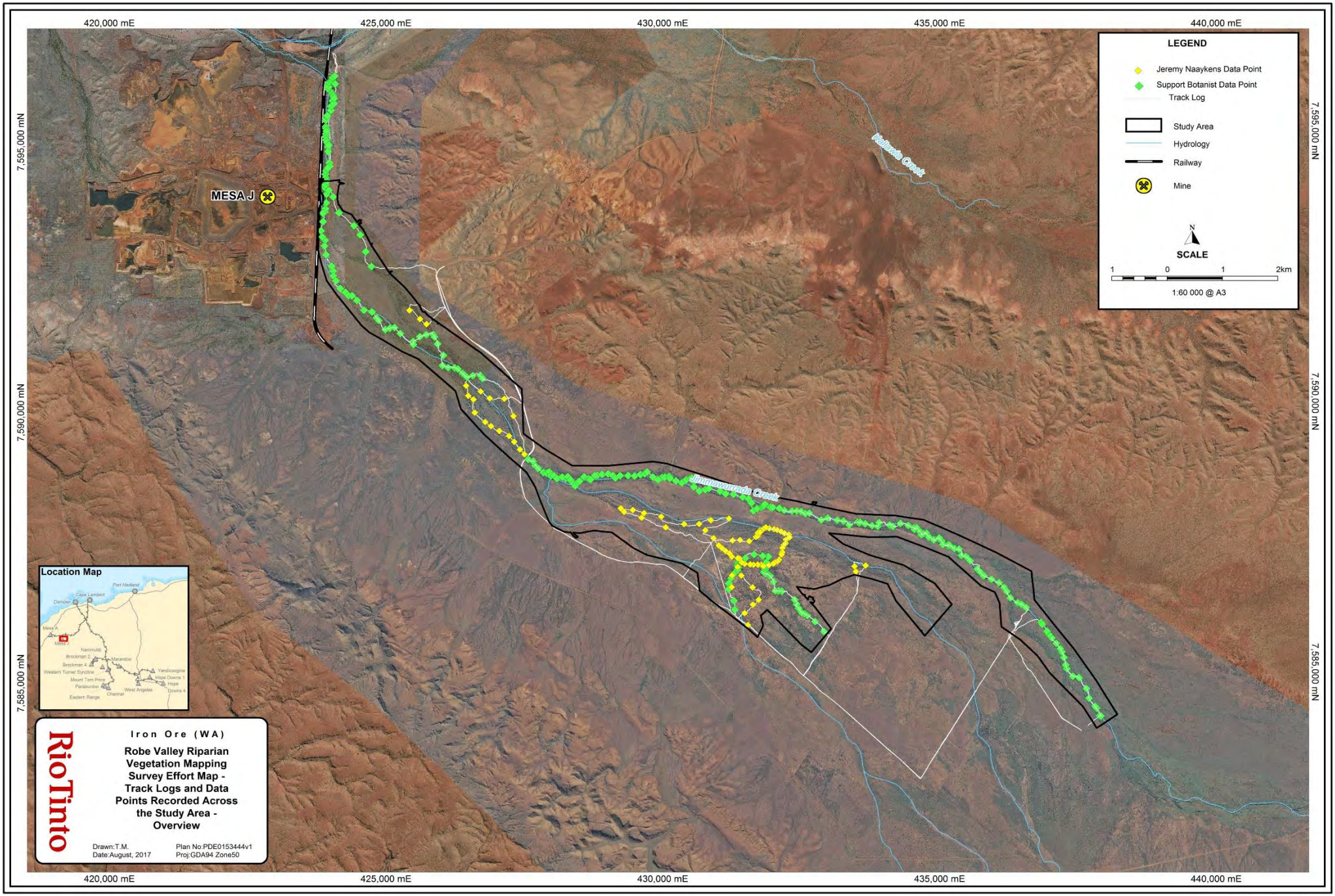


Figure 3-1: Survey Effort map, depicting the survey effort conducted within the study area by showing the track logs and data points collected throughout using a GPS.

3.2 SIGNIFICANCE FRAMEWORK USED TO ASSESS THE LOCAL SIGNIFICANCE OF RIPARIAN COMMUNITES MAPPED WITHIN THE STUDY AREA

For the purpose of incorporating a sense of "quantification" to the process of attributing significance to riparian communities within the study area, the following "framework for Significance" was developed in Rio Tinto (2015) and adapted in this study as a means of providing a more systematic qualitative assessment of significance. This Framework incorporates an assessment of the ecological values provided, the distribution or degree to which it is represented in the environment (local, sub-regional, regional), the condition, and the sensitivity to change of each community mapped within the study area.

Key steps for considering the relevant factors/attributes are:

1. Part one - consider the number and magnitude of ecological values associated with or provided by a biological feature.
2. Part two - determine the distribution and therefore degree to which it is restricted in the environment, the degree of representation (the degree to which a vegetation unit is represented by other communities outside of the study area), and potential rarity of this feature within local, sub-regional, and regional scales.
3. Part three – consider the condition of the biological feature, and its inherent resilience to perturbation.

Once determined, the combined consideration of parts one and two result in the determination of an initial significance rating. The inherent sensitivity or resilience of a feature to perturbation will tend to increase or decrease the likelihood of impact, as well as the consequences of the impact. In addition, the current condition of the feature at the time of consideration will have an influence on its significance. In order to incorporate sensitivity/resilience and locally known potential anthropogenic impacts into the resultant significance, it is proposed that for this study, a final "Resultant Local Significance rating" will be determined via part three of the framework and used to attribute an alternative and more locally measured significance to the biological features being assessed.

In addition to the considering physical and biological condition of a feature; this final significance will incorporate some consideration of the inherent risks and potential consequences of development on this feature into the attributed resultant significance. The result of this framework is that ultimately the final resultant local Significance will in turn provide a more measured guidance to management and mitigation as development is undertaken or continued.

The local significance framework attributed to each riparian vegetation unit is initially and finally assigned to one of the following significance ratings (Table 3-1).

Table 3-1: Ten tier "Significance Rating" scale adapted for this study

(1) Very High	(2) Moderate
(3) High+	(4) Minor-Moderate
(5) High	(6) Minor +
(7) Moderate-High	(8) Minor
(9) Moderate+	(10) Low

It should be noted that this scale assumes the most common and widespread of the vegetation-types/habitats within a study area are considered to fall outside this scale such that the Low rating is attributed to vegetation of slightly elevated significance when compared to the remaining "common" vegetation units.

3.3 GDE SENSITIVITY AND RISK MAPPING

For the purpose of mapping the spatial distribution of risk within the study area, each community is attributed a risk rating. This process firstly involves providing an interpretation of the degree of sensitivity (or vulnerability) to hydrological change held by each community. Secondly; using this degree of sensitivity/vulnerability; produce a rating of the risk that "measurable" impact/change to a community could result from a significant degree of hydrological change. A significant degree of hydrological change may be in multiple forms, including:

- a 2-5m drop (or more) in the average groundwater height within the alluvium immediately adjacent to features of value;
- a discernible (statistically significant) reduction in catchment reporting to the river, and
- a physical obstruction to river flow significantly changing flow patterns.

A "measurable" impact is defined as detectable (beyond natural variability) changes to the health, composition and structure of riparian communities, brought about by changes to groundwater access. Natural impacts to vegetation as a result of changing water availability are common in arid riparian habitats of the Pilbara region. Such arid habitats exhibit extremes in climate and therefore local vegetation inherently possess numerous adaptive traits to facilitate their persistence. As a result, significant impacts are best defined as those changes which are able to be distinguished from the natural variability in effect at the locality. For this reason it is important to be able to distinguish anthropogenic impacts from the inherent degree of natural variation and associated riparian changes. This baseline (or natural) riparian vegetation change is generally restricted to changes in health and at times structure, but less often leading to vegetation compositional changes. As a result "measurable" impact is restricted to that level of riparian change which includes both health changes as well as at least one of either compositional (loss or addition of dominant species) or structural change in resident vegetation.

Conceptually, a significant degree of hydrological change may be best viewed as a magnitude equal to or greater than that hydrological variability experienced naturally at least every 1 to 2 decades. However at this stage, the magnitude of hydrological change, or the definition of a "measurable" impact is not the important factor. What is most important to understand is that an interpretation of sensitivity has been combined with additional influential environmental factors to attribute a risk rating. Thus; once the magnitude of potential hydrological change can be measured, the risk rating can be used as a factor by which to multiply the magnitude of hydrological change to in–turn give an idea of the potential size of the resulting ecological perturbation.

To interpret this sensitivity and therefore attribute a final risk rating; the following factors are considered:

(1) Water use strategy (i.e. obligate phreatophyte, facultative, etc.) and associated groundwater dependence associated;
(2) Obligate phreatophyte age structure (maturity);
(3) Obligate phreatophyte structural dominance;
(4) Distribution within the bed profile;
(5) Vegetation cover (i.e. stand density);
(6) Proximity to surface water; and
(7) Inherent Significance; broadly as a measure of degree of restriction, and magnitude of associated values.

Once all of these factors are considered a risk rating is attributed. This rating is attributed from a 10 tier risk scale which is presented in Table 3-2. In situations where, almost no risk was perceived to be present, a rating of Negligible was determined as the relevant rating to be attributed.

Table 3-2: Ten tier "Risk Rating" scale adapted for this study

(1) Very High	(2) Moderate
(3) High+	(4) Low-Moderate
(5) High	(6) Low+
(7) Moderate-High	(8) Low
(9) Moderate+	(10) Very Low

The final step in the risk mapping process is to incorporate a consideration of the attributed significance rating of each community and also the determined condition of each, so that a final "Residual Risk Rating" which incorporates significance and condition can represent the overall perceived risk.

3.4 LIMITATIONS OF THIS STUDY

Overarching

- For the most part the study area was easily accessed.
- Despite the dry period which was felt in the Robe Valley from approximately 2010 climaxing in mid-2016, the 2016/2017 rainfall season (but including winter rainfall in 2016) was well above average. In fact; rainfall for the May 2016 to April 2017 period totalled approximately 830 mm, which is essentially twice the annual for that area (see Figure 3-2). While this 12 month period did include the significant winter rainfall received in 2016 (230 mm from May-July), the rainfall figures are still significant, and resulted in meaningful flows in both the Robe River and Jimmawurrada Creek. As a result of the good rainfall received in the area, seasonal conditions were optimal for observing the full suite of flora species likely to inhabit the local riparian habitats. Base flow in the Robe River was anecdotally much reduced preceding (for at least 1-2 years prior) and at the time of the first survey. Rainfall/seasonal conditions and flowering/fruiting conditions were sub-optimal. In addition; the recent dry period and remaining stress indicators in riparian canopies enabled collection of information on the spatial distribution of low to moderate degrees of recent hydrological stress within facultative phreatophytes across the study area.
- The vast majority of the field work required for mapping the extent and distribution of riparian communities within Jimmawurrada Creek was successfully completed and reported upon herein. However; some of the planned outer reaches of Robe River and parts of the primary and secondary channels associated with tributaries on the more upstream end of the current Jimmawurrada Creek study area remain to be assessed with the methodology adopted in this study. Only those information requirements needed in the short term have been completed and included in addendum to the Stage 1 report. Once all riparian areas of relevance to the robe Valley are assessed (Stage 2) they will be included into one report for the Robe Valley. This final report will utilise new high-resolution aerial photography to validate mapping boundaries within the complete study area.

Desktop and Field Data Acquisition Tools

- Size classes attributed to *M. argentea* populations are a visual estimate and potentially inaccurate in some cases.

- As previously experienced limitations in the correlation between NDVI cover anomalies and FPV & OPV were again apparent for the more mesic riparian communities. This essentially determined that such communities (mainly the C1A and C1b vegetation type) were much harder to distinguish at a desktop level from that of more common mature *Eucalyptus* spp. FPV communities. In these instances; true colour aerial photo signatures and relatively comprehensive creek coverage was relied upon to minimise false negative recordings.

Ground Truthing and Vegetation Mapping Field Work

- The amount of standing water in the creek at the time of survey only restricted movement across creek in 2 situations; consequently ground truthing traverse patterns were not hindered.
- Not all species of interest were in optimal condition at the time of the survey. For the most part key eucalypt species were not regularly fruiting/flowering at the time of survey. This did hinder quick differentiation between riparian eucalypts, however, given that the study area was large, it was not feasible to differentiate between these species often enough in the field to provide meaningful differentiation at the scale of the mapping produced. As a result high resolution aerial photo signatures of *E. camaldulensis* and *E. victrix* was inevitably the key tool for mapping the distribution patterns of these two key riparian eucalypt species. However; some field data for ground-truthing aerial photo signatures was required, and where fruit was not available the following technique was used.
- Where riparian eucalypt fruit/flowers were not available, hand lenses were used to determine the identification of the resident eucalypts within a number of representative patches of vegetation via leaf anatomy. *E. camaldulensis* typically possesses true oil glands within the endoplasmic reticulum of its leaves, whereas *E. victrix* does not. Combined with the distinctive differences in lateral vein architecture of the two species (broad/sparse and wavy in *E. camaldulensis*, and tight/uniform and straight in *E. victrix*) identifications were considered accurate on all occasions rather than potentially inaccurate in certain conditions without hand lens techniques.
- Flora and vegetation data collected as part of this study came from a single phase of work and as such were not seasonally sampled.

Post Field Work Vegetation Mapping Process

- Data quantity and resolution was more than adequate for the scope of the targeted assessment.
- Coverage was more than adequate for the scope of the targeted assessment.

Mapping errors have been significantly minimised through extensive ground-truthing and 4-band aerial photo interpretations. The degree of ground-truthing effort conducted for the included groundwater dependent communities, and particularly the OPV communities, is such that the mapping is considered to be significantly more accurate than vegetation mapping typically undertaken within riparian areas.

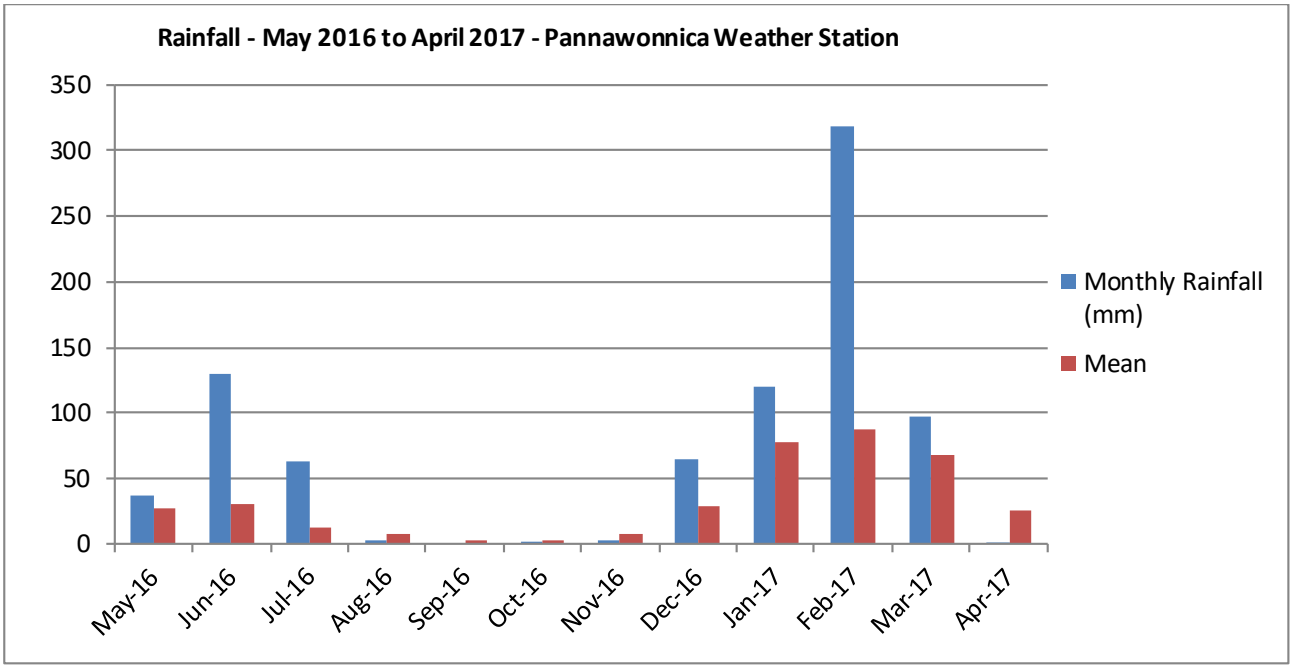


Figure 3-2: Monthly rainfall totals at Pannawonica weather station for the 12 months preceding the survey.

4 RESULTS

4.1 VEGETATION MAPPING

Table 4-1 below presents the resultant vegetation types described as part of the GDE focused vegetation mapping process. A list of the associated species recorded in each is included in Appendix 2. Representative photos of the riparian vegetation types mapped as part of this study are presented in Appendix 3. For each vegetation type mapped, multiple photos are provided in Appendix 3 to provide some indication of the degree of variation which was observed in each. Maps presenting the resultant vegetation mapping for the complete suite of Jimmawurrada Creek vegetation types are presented in Figures 4-1 to 4-4. These figures present the full degree of mapping detail resulting from stage 1 of the riparian mapping project within the Robe River and Jimmawurrada Creek.

4.1.1 Vegetation Coding

As detailed in the methods, the same coding regime as Rio Tinto (2015) was attributed to vegetation types identified in this study. To help equate the resultant vegetation types to the most recent and relevant vegetation mapping in the Sub-region, the equivalent Astron (2015, 2016) and Biota (2012) vegetation code for each vegetation type in this addendum study is provided in Table 4-1. The original codes and the hierarchy of significance which they were defined to convey in Rio Tinto (2015) have been maintained as much as possible while still allowing them to reflect the compositional findings and resultant vegetation structure identified in the study area. The most important differences between the coding of these two studies, while minor, relate to the C1AA end of the coding spectrum (communities with an overstorey dominated by obligate phreatophytes) and to the C4-C6 (differing shrublands) end of the coding spectrum. In addition; codes relating to *E. camaldulensis* dominated woodlands/open-forests were required to be integrated due to their delineation in this study and absence in Rio Tinto (2015).

4.2 GROUNDWATER DEPENDENT VEGETATION COMMUNITIES MAPPED

Broadly speaking; as you move upstream within Jimmawurrada creek, and away from the Robe River confluence, while minimal and laterally restricted, the first 2 km of Jimmawurrada creek (the majority of the topographically confined stretch of the creek) still possesses the lower significance, C1b coded OPV community of the Robe River (along with some C1A coded OPV at the mouth). By the 2.5 km mark, OPV communities are essentially absent, and while the *E. camaldulensis* and *E. victrix* dominated Woodland/Open forest communities of the Robe River still remain, they are less substantial in extent and becoming more ephemeral in nature as Jimmawurrada creek enters Bungaroo valley. As Jimmawurrada creek enters the valley, it also leaves the topographical confinement of the Mesa J range where it dissects finer valley sediments and is dominated by much smaller scale FPV riparian communities, less mesic alluvial conditions and apparently intensified grazing regimes. From the ~3 km mark the eucalypt dominated FPV communities of the Robe River transition to smaller but similar *Eucalyptus* spp.(*E. camaldulensis* and *E. victrix*) dominated communities with less mesic understorey assemblages reflective of the more ephemeral flow regimes, local grazing pressures and finer sediments. This story is replicated as you continue upstream through areas where the creek switches, in stretches, from more braided profiles to a relatively confined single channel, but where the riparian vegetation continues to be dominated by smaller scale eucalypt dominated creekline communities.

As part of the vegetation mapping process, six key types of groundwater dependent vegetation were identified. Listed in order of relative hydrological sensitivity, these are:

1. OPV-A: Vegetation dominated by mature Obligate Phreatophytes
2. OPV-B: Vegetation co-dominated by mature Obligate Phreatophytes
3. OPV-C: Vegetation co-dominated by immature Obligate Phreatophytes
4. FPV-A: Vegetation dominated by *Eucalyptus camaldulensis* (the most hydrologically sensitive local Facultative Phreatophyte) and at times supporting *Sesbania formosa*
5. FPV-B: Vegetation co-dominated by *Eucalyptus camaldulensis*
6. FPV-C: Vegetation dominated by *Eucalyptus victrix* (the second most hydrologically sensitive local Facultative phreatophyte)

These GDE types are conceptual and generally relevant to the local Pilbara environment; however the structural concepts and physiological scales which they describe can be applied more widely. It should be noted that the applied differentiation (i.e. A, B, and C) within each accepted hydrological strategy (i.e. Obligate, Facultative etc.), nor the application of water use strategy terminology to vegetation assemblages is not widely known or accepted. However; the varying degrees of groundwater availability inferred by the degrees of phreatophyte structural dominance (and maturity) which they intend to classify, are entirely relevant and a useful way of classifying groundwater dependence among vegetation types.

Table 4-1: Vegetation descriptions and GDE summary info for all riparian vegetation types mapped in the study area.

Veg Code	GDE / Community Summary Info	GDE Type	Vegetation Description	Distribution	Condition	Equivalent Astron 2015 and 2016, and Biota 2012 Code
C1A (only present at the confluence with the Robe)	Mature MA and EC dominated Open forest to Low Woodland	**OPV-B**	**Tree Strata:** *Melaleuca argentea* and *Eucalyptus camaldulensis* subsp. *refulgens* (plus scattered *Sesbania formosa*) Low open forest (to woodland in places), over **Shrub Strata:** *Melaleuca argentea*, *Petalostylis labicheoides*, *Acacia trachycarpa*, *Acacia ampliceps* and *Melaleuca glomerata* open shrubland (to shrubland in places), over **Lower Strata:** Scattered sedges/shrubs of *Cyperus vaginatus*, *Stemodia grossa* and at times; **Cenchrus ciliaris*, **Cenchrus setiger*, **Setaria verticillata* very open tussock grassland.	Consistently fringing low flow channels or scattered around moist alluvial features where groundwater appeared shallow	Excellent to Very Good	Similar to: EcMaCvCspp (Astron 2015) **or** MaEcCv (Astron 2016)
C1b	Semi-Mature MA and EC dominated Low Woodland Discharge established community within Jimmawurrada creek	**OPV-C**	**Tree Strata:** *Melaleuca argentea*, *Eucalyptus camaldulensis* subsp. *refulgens* variable low woodland (to low open woodland) (also includes low open forests of *M. argentea* & *E. camaldulensis* saplings fringing pools and channels), over; **Shrub Strata:** *Melaleuca argentea*, *Petalostylis labicheoides*, *Acacia trachycarpa*, and *Melaleuca glomerata* variable open shrubland to shrubland, over; **Lower Strata:** *Cyperus vaginatus* scattered sedges, over *Stemodia grossa* scattered low shrubs.	Scattered along low flow or secondary channels of Jimmawurrada Creek, including some high flow channels	Very Good	Similar to: EcMaCvCspp (Astron 2015) **or** similar to MaEcCv (Astron 2016)
C1bb	Semi-Mature MA and EC dominated Low Woodland Baseline community; some discharge influence	**OPV-C**	**Veg description equal to C1b (above)**	Located along a small stretch of the low flow channel at the mouth of Jimmawurrada creek with its confluence with the Robe River	Very Good	Similar to: EcMaCvCspp (Astron 2015) **or** similar to MaEcCv (Astron 2016)

Veg Code	GDE / Community Summary Info	GDE Type	Vegetation Description	Distribution	Condition	Equivalent Astron 2015 and 2016, and Biota 2012 Code
C2A	EC dominated Open Forest	**FPV-A**	**Tree Strata:** *Eucalyptus camaldulensis* subsp. *refulgens* open forest (to low open forest with scattered *Eucalyptus victrix* and at times *Sesbania formosa*), over; **Shrub Strata:** *Petalostylis labicheoides*, *Acacia trachycarpa*, *Melaleuca glomerata* and *Acacia ampliceps* tall shrubland (to tall open shrubland in places), over; **Lower Strata:** *Cyperus vaginatus* scattered sedges and in places **Cenchrus ciliaris*, **Cenchrus setiger*, **Setaria verticillata* very open tussock grassland.	Consistently scattered along low flow channels, secondary channels and terrace features of the terminal (downstream) stretches of Jimmawurrada creek	Very Good to Good	Similar to: EcCv (Astron 2015) **or** EcEvAtrApyPlTw (Astron 2016)
C2A-Cr	**C2AA-Cr**	EC dominated woodland to open forest - Creek	**FPV-A**	**Tree Strata:** *E. camaldulensis* woodland to open forest (with scattered to isolated *Sesbania formosa* low trees in mesic areas), over; **Shrub Strata:** Mixed tall open shrubland (to shrubland in places) of *Acacia trachycarpa*, *Melaleuca glomerata*, *M. bracteata*, and *Gossypium robinsonii* (with scattered *Ficus aculeata*, *Phyllanthus baccatus* and *Phoenix dactylifera* in more mesic zones; outer areas often dominated by *Acacia colei*), over; **Lower Strata:** Variable understorey of *C. vaginatus* open sedgeland, patchy **Cenchrus ciliaris* & **C. setiger* open tussock grassland, over *Triodia epactia/T. longiceps/T. angusta* scattered hummock grasses, (with low lying wet areas typically dominated by *Typha domingensis* and other emergent macrophytes).	Scattered along low flow channels, secondary channels and terrace features of Jimmawurrada Creek in the moister reaches of Jimmawurrada Creek	Poor	Similar to: EcEvMgCYPvCEc (Biota 2012)
	C2A-Cr	EC dominated woodland to open forest - Creek	**FPV-A**	**Tree Strata:** *E. camaldulensis* woodland to open forest, over; **Shrub Strata:** Mixed tall open shrubland (to shrubland in places) of *Acacia trachycarpa*, *Melaleuca glomerata*, *A. bivenosa*, and *Gossypium robinsonii* (with outer patches often dominated by *A. colei*), over; **Lower Strata:** Variable understorey of *Cyperus vaginatus* very open sedgeland, over patchy **Cenchrus ciliaris* & **C. setiger* open tussock grassland, over *Triodia epactia/T. longiceps/T. angusta* scattered hummock grasses.	Consistently scattered along low flow channels, secondary channels and terrace features of Jimmawurrada Creek	Poor	Similar to: EcEvMgCYPvCEc (Biota 2012)

Veg Code		GDE / Community Summary Info	GDE Type	Vegetation Description	Distribution	Condition	Equivalent Astron 2015 and 2016, and Biota 2012 Code
C2A-SW		EC dominated woodland/Mesic open shrubland	**FPV-A**	**Tree Strata:** *Eucalyptus camaldulensis* woodland (generally dominated by relatively young to semi-mature individuals - to open forest in places), over; **Shrub Strata:** Mixed shrubland to open shrubland of *Acacia sclerosperma*, *Melaleuca glomerata* and *Melaleuca bracteata* (*Acacia ampliceps*), over; **Lower Strata:** *Triodia angusta/Triodia longiceps* very open hummock grassland, over *Cyperus vaginatus* very open sedgeland.	Scattered patches occurring in low lying areas within the large Sump/Wetland zone present on the southern floodplain of Bungaroo Creek	Very Good	Similar to: Wetland-Mosiac (Biota 2012)
C2B		EC & EV co-dominated Open Forest	**FPV-B**	**Tree Strata:** *Eucalyptus camaldulensis* subsp. *refulgens*, *E. victrix* open forest (to woodland in places), over; **Shrub Strata:** *Acacia trachycarpa*, *Petalostylis labicheoides* and *Melaleuca glomerata* tall open shrubland (to tall shrubland in places), over; **Lower Strata:** **Cenchrus ciliaris*, **Cenchrus setiger* (**Setaria verticillata*) very open (to open) tussock grassland with scattered sedges of *Cyperus vaginatus*.	Scattered throughout the bed, but often along secondary channels and banks of the terminal reaches of Jimmawurrada Creek including high flow channels	Good to Poor	Similar to: EcEvCspp (Astron 2015) **or** EcEvAtrApyPlTw (Astron 2016)
C2B-Cr	**C2BB-Cr**	EC & EV dominated woodland - Creek	**FPV-B**	**Tree Strata:** *Eucalyptus victrix* and *E. camaldulensis* woodland (to open forest in places; with isolated *Sesbania formosa* low trees in mesic areas), over; **Shrub Strata:** Mixed tall open shrubland of *Acacia trachycarpa*, *Acacia colei*, *Gossypium robinsonii*, *Melaleuca glomerata* (*M. bracteata*), (with isolated *Ficus aculeata*, *Phyllanthus baccatus* and *Phoenix dactylifera* in more mesic zones), over; **Lower Strata:** Variable understorey of **Cenchrus ciliaris* open tussock grassland (to tussock grassland), and patchy *Cyperus vaginatus* open sedgeland, with *T. epactia/T. longiceps/T. angusta* scattered hummock grasses (with low lying wet areas typically dominated by *Typha domingensis* and other emergent macrophytes).	Scattered throughout the bed, but often along secondary channels and banks, and high flow channels of the moister reaches of Jimmawurrada Creek	Poor to Very Poor	Similar to: EcEvMgCYPvCEc (Biota 2012)
	C2B-Cr	EC & EV dominated woodland - Creek	**FPV-B**	**Tree Strata:** *Eucalyptus victrix* and *E. camaldulensis* woodland (to open forest in places), over; **Shrub Strata:** Mixed scattered to tall open shrubland of *Acacia trachycarpa*, *Acacia colei*, *Gossypium robinsonii*, *Acacia bivenosa*, and *Melaleuca glomerata*, over;	Scattered throughout the bed, but often along secondary channels and banks, and high flow channels of Jimmawurrada Creek	Poor	Similar to: EcEvMgCYPvCEc (Biota 2012)

Veg Code	GDE / Community Summary Info	GDE Type	Vegetation Description	Distribution	Condition	Equivalent Astron 2015 and 2016, and Biota 2012 Code
			Lower Strata: Variable understorey of **Cenchrus ciliaris* open tussock grassland (to tussock grassland), and patchy *Cyperus vaginatus* very open sedgeland, with *Triodia epactia/T. longiceps/T. angusta* scattered hummock grasses.			
C2A-B	EC dominated Woodlands	**FPV-A**	**Tree Strata:** *Eucalyptus camaldulensis* subsp. *refulgens* woodland (to open forest in places), over; **Shrub Strata:** *Acacia trachycarpa*, *Petalostylis labicheoides* (*Acacia pyrifolia*, *Gossypium robinsonii*) tall open shrubland (plus *Melaleuca glomerata* in some areas), over; **Lower Strata:** **Cenchrus ciliaris*, **Cenchrus setiger* very open (to open) tussock grassland (plus scattered *Cyperus vaginatus* and *Stemodia grossa* and at times very open hummock grassland of *Triodia epactia* & *T. wiseana*).	Scattered throughout the bed, but often along secondary channels and banks of the terminal reaches of Jimmawurrada Creek	Good	Similar to: EcCv (Astron 2015) **or** EcEvAtrApyPlTw (Astron 2016)
C2B-B	EC & EV co-dominated Woodland	**FPV-B**	**Tree Strata:** *Eucalyptus camaldulensis* subsp. *refulgens*, *Eucalyptus victrix* woodland (to low woodland), over; **Shrub Strata:** *Acacia trachycarpa*, *Petalostylis labicheoides* (*Acacia pyrifolia*, *Gossypium robinsonii*) tall open shrubland (plus *Melaleuca glomerata* in some areas), over; **Lower Strata:** **Cenchrus ciliaris*, **Cenchrus setiger* very open (to open) tussock grassland (plus scattered *Cyperus vaginatus* and *Stemodia grossa* and at times very open hummock grassland of *Triodia epactia* & *T. wiseana*).	Scattered throughout the bed, often along secondary channels and banks of the terminal reaches of Jimmawurrada Creek, including some minor tributaries & high flow channels	Good to Poor	Similar to: EcEvCspp (Astron 2015) **or** EcEvAtrApyPlTw (Astron 2016*)
C2C	EV Dominated Woodland	**FPV-C**	**Tree Strata:** *Eucalyptus victrix* woodland (to low woodland with scattered *E. camaldulensis*), over; **Shrub Strata:** *Acacia trachycarpa*, *Petalostylis labicheoides* (*Acacia pyrifolia*) tall open shrubland (to scattered tall shrubs in places), over; **Lower Strata:** **Cenchrus ciliaris*, **Cenchrus setiger* very open (to open) tussock grassland (and at times very open hummock grassland of *Triodia epactia* & *T. wiseana*).	Scattered throughout the bed, often along secondary channels and banks of the terminal reaches of Jimmawurrada Creek, including some minor tributaries & high flow channels	Good to Poor	Similar to: EvMgCv (Astron 2015) **or** EvAtrTwCspp (Astron 2016)

Veg Code	GDE / Community Summary Info	GDE Type	Vegetation Description	Distribution	Condition	Equivalent Astron 2015 and 2016, and Biota 2012 Code
C2C-Cr	EV dominated Low Woodland - Creek	**FPV-C**	**Tree Strata:** *Eucalyptus victrix* low woodland (to low open woodland), over; **Shrub Strata:** *Acacia trachycarpa*, *A. bivenosa* and *A. colei* scattered tall shrubs (to tall open shrubland), over; **Lower Strata:** **Cenchrus ciliaris* tussock grassland (with patches of *Cyperus vaginatus* very open sedgeland), over *Triodia longiceps* and *Triodia epactia* scattered hummock grasses (to open hummock grassland).	Scattered throughout the bed, often along secondary channels and banks of Jimmawurrada Creek, including some minor tributaries	Poor to Very Poor	Similar to: EcEvMgCYPvCEc (Biota 2012)
C2C-SW1	EV dominated Woodland/Mesic Shrubland	**FPV-C**	**Tree Strata:** *Eucalyptus victrix* woodland (generally dominated by relatively young individuals - to low woodland), over; **Shrub Strata:** Mixed shrubland to open shrubland of *Acacia sclerosperma*, *Melaleuca glomerata*, *M. bracteata* and *Acacia colei*, over; **Lower Strata:** *Triodia angusta*/*Triodia longiceps* very open hummock grassland.	Scattered patches occurring in low lying areas within the large Sump/Wetland zone present on the south floodplain of Bungaroo creek	Very Good	Similar to: Wetland-Mosiac (Biota 2012)
C2C-SW2	EV & CH dominated Woodland/ Mesic open shrubland	**FPV-C**	**Tree Strata:** *Eucalyptus victrix* & *Corymbia hamersleyana* low open woodland (to low woodland in places), over; **Shrub Strata:** *Acacia trachycarpa*, *A. bivenosa* and *A. colei* and *A. sclerosperma* tall open shrubland, over; **Lower Strata:** *Triodia longiceps* and *Triodia angusta* open hummock grassland (to very open hummock grassland).	Fringing patches (ecotonal communities) occurring surrounding C2A and C2C communities within the Sump/Wetland area	Good to Very Good	Similar to: Wetland-Mosiac (Biota 2012)
C3A	EC & EV co-dominated Open woodland	**FPV-B**	**Tree Strata:** *Eucalyptus camaldulensis* subsp. *refulgens*, *Eucalyptus victrix* open woodland (to scattered trees in places), over; **Shrub Strata:** *Acacia trachycarpa*, *Petalostylis labicheoides* (*Acacia pyrifolia*) tall shrubland (to tall open shrubland), over; **Lower Strata:** Gravel beds at times colonised by **Cenchrus ciliaris*, **Cenchrus setiger* very open (to open) tussock grassland (at times including a very open hummock grassland of *Triodia epactia* & *T. wiseana*).	Scattered throughout the drier, often elevated sections of the terminal stretches of Jimmawurrada creek and associated tributaries	Good to Poor	Similar to: EcEvCspp (Astron 2015) **or** similar to EcEvAtrApyPlTw (Astron 2016*)

Veg Code	GDE / Community Summary Info	GDE Type	Vegetation Description	Distribution	Condition	Equivalent Astron 2015 and 2016, and Biota 2012 Code
C3B	EV Dominated Open Woodland	**FPV-C**	**Tree Strata:** *Eucalyptus victrix* low open woodland (to scattered trees in places), over; **Shrub Strata:** *Acacia trachycarpa*, *Petalostylis labicheoides* (*Acacia pyrifolia*) tall shrubland (to tall open shrubland), over; **Lower Strata:** Gravel beds at times colonised by **Cenchrus ciliaris*, **Cenchrus setiger* very open (to open) tussock grassland (at times including a very open hummock grassland of *Triodia epactia* & *T. wiseana*).	Scattered throughout the drier, often elevated sections of the terminal stretches of Jimmawurrada Creek	Good	Similar to: EvMgCv (Astron 2015) **or** EvAtrTwCspp (Astron 2016)
C3B-Cr	EV & CH dominated Low Open Woodland - Creek	**FPV-C**	**Tree Strata:** *Eucalyptus victrix*, *Corymbia hamersleyana* low open woodland (to woodland in places), over; **Shrub Strata:** *Gossypium robinsonii*, *Acacia colei*, *A. sclerosperma*, *Petalostylis labicheoides* open shrubland (to tall open scrub in places), over; **Lower Strata:** **Cenchrus ciliaris* open tussock grassland, over variable open hummock grassland of *Triodia epactia*, *T. wiseana*, and *T. angusta*.	Scattered throughout the drier, often elevated sections and floodplain zones of Jimmawurrada Creek	Poor to Good	Similar to: EcEvMgCYPvCEc (Biota 2012)
C3C-Cr	CH scattered low trees/ Variable Open Shrubland	**FPV-C**	**Tree Strata**: *Corymbia hamersleyana* scattered low trees (to low open woodland in places; at times with scattered *Eucalyptus victrix*), over; **Shrub Strata:** Variable open shrubland (to scattered shrubs) of *Acacia trachycarpa*, *A. sclerosperma*, *A. bivenosa*, and *A. synchronicia*, over; **Lower Strata:** Variable understorey; open hummock grassland of *T. epactia*/*T. longiceps*/*T. angusta* (and mixes), with patches of **Cenchrus ciliaris* & **C. setiger* very open tussock grassland.	Scattered throughout areas fringing the outer high flow channels and occurring on elevated sections and floodplain zones of Jimmawurrada Creek	Good	Similar to: EcEvMgCYPvCEc (Biota 2012)
C4	Shrublands	**Vadophytic**	**Tree Strata:** N/A **Shrub Strata:** *Acacia trachycarpa*, *Petalostylis labicheoides* (*Acacia pyrifolia*) tall shrubland (to tall open shrubland), over; **Lower Strata:** Gravel beds generally dominated by scattered mixed grasses and herbs; but at times colonised by **Cenchrus ciliaris*, **C. setiger* very open (to open) tussock grassland and *Triodia epactia* very open hummock grassland.	Scattered throughout the terminal stretches of Jimmawurrada Creek on terrace zones; often associated with periodically scoured bed formations	Good to Very Good	Similar to: AtrEs & AtTeCc (Astron 2015) **or** AtrPl (Astron 2016)

Veg Code	GDE / Community Summary Info	GDE Type	Vegetation Description	Distribution	Condition	Equivalent Astron 2015 and 2016, and Biota 2012 Code
C5	Beds with minimal vegetation	**Vadophytic**	**Tree Strata:** Expansive open gravel beds with isolated trees, over; **Shrub Strata:** Isolated to scattered tall shrubs of *Acacia trachycarpa*, *Petalostylis labicheoides*, over; **Lower Strata:** Variable; Scattered herbs of *Euphorbia schultzii*.	Scour zones present throughout the terminal stretches of Jimmawurrada Creek; in preferential flow zones where scouring is high	Excellent	Similar to: AtrEs (Astron 2015) **or** Es (Astron 2016)
C6	Shrublands	**Vadophytic / Xerophytic**	**Tree Strata:** N/A **Shrub Strata:** Variable; tall shrubland (to tall open shrubland) of *Acacia trachycarpa*, *A. pyrifolia* & *Petalostylis labicheoides* (dominating riparian fringes); *A. bivenosa*, *A. inaequilatera*, *A. synchronicia* & *A. ancistrocarpa* with scattered *Corymbia hamersleyana* low trees (dominating terraces), over; **Lower Strata:** Variable grasslands: **Cenchrus ciliaris*, **Cenchrus setiger* open tussock grassland and *Triodia epactia* (*T. wiseana*) very open hummock grassland (fringing riparian zones); *T. wiseana* (*T. epactia*) open hummock grassland (on terraces).	Distributed throughout the terminal stretches of Jimmawurrada Creek on the terrace and high flow channel zones	Good to Very Good	Similar to: AtTeCc & ChAsppTwTe (Astron 2015) **or** ChAsppGOrGsppPlSsTeTw & ChPlAbGOrTw (Astron 2016)
C7-SW	Mesic Tall open scrub/ Scattered trees	**FPV-C**	**Tree Strata:** *Eucalyptus victrix*, *E. camaldulensis* and *Corymbia hamersleyana* scattered low trees (to low open woodland in places), over; **Shrub Strata:** *Melaleuca bracteata*, *Acacia ampliceps*, *M. glomerata* (*A. sclerosperma*) tall open scrub (to tall closed scrub or tall shrubland), over; **Lower Strata:** *Cyperus vaginatus* scattered sedges over *Triodia angusta*/*Triodia longiceps* scattered hummock grasses (to very open hummock grassland).	Fringing shrublands occurring surrounding and intermingling with C2A and C2C communities within the Sump/Wetland area, often where clay levels are high and ponding is more persistent	Very Good	Similar to: Wetland-Mosiac (Biota 2012)
CL-SW	Mixed open shrublands on clay pans	**Vadophytic**	**Tree Strata:** **N/A (**Clay Pan Habitats) **Shrub Strata:** Mixed open shrublands (*Acacia sclerosperma*, *Melaleuca glomerata*, *Acacia bivenosa*, *A. colei*), over; **Lower Strata:** Very open hummock grasslands of *Triodia longiceps*/*Triodia angusta* on open clay sumps. These areas often include populations of the Priority species *Eragrostis surreyana* (P2).	Clay pan habitats often occurring in low lying clay rich habitats within the Sump/Wetland area	Good to Very Good	Similar to: Wetland-Mosaic (Biota 2012)

Veg Code	GDE / Community Summary Info	GDE Type	Vegetation Description	Distribution	Condition	Equivalent Astron 2015 and 2016, and Biota 2012 Code
F1	C.H. Scattered trees/*T. wiseana* Hummock grassland	**Vadophytic**	**Tree Strata:** *Corymbia hamersleyana* scattered low trees, over; **Shrub Strata:** *Acacia* spp. scattered shrubs, over; **Lower Strata:** *Triodia wiseana* hummock grassland.	Scattered throughout floodplain habitats and outer riparian margins of Jimmawurrada Creek	Good to Very Good	* **ChAspp.Tw (Biota 2012)**
F2	*A. synchronicia* Tall open shrubland.	**Vadophytic**	**Tree Strata:** - **Shrub Strata:** *Acacia synchronicia* tall open shrubland, over; **Lower Strata:** *Triodia epactia* hummock grassland over **Cenchrus setiger* open tussock grassland.	Scattered throughout floodplain habitats and outer riparian margins of Jimmawurrada Creek; often where clay-loam substrates are prevalent.	Good to Poor	* **AsyTeCEs (Biota 2012)**
F3	*A. xiphophylla* low open woodland	**Vadophytic**	**Tree Strata:** - **Shrub Strata:** *Acacia xiphophylla* low open woodland, over; **Lower Strata:** *Triodia epactia* open hummock grassland.	Scattered in stony plain habitats where substrate conditions are atypical and often clay rich.	Excellent to Very Good	* **AxTe (Biota 2012)**
F4	C.H. Scattered trees/*T. epactia* Hummock grassland	**Vadophytic**	**Tree Strata:** *Corymbia hamersleyana* scattered trees, over; **Shrub Strata:** *Acacia inaequilatera* scattered tall shrubs, over; **Lower Strata**: *Triodia epactia* hummock grassland.	Scattered shrublands fringing floodplain zones and areas where tributaries and adjacent flow zones meet floodplains of Jimmawurrada creek	Very Good	* **ChAiTe (Biota 2012)**
F5	*Acacia* spp. Tall Shrubland/*T. epactia* Hummock grassland	**Vadophytic**	**Tree Strata:** *Corymbia hamersleyana* scattered trees, over; **Shrub Strata:** *Acacia synchronicia, A. bivenosa* tall shrubland, over; **Lower Strata:** *Triodia epactia* hummock grassland.	Scattered shrublands fringing floodplain zones and outer margins of adjacent tributaries of Jimmawurrada creek	Very Good	* **ChAsyAbTe (Biota 2012)**

Veg Code	GDE / Community Summary Info	GDE Type	Vegetation Description	Distribution	Condition	Equivalent Astron 2015 and 2016, and Biota 2012 Code
F6	*Acacia* spp. open shrublands/*T. epactia* hummock grassland	**Vadophytic**	**Tree Strata:** - **Shrub Strata:** *Acacia sclerosperma*, *A. synchronicia* open shrubland, over; **Lower Strata:** *Triodia epactia* hummock grassland.	Scattered shrublands fringing moist floodplain zones and outer margins of adjacent tributaries of Jimmawurrada creek	Excellent to Very Good	* **AsclAsyTe (Biota 2012)**
H1	EL Scattered Trees/*T. wiseana* hummock grassland	**Vadophytic**	**Tree Strata:** *Eucalyptus leucophloia* scattered low trees, over; **Shrub Strata:** *Acacia inaequilatera*, *A. bivenosa* scattered tall shrubs, over; **Lower Strata:** *Triodia wiseana* hummock grassland.	Scattered in areas where hillslope habitats are adjacent to creek habitats of Jimmawurrada Creek.	Excellent	* **ElAiAbTw (Biota 2012)**
HD	Highly Disturbed Ground - Cleared	-	**Tree Strata:** - **Shrub Strata:** - **Lower Strata:** -	-	Completely Degraded	N/A

Equivalent codes from: (1) Astron Environmental Services Pty Ltd. (2015). Middle Robe and East Deepdale Level 2 Vegetation and Flora Assessment. **(2)** Astron Environmental Services Pty Ltd. (2016). Mesa H flora level 2 flora and vegetation survey, May 2016. **(3)** Biota, Environmental Sciences (2012). Greater Bungaroo Flora and Vegetation Survey.

* Denotes that vegetation descriptions and codes were applied directly from Biota (2012) (i.e. were exactly equivalent), as units broadly related to fringing communities to the core riparian zone.

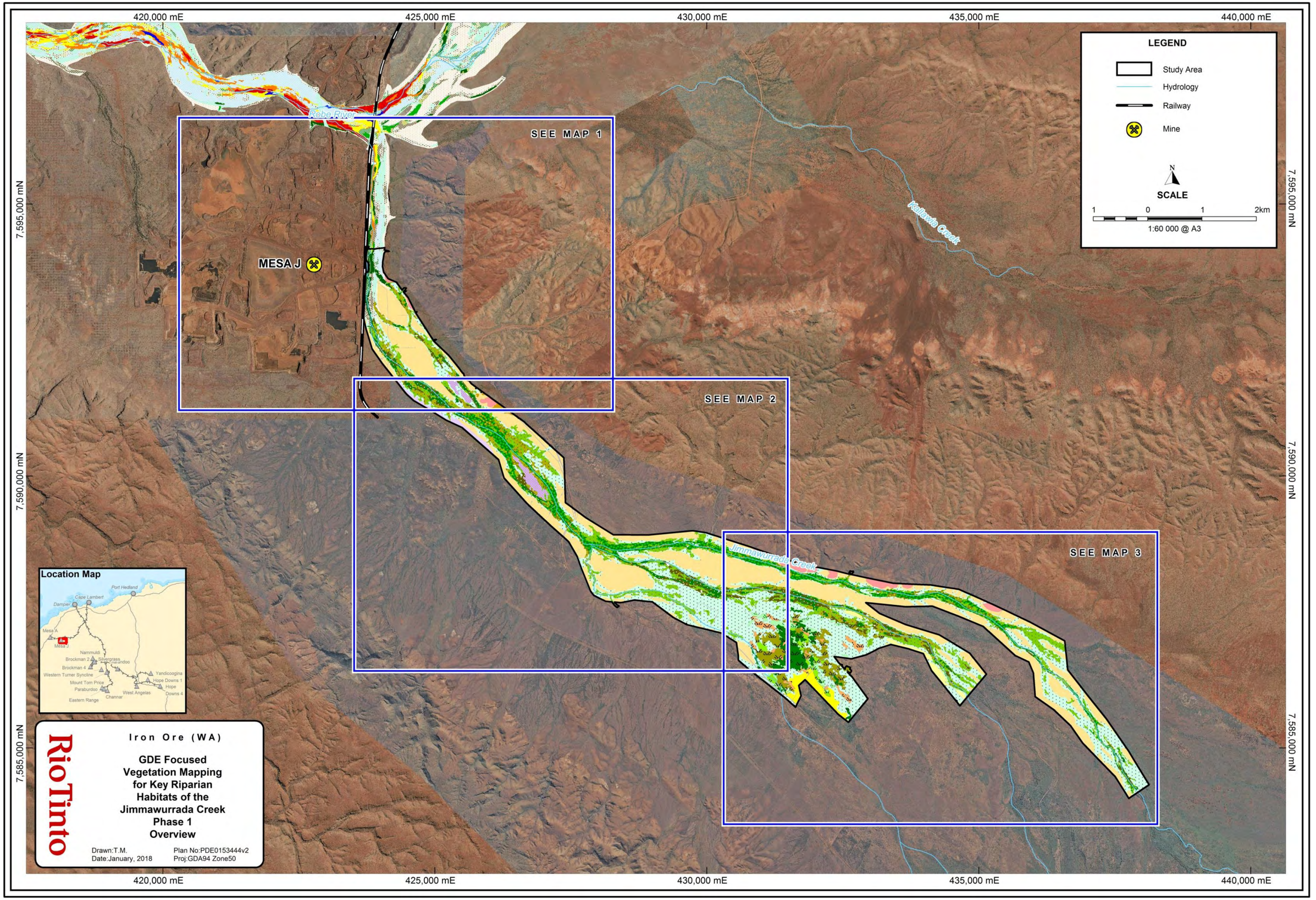


Figure 4-1: **Overview map with the layout of the 3 maps showing the results of the Jimmawurrada Creek riparian vegetation mapping project.**

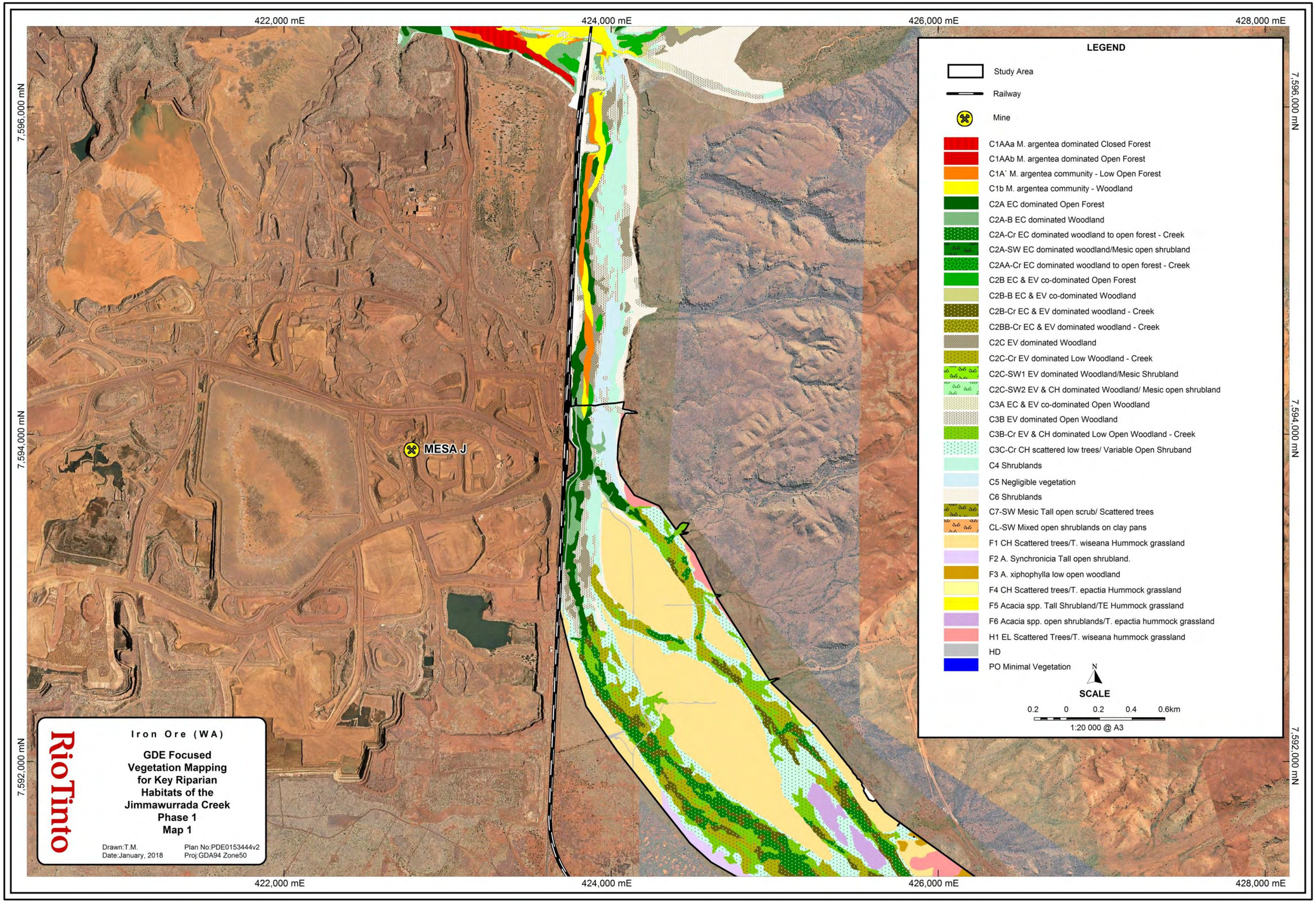


Figure 4-2: Results of the riparian vegetation mapping of Jimmawurrada Creek; Map 1 of 3

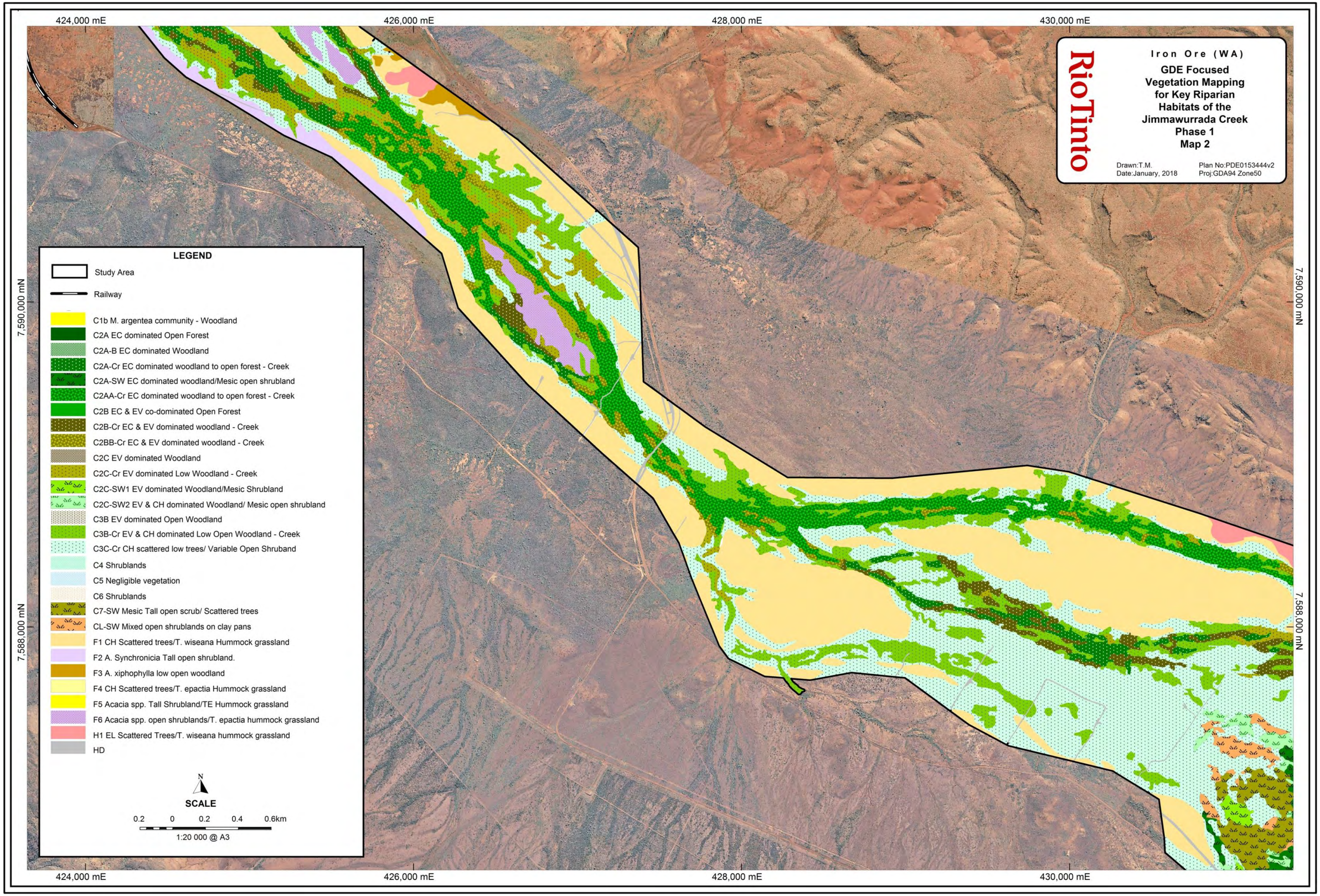


Figure 4-3: Results of the riparian vegetation mapping of Jimmawurrada Creek; Map 2 of 3

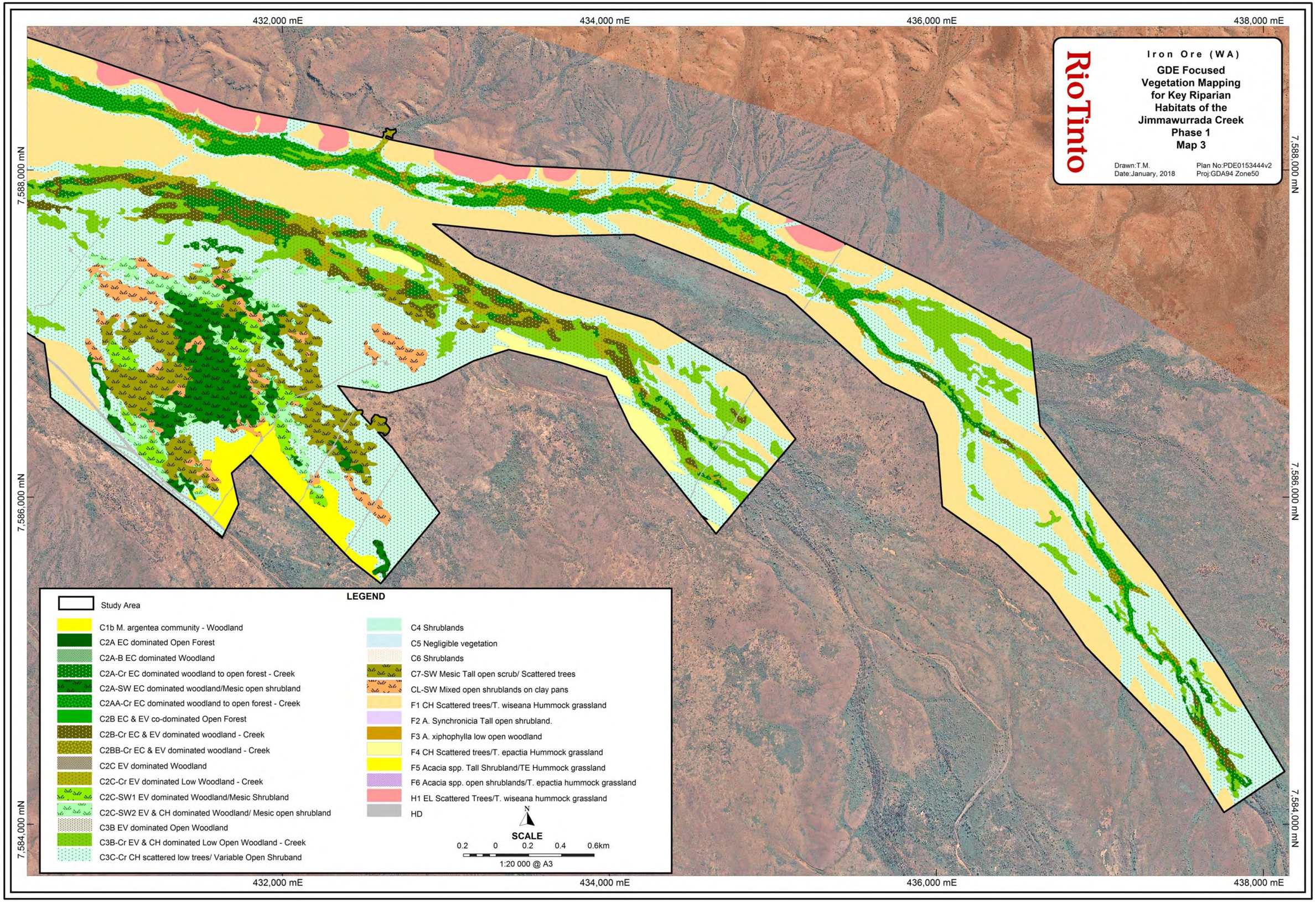


Figure 4-4: Results of the riparian vegetation mapping of Jimmawurrada Creek; Map 3 of 3

4.3 SIGNIFICANCE OF THE RIPARIAN VEGETATION COMMUNITIES IN THE STUDY AREA

The large distances traversed during the field survey enabled a relatively comprehensive understanding of the structure, composition and distribution of key riparian communities throughout the study area. Through this process a thorough appreciation of the ecological values and significance held by vegetation communities within Jimmawurrada Creek was also attained. From this combined experience a number of communities of note, significance or elevated hydrological sensitivity were identified.

While some stretches of Jimmawurrada Creek were observed to possess a series of ephemeral pools with increased persistence, these intermittent pools were very small scale features and were observed upstream and beyond the modelled influence of the Mesa H proposal; from the 12km (from the Robe River Confluence) mark onwards upstream. Due to the fact that strictly intermittent, ephemeral pools (no permanent or semi-permanent pools), have been identified along the 12 km section of Jimmawurrada Creek nearest to Mesa J, the predicted drawdown will not have a direct impact to these intermittent pools; these pools are broadly surface water driven. Furthermore; ephemeral pool representations present on Jimmawurrada creek were observed to be substantially degraded due to grazing pressures present in the broader valley. While similar grazing pressures may be present on the Robe River, the abundance of semi-permanent (and permanent) water features on the Robe River in combination with the River's broader extent and gravel dominated substrates determines that pool habitats on the Robe River maintain significantly better condition. While small-scale, potentially semi-permanent water features were noted and recorded in upstream parts of the study area; subsequent visits later in the year (as part of other work) confirmed they had dried up, and so were not noted as part of the riparian vegetation mapping process. In all cases such areas were deemed unlikely to consistently hold water and were suffering from reduced mesic species diversity, weed infestation, minor erosion, and the general effects of significant trampling and grazing. For these reasons, unlike the pool features mapped on the Robe River, the mesic areas on Jimmawurrada creek were not deemed to be relevant for or significant enough to be mapped. At the time of survey and generally as a result of the well above average wet season of 2016/2017; Jimmawurrada Creek was showing good signs of recovery (mainly in the canopies of riparian trees) from the significant dry period noted within the Robe River mapping component (Rio Tinto 2018b) to culminate in 2016. Despite this observed canopy recovery; drought-induced canopy decline evidence in the form of overstorey sections maintaining substantial numbers of dead branches were still evident among the new growth.

The physical characteristics of the study area in comparison to the Robe River (creekline as opposed to riverine habitats), changed significantly once Jimmawurrada creek was no longer confined by the range features (forming a gorge like feature adjacent to Mesa J) which also constrict the Robe River in this locality. Despite this, the first 3-4 km of Jimmawurrada creek (extending from the confluence) is still tightly confined by these features and as such many of the vegetation units mapped within the Robe River continued through this area. Once within Bungaroo valley, the substrates of Jimmawurrada Creek are instead dominated by fine sediments, and as a result the supported shrub and understorey assemblages changed as well. As a result new creekline vegetation units were mapped for similar overstorey structures and assemblages mapped along the Robe. These units tried to follow the coding of the Robe River units but in this case with the "Cr" (creekline) tag added. For this reason the "Cr" coded units generally possessed a similar significance rating as their broadly equivalent Robe river relatives. However in the case of the creekline units, the relevant significance of each was diminished due to the significant grazing pressures they exhibited. Of the Creekline units the most significant were represented by the C2AA-Cr

unit which was attributed a "Moderate" significance rating. The majority of the more structurally dense riparian communities on Jimmawurrada Creek were attributed a Minor-Moderate significance rating.

A Sump/Wetland type mosaic of communities was recorded in the south east of the study area and relevant units associated with this community were attributed the "SW" coding tag. This area possesses a mosaic of several vegetation sub-associations restricted to a large soak type feature which lies approximately 7 km south east of the Mesa H development envelope. The area possesses various combinations of open *Eucalyptus victrix*/*E. camaldulensis* forest/woodland, *Melaleuca bracteata*/*M. glomerata* and *Acacia ampliceps*/*A. sclerosperma* tall shrubland to tall open scrub and *Triodia longiceps* and *T. angusta* hummock grasslands.

Five separate communities were mapped in relation to Sump/Wetland area. The C7-SW (scrub community) and C2A-SW (woodland/open-forest community) were both attributed a Moderate-High significance rating due to the highly restricted nature of such habitats and associations within the Pilbara. Of particular note was the C7-SW Open-scrub community dominated by mesic shrub species such as *Melaleuca bracteata* and *Acacia ampliceps*. This community is unusual and very rare outside of riverine/creekline environments. The communities present in this Sump/wetland area suggest that either the broader groundwater table, or a perched aquifer on a clay lens is providing consistently shallow groundwater access in this area.

While some representations of the significant C1B coded community (attributed a Moderate-High significance rating) was mapped to occur in the first 2-3 km of Jimmawurrada Creek, it seems reasonably clear from surveys conducted by Trudgen (1991) (pre-discharge at Mesa J) that these communities have established as a result of the surplus water discharge (augmenting resident phreatophytic vegetation) which has been introduced to this section of Jimmawurrada Creek for approximately 15 years. Prior to surplus mine water discharge and the construction of the Mesa J rail line (which intersects the original confluence point of Jimmawurrada Creek with the Robe River), a baseline flora and vegetation survey was conducted by Trudgen (1991). This survey stated that with respect to the flowlines of Jimmawurrada Creek, near the Robe River there was a woodland of *Eucalyptus camaldulensis* with occasional *Melaleuca argentea* scattered within, but that the remainder was free of obligate phreatophytes.

Data gathered within the vegetation on Jimmawurrada Creek along the first 2 km suggested that the age structure within Obligate Phreatophytic Species (**OPS**) populations in the area were quite even, and in general "semi-mature" in nature, with populations at the northern end near the confluence approaching or at times becoming "mature" with respect to their diameter at Breast height (DBH). *Melaleuca argentea* has been proven as a very fast growing species (Rio Tinto 2015), and data suggests that semi-mature individuals are able to establish in approximately 10+ years from a sapling. As a result it is suggested that those individuals recorded in Jimmawurrada Creek as currently equivalent to or bordering upon being "mature" (in DBH) are likely to represent those scattered individuals which were present pre-discharge; with the remainder having established since mining and discharge has begun. For this reason OPV near the mouth of Jimmawurrada Creek and recently recorded as possessing populations bordering on that equivalent to the C1A community have instead been mapped as the C1bb community, and described as being apparently representative of a baseline C1b community with discharge influence. In addition; the remainder of OPV within Jimmawurrada Creek has been mapped as C1b coded vegetation and described as a discharge established community due to its apparent absence pre-discharge. The key justification for this is that there is enough evidence to suggest that the structure, density and maturity levels of baseline communities in this section of Jimmawurrada Creek would at best have been consistent with C1b coded OPV and current day age structure and maturity levels are not clearly representative of the C1A

community unit especially in light of its general absence pre-discharge. Regardless of the mapping decisions made, a substantial proportion of the significance associated with these communities is associated with the perennial groundwater availability in such areas. As a result, the maintenance of intermittent discharge in this area should help maintain these values and the associated communities which appear to have established under the influence of mining and elevated rainfall conditions.

The results of the field work and vegetation mapping exercise were used to contribute to an assessment of the significance of each of the communities mapped to occur within the study area. The significance value attributed to each community is derived from consideration of the factors deemed to be relevant when considering vegetation significance, and which are presented in Section 2.3. To do this in a relatively systematic qualitative manner the significance values attributed within this study followed a local significance framework developed in Rio Tinto 2015, adapted within this study and presented in Section 3.2.

This Framework incorporates an assessment of the ecological values provided, the distribution or degree to which it is represented in the environment (local, sub-regional, regional), the condition, and the sensitivity to change of each community mapped within the study area.

The results of the significance assessment are presented in Table 4-3 below. It should be noted that Table 4-3 does not provide an indication of conservation significance, rather provides a relative ranking in the locality for the context of this study.

Table 4-2: Significance ratings attributed to each community mapped in the study area and the associated factors contributing to assigned significance ratings.

Vegetation Code	Broad Vegetation Type	GDE Classification	Associated Ecological Values	Distribution/Representation/Rarity & Presence in the Pilbara environment	Initial Local Significance	Condition	Sensitivity to Relevant Impacts	Resultant Significance Rating
C1A	Mature *Melaleuca argentea* and *Eucalyptus camaldulensis* dominated Open forest to Low Woodland	OPV-B	Relatively mature mesic woodland habitat.	**Locally and somewhat sub-regionally restricted and significant.**	**Moderate-high**	**Excellent to Very Good**	**High**	**High**
			Perennial groundwater availability, with some scattered semi-permanent pools also associated.	The rocky rangeland river variant of this community is uncommon and relatively restricted within the Hamersley sub-region. Larger areal extent representations of this community are restricted in the Hamersley sub-region. The unique substrates and adjacent rocky habitats which potentially support this community make it relatively unique when compared to riverine representations occurring in the wider Pilbara Bioregion.				
			Above average to High mesic flora species diversity.					
			Cryptic and conservation significant fauna habitat (likely to include the Pilbara olive python, Northern Quoll, and potentially the Ghost Bat, and Pilbara leaf nosed bat).					
			Cryptic and conservation significant flora species habitat (e.g. *Livistona alfredii*).					
			High subsurface aquatic invertebrate diversity.					
			High local avifauna and bat species diversity.	**Potentially significant from biological and cultural standpoints.**				
			Some reduced value from direct and indirect impacts.					
			Some reduced value from direct impacts (e.g. tracks & rail line footings) and cumulative impact. Some vegetation augmentation from surplus water discharge (mainly in the Mesa J vicinity).	The representations present in the study area are at times relatively large and possess relatively wide lateral extents within the River Channel. Some degree of impact has already been suffered by these communities due to the construction of mining related infrastructure and minimal degrees of surplus water discharge.				
			Above average representation of the Major Creeklines of the Pilbara Ecosystem at Risk.					
			Potential for elevated sedge diversity, possibly including conservation significant species such as *Fuirena ciliaris* and *Eleocharis geniculata*, as well as a suite of habitat specific sedges, grasses and herbs (Note: *Fuirena ciliaris* has not been detected in previous surveys in the area; *Eleocharis geniculata* was recorded once in 2004).					
C1b on Jimmawurrada Creek	Young to Semi-Mature *Melaleuca argentea* and *Eucalyptus camaldulensis* dominated Low Woodland. **Discharge Established**	OPV-C	Young to semi-mature mesic woodland habitat	**Locally restricted and somewhat significant.**	**Moderate to High**	**Very Good**	**Moderate to High**	**Moderate**
			At least semi-permanent to permanent groundwater availability, with surface water expressions common (discharge related).					
			Relatively high mesic flora species diversity.	The rocky rangeland river variant of this community is somewhat uncommon and relatively restricted within the Hamersley sub-region. The unique substrates and adjacent rocky habitats which potentially support this community make it somewhat unique when compared to riverine representations occurring in the wider Pilbara Bioregion.				
			At times relevant as cryptic and conservation significant fauna habitat (potential to include the Pilbara olive python, Northern Quoll, and potentially the Ghost Bat, and Pilbara leaf nosed bat).					
			Cryptic flora species habitat and some potential as habitat for conservation significant flora (e.g. *Livistona alfredii*).					
			High subsurface aquatic invertebrate diversity.					

Vegetation Code	Broad Vegetation Type	GDE Classification	Associated Ecological Values	Distribution/Representation/Rarity & Presence in the Pilbara environment	Initial Local Significance	Condition	Sensitivity to Relevant Impacts	Resultant Significance Rating
C1b on Jimmawurrada Creek (Continued)			Relatively high local avifauna and bat species diversity. Significant reduction in value from direct and indirect impacts. Some reduced value due to the interpreted likely transient nature of this type of community within relevant zones of a Pilbara ephemeral river system.	The representations present in the study area are considered to be discharge established and thus a product of augmentation. Some degree of impact has already been suffered by these communities due to the construction of infrastructure and surplus water discharge.			(Generally High, but due to likely transient nature; rating is reduced)	Community established through anthropogenic influence (discharge)
C1bb	Young to Semi-Mature (+) *Melaleuca argentea* and *Eucalyptus camaldulensis* dominated Low Woodland **Discharge augmented**	OPV-C	Young to semi-mature mesic woodland habitat At least semi-permanent to permanent groundwater availability, with surface water expressions common (discharge related). Relatively high mesic flora species diversity. At times relevant as cryptic and conservation significant fauna habitat (potential to include the Pilbara olive python, Northern Quoll, and potentially the Ghost Bat, and Pilbara leaf nosed bat). Cryptic flora species habitat and some potential as habitat for conservation significant flora (e.g. *Livistona alfredii*). High subsurface aquatic invertebrate diversity. Relatively high local avifauna and bat species diversity. Some reduced value due to discharge augmentation and the interpreted likely transient nature of this type of community.	**Locally restricted and significant.** The rocky rangeland river variant of this community is somewhat uncommon and relatively restricted within the Hamersley sub-region. The unique substrates and adjacent rocky habitats which potentially support this community make it somewhat unique when compared to riverine representations occurring in the wider Pilbara Bioregion This community is interpreted as a baseline representation of the C1b OPV, but having undergone augmentation from anthropogenic discharge. Impact has already been suffered by this community from infrastructure construction and surplus water discharge.	Moderate to High	Very Good	High (Generally High, but due to likely transient nature; rating is reduced)	Moderate to High (Maintained due to close proximity to High significance communities)
C2A	*Eucalyptus camaldulensis* dominated Open Forest	FPV-A	Mature to semi-mature mesic open-forest habitat. Apparent; at least semi-permanent groundwater availability. Above average mesic flora species diversity. Cryptic and mesic fauna habitat (May include the Pilbara olive python). Cryptic flora species habitat (may include *Stylidium weeliwolli*). Above average subsurface aquatic invertebrate diversity. Above average local avifauna diversity. Some reduced value from direct and cumulative impacts. Above average representation of Riverine Eucalypt forests.	**Somewhat locally restricted but not uncommon.** The rocky rangeland River variant of this community is somewhat restricted within the Hamersley sub-region, but is not considered uncommon.	Moderate	Very Good to Good	Moderate to high	Moderate

Vegetation Code		Broad Vegetation Type	GDE Classification	Associated Ecological Values	Distribution/Representation/Rarity & Presence in the Pilbara environment	Initial Local Significance	Condition	Sensitivity to Relevant Impacts	Resultant Significance Rating
C2A-Cr	C2AA-Cr	EC dominated woodland to open forest - Creek	FPV-A	Mature to semi-mature mesic riparian woodland to open-forest (habitat).	**Somewhat locally and Sub-regionally restricted but not overly uncommon.**	Moderate (+)	Poor	Medium (+) (to High in places)	Moderate
				Floristic composition suggests at least semi-permanent groundwater availability (within proximity of surface).	The more mesic rocky rangeland creek variant of this riparian community is somewhat restricted within the Hamersley sub-region, but is not considered uncommon.				
				Above average mesic flora species diversity. Isolated *Melaleuca argentea* recorded.					
				Cryptic and mesic fauna habitat (May include the Pilbara olive python - recorded on survey).					
				Cryptic flora species habitat (may include *Stylidium weeliwolli*; *Gymnanthera cunninghamii* recorded on survey).					
				Likely above average subsurface aquatic invertebrate diversity.					
				Above average local avifauna diversity.					
				Significantly reduced value from direct and cumulative impacts; particularly grazing pressure.					
				Above average representation of Pilbara mesic creekline eucalypt forest/woodland.					
	C2A-Cr	EC dominated woodland to open forest - Creek	FPV-A	Mature to semi-mature mesic riparian woodland to open-forest (habitat).	**Somewhat locally and sub-regionally restricted but not uncommon.**	Moderate	Poor	Medium (+)	Minor-Moderate
				Floristic composition suggests at least semi-permanent groundwater availability (within proximity of surface).					
				Above average mesic flora species diversity.					
				Cryptic and mesic fauna habitat (May include the Pilbara olive python - recorded on survey).	The more mesic rocky rangeland creek variant of this riparian community is somewhat restricted within the Hamersley sub-region, but is not considered uncommon.				
				Cryptic flora species habitat (*Gymnanthera cunninghamii* recorded on survey).					
				Likely above average subsurface aquatic invertebrate diversity.					
				Above average local avifauna diversity.					
				Significantly reduced value from direct and cumulative impacts; particularly grazing pressure.					
				Above average representation of Pilbara mesic creekline eucalypt forest/woodland.					

Vegetation Code	Broad Vegetation Type	GDE Classification	Associated Ecological Values	Distribution/Representation/Rarity & Presence in the Pilbara environment	Initial Local Significance	Condition	Sensitivity to Relevant Impacts	Resultant Significance Rating
C2A-SW	EC dominated woodland/Mesic open shrubland	FPV-A	Mature to Semi-Mature mesic riparian woodland habitat. Generally ephemeral water availability, however floristic composition suggests relatively permanent groundwater availability via either perched (clay lenses) or broader groundwater proximity. Above average mesic flora species diversity, (particularly the mesic shrub composition). Cryptic and mesic fauna habitat.	**Locally and sub-regionally restricted and significant to highly significant.**	**Moderate+**	**Very Good**	**Medium (+) to High**	**Moderate-High**
			Cryptic flora species habitat (*Eragrostis surreyana* occasionally recorded on survey). Potential above average subsurface aquatic invertebrate diversity. Above average local avifauna diversity. Some reduced value from direct and cumulative impacts (mainly grazing). Above average representation of a floodplain / clay-pan scrub.	This community is in good condition and in general represents a component of a very restricted community within the Pilbara. At times forming a wetland, but most often representing a large sump zone where water accumulates, but more specifically where groundwater (perched or broader scale) seems to be consistently shallow.				
C7-SW	Mesic Tall open scrub/ Scattered trees	FPV-C	Mature to semi-mature mesic riparian scrub habitat. Generally ephemeral water availability, however floristic composition suggests relatively permanent groundwater availability via either perched (clay lenses in area) or broader groundwater proximity. Above average mesic flora species diversity, (particularly the mesic shrub composition). Cryptic and mesic fauna habitat (particularly for fauna burrows under thick scrub).	**Locally and sub-regionally restricted and likely to be highly significant.**	**Moderate+**	**Very Good**	**Medium (+) (potentially to High)**	**Moderate-High**
			Cryptic flora species habitat (*Eragrostis surreyana* recorded on survey). Likely above average subsurface aquatic invertebrate diversity. Above average local avifauna diversity. Some reduced value from direct and cumulative impacts (mainly grazing). Above average representation of a floodplain / clay-pan eucalypt woodland.	This community is in good condition and in general represents a component of a highly restricted community within the Pilbara. At times forming a wetland, but most often representing a large sump zone where water accumulates, but more specifically where groundwater (perched or broader scale) seems to be consistently shallow. A floodplain scrub dominated by mesic species such				

Vegetation Code		Broad Vegetation Type	GDE Classification	Associated Ecological Values	Distribution/Representation/Rarity & Presence in the Pilbara environment	Initial Local Significance	Condition	Sensitivity to Relevant Impacts	Resultant Significance Rating
C2B		*Eucalyptus camaldulensis* & *Eucalyptus victrix* co-dominated Open Forest	FPV-B	Mature somewhat mesic riparian woodland/open-forest habitat. Apparent; at least semi-permanent groundwater availability. Elevated mesic flora species diversity. Cryptic and mesic fauna habitat (Some potential for conservation significant fauna).	**Somewhat locally restricted but not uncommon.**	**Minor-Moderate**	**Very Good to Good (and regularly Poor)**	**Moderate (+)**	**Moderate**
				Cryptic flora species habitat (may include *Stylidium weeliwolli*). Potential above average subsurface aquatic invertebrate diversity. Elevated local avifauna diversity. Some reduced value from direct and cumulative impacts, particularly grazing and grazing related weed infestation. Average representation of Riverine Eucalypt forests.	The rocky rangeland river variant of this community is somewhat restricted within the Hamersley sub-region, but is not considered uncommon.				
C2B-Cr	**C2BB-Cr**	EC & EV dominated woodland - Creek	FPV-B	Mature mesic riparian woodland habitat. Floristic composition suggests at least semi-permanent groundwater availability (within proximity of surface). Elevated mesic flora species diversity. Elevated local avifauna diversity.	**Somewhat locally and sub-regional restricted but not overly uncommon.**	**Moderate**	**Poor to Very Poor**	**Medium (+)**	**Minor-Moderate**
				Cryptic flora species habitat (may include *Stylidium weeliwolli*; *Gymnanthera cunninghamii* recorded on survey). Likely above average subsurface aquatic invertebrate diversity. Cryptic and mesic fauna habitat (Some potential for conservation significant fauna). Significantly reduced value from direct and cumulative impacts; particularly grazing pressure. Above average representation of mesic Pilbara creekline eucalypt woodland.	The rocky rangeland river variant of this community is somewhat restricted within the Hamersley sub-region, but is not considered uncommon.				
	C2B-Cr	EC & EV dominated woodland - Creek	FPV-B	Mature somewhat mesic riparian woodland / open-forest habitat. Floristic composition suggests at least semi-permanent groundwater availability (within proximity of surface). Elevated mesic flora and avifauna species diversity	**Somewhat locally restricted but not uncommon.**	**Minor-Moderate**	**Poor**	**Medium**	**Minor (+)**
				Cryptic and mesic fauna habitat (some potential for conservation significant fauna). Cryptic flora species habitat. Likely above average subsurface aquatic invertebrate diversity. Significantly reduced value from direct and cumulative impacts; particularly grazing pressure. Above average representation of mesic Pilbara creekline eucalypt woodland.	The rocky rangeland river variant of this community is somewhat restricted within the Hamersley sub-region, but is not considered uncommon.				

Vegetation Code	Broad Vegetation Type	GDE Classification	Associated Ecological Values	Distribution/Representation/Rarity & Presence in the Pilbara environment	Initial Local Significance	Condition	Sensitivity to Relevant Impacts	Resultant Significance Rating
C2A-B	*Eucalyptus camaldulensis* dominated Woodlands	FPV-A	Mature somewhat mesic riparian woodland habitat. Apparent; at least semi-permanent to permanent groundwater proximity. Elevated mesic flora species diversity. Cryptic and mesic fauna habitat (some potential for conservation significant fauna). Cryptic flora species habitat (may include *Stylidium weeliwolli*). Above average subsurface aquatic invertebrate diversity. Elevated local avifauna diversity. Some reduced value from direct and cumulative impacts, particularly grazing and grazing related weed infestation. Average representation of Riverine Eucalypt Woodland.	**Relatively common but somewhat restricted locally.**	**Minor-Moderate**	**Very Good to Good (and regularly Poor)**	**Moderate**	**Minor-Moderate**
C2B-B	*Eucalyptus camaldulensis* & *Eucalyptus victrix* co-dominated Woodland	FPV-B	Mature somewhat mesic riparian woodland habitat. Apparent; at least semi-permanent to permanent groundwater proximity. Elevated mesic flora species diversity. Cryptic and mesic fauna habitat (Some potential for conservation significant fauna). Cryptic flora species habitat (may include *Stylidium weeliwolli*). Above average subsurface aquatic invertebrate diversity. Elevated local avifauna diversity. Significantly reduced value from direct and cumulative impacts, particularly grazing and grazing related weed infestation. Average representation of Riverine Eucalypt Woodland.	**Relatively common but somewhat restricted locally.**	**Minor (+)**	**Good to Poor**	**Moderate**	**Minor-Moderate**
C2C-SW1	EV dominated Woodland/Mesic Shrubland	FPV-C	Mature relatively mesic floodplain woodland habitat. Generally ephemeral water availability, however floristic composition suggests relatively permanent groundwater availability via either perched (clay lenses) or broader groundwater proximity. Above average mesic flora species diversity, (particularly the mesic shrub composition) Cryptic and mesic fauna habitats present. Cryptic flora species habitat present (*Eragrostis surreyana* occasionally recorded on survey) Likely above average subsurface aquatic invertebrate diversity. Above average local avifauna diversity. Some reduced value from direct and cumulative impacts (mainly grazing). Above average example of a floodplain/clay-pan Eucalypt woodland.	**Locally and sub-regionally restricted and significant to highly significant** (due to association with other units in the complex). This community is in good condition and in general represents an intermediately mesic component of a very restricted community within the Pilbara. At times forming a wetland, but most often representing a large sump zone where water accumulates, but more specifically where groundwater (perched or broader scale) seems to be consistently shallow.	**Moderate**	**Very Good**	**Medium (-)**	**Moderate (+)**

Vegetation Code	Broad Vegetation Type	GDE Classification	Associated Ecological Values	Distribution/Representation/Rarity & Presence in the Pilbara environment	Initial Local Significance	Condition	Sensitivity to Relevant Impacts	Resultant Significance Rating
C2C-SW2	EV & CH dominated Woodland/ Mesic open shrubland	FPV-C	Mature relatively mesic floodplain woodland habitat. Generally ephemeral water availability, however floristic composition suggests groundwater likely accessible via either perched (clay lenses in area) or broader groundwater proximity. Average to Above average mesic flora species diversity, Cryptic flora species habitat (*Eragrostis surreyana* occasionally recorded on survey). Likely above average subsurface aquatic invertebrate diversity. Above average local avifauna diversity. Some reduced value from direct and cumulative impacts (mainly grazing). Above average representation of a floodplain / clay-pan Eucalypt woodland mosaic.	**Locally and Sub-regionally restricted and significant to highly significant** (due to association with other units in the complex). This community is in good condition and in general represents an intermediate ecotone / mosaic component of a very restricted community within the Pilbara. At times forming a wetland, but most often representing a large sump zone where water accumulates, but more specifically where groundwater (perched or broader scale) appears consistently shallow.	**Minor-Moderate**	**Good to Very Good**	**Medium (+)**	**Moderate**
CL-SW	Mixed open shrublands on clay pans	Vadophytic	Generally ephemeral water availability, however elements of floristic composition suggest groundwater potentially accessible via either perched (clay lenses in area) or broader groundwater proximity. Mesic and cryptic flora species habitat (*Eragrostis surreyana* commonly recorded on survey). Mesic fauna habitats present (clays predominate) Some reduced value from direct and cumulative impacts (mainly grazing). Above average representation of a floodplain / clay-pan shrubland mosaic.	**Locally and potentially Sub-regionally restricted and significant** This Community is in good condition and in general represents a clay-pan mosaic component of a very restricted community within the Pilbara. At times forming a wetland, but most often representing a large sump zone where water accumulates, but more specifically where groundwater (perched or broader scale) appears consistently shallow.	**Minor (+)**	**Good to Very Good**	**Low (+)**	**Minor-Moderate**
C3A	*Eucalyptus camaldulensis* & *Eucalyptus victrix* co-dominated Open Woodland	FPV-B	Mature somewhat mesic riparian open woodland habitat. Apparent; at least regular to intermittent groundwater proximity. Elevated subsurface aquatic invertebrate diversity. Mesic flora species present. Mesic fauna habitats present. Elevated local avifauna diversity. Significantly reduced value from direct and cumulative impacts, particularly grazing and grazing related weed infestation. Average representation of Riverine Eucalypt Woodland.	**Relatively common but somewhat restricted locally.**	**Minor (+)**	**Good to Poor**	**Low (+)**	**Minor (+)**
C2C	*Eucalyptus victrix* dominated Woodland	FPV-C	Mature somewhat mesic Riparian woodland habitat. Generally ephemeral water availability, with indications that groundwater may be accessed but accessibility is moderately variable. Elevated to average mesic flora species diversity.	**Relatively common but somewhat restricted locally.**	**Minor**	**Good to Poor**	**Low-Moderate**	**Minor**

Vegetation Code	Broad Vegetation Type	GDE Classification	Associated Ecological Values	Distribution/Representation/Rarity & Presence in the Pilbara environment	Initial Local Significance	Condition	Sensitivity to Relevant Impacts	Resultant Significance Rating
C2C (Cont'd)			Mesic fauna habitat. Elevated subsurface aquatic invertebrate diversity. Elevated local avifauna diversity. Significantly reduced value from direct and cumulative impacts, particularly grazing and grazing related weed infestation. Average representation of Riverine Eucalypt Woodland.					
C2C-Cr	EV dominated Low Woodland - Creek	FPV-C	Mature somewhat mesic riparian woodland habitat. Generally ephemeral water availability, with indications that groundwater likely to be accessible but accessibility can be variable. Elevated to average mesic flora species diversity. Mesic fauna habitats present Likely elevated subsurface aquatic invertebrate diversity. Elevated local avifauna diversity. Significantly reduced value from direct and cumulative impacts, particularly grazing and grazing related weed infestation. Average representation of a Pilbara creekline Eucalypt Woodland.	Relatively common	**Minor**	**Poor to Very Poor**	**Low (+)**	**Minor**
C3B	*Eucalyptus victrix* dominated Open Woodland	FPV-C	Mature riparian open woodland habitat. Generally ephemeral water availability, with indications that groundwater may be accessed but accessibility is highly variable. Mesic flora species present. Mesic fauna habitat. Elevated subsurface aquatic invertebrate diversity. Elevated local avifauna diversity. Significantly reduced value from direct and cumulative impacts, particularly grazing and grazing related weed infestation. Average representation of Riverine Eucalypt Woodland.	**Common and not locally restricted**	**Minor**	**Good**	**Low (+)**	**Minor**
C3B-Cr	EV & CH dominated Low Open Woodland - Creek	FPV-C	Mature riparian open woodland habitat. Generally ephemeral water availability, with indications that groundwater may be accessed but accessibility is highly variable. Some mesic flora species present. Mesic fauna habitats present. Likely elevated subsurface aquatic invertebrate diversity. Elevated local avifauna diversity. Significantly reduced value from direct and cumulative impacts, particularly grazing and grazing related weed infestation. Average representation of creekline Eucalypt Woodland.	**Common and not locally restricted**	**Minor**	**Good**	**Low**	**Minor**

Vegetation Code	Broad Vegetation Type	GDE Classification	Associated Ecological Values	Distribution/Representation/Rarity & Presence in the Pilbara environment	Initial Local Significance	Condition	Sensitivity to Relevant Impacts	Resultant Significance Rating
C3C-Cr	CH scattered low trees/ Variable Open Shrubland	FPV-C	Floodplain riparian shrubland habitat. Generally ephemeral water availability, with indications that groundwater may be accessed (only by larger trees), but accessibility is highly variable. Some mesic flora diversity, minor mesic fauna habitats present. Somewhat elevated local avifauna diversity. Significantly reduced value from direct and cumulative impacts, particularly grazing and grazing related weed infestation.	**Common and not locally restricted**	**Minor**	**Poor to Good**	**Low**	**Low**
C4	River bed Shrublands	Vadophytic with isolated facultative phreatophytes	Riparian habitat with ephemeral water availability. Mesic fauna habitat. Elevated to average subsurface aquatic invertebrate diversity. Elevated local avifauna diversity. At times significantly reduced value from direct and cumulative impacts, particularly grazing and grazing related weed infestation. Some increased value from discharge enhancement.	**Relatively common but somewhat restricted.** This community is relatively common within the western half of the Hamersley sub-region, but riparian representations are restricted to larger creek/river systems.	**Minor**	**Very Good to Good (and regularly Poor)**	**Low**	**Minor**
C5	Scoured Beds with minimal vegetation	Vadophytic with isolated facultative phreatophytes	Ephemeral water availability. Mesic fauna habitat. Potentially elevated subsurface aquatic invertebrate diversity. Some reduced value from direct impacts. High potential for reversion to pre-impact condition due to fluvial processes in effect. Large repository of coarse alluvial sediments important for aquatic invertebrate habitats.	**Minimal vegetation; habitat relatively common but somewhat restricted.**	**Low**	**Excellent to Very Good**	**Low**	**Low**
C6	Floodplain Shrublands	Vadophytic / Xerophytic	Ephemeral water availability (Perennial in some areas at present). Slightly elevated mesic flora species diversity. Mesic fauna habitat. Elevated local avifauna diversity. At times significantly reduced value from direct and cumulative impacts, particularly grazing and grazing related weed infestation.	**Common and not locally restricted.**	**Low**	**Very Good to Good (and regularly Poor)**	**Very Low**	**Low**
F1	*Corymbia hamersleyana* Scattered trees / *T. wiseana* Hummock grassland	Vadophytic	Ephemeral water availability. Floodplain type community with slightly elevated mesic flora species diversity. Minor mesic fauna habitats present. Elevated local avifauna diversity. Somewhat reduced value from direct and cumulative impacts, particularly grazing and grazing related weed infestation.	**Common and not locally restricted.**	**Low**	**Good to Very Good**	**Negligible**	**Low**

Vegetation Code	Broad Vegetation Type	GDE Classification	Associated Ecological Values	Distribution/Representation/Rarity & Presence in the Pilbara environment	Initial Local Significance	Condition	Sensitivity to Relevant Impacts	Resultant Significance Rating
F2	*Acacia synchronicia* Tall open shrubland.	Vadophytic	Ephemeral water availability. Floodplain type community with slightly elevated mesic flora species diversity. Minor mesic fauna habitats present. Elevated local avifauna diversity. Reduced value from direct and cumulative impacts, particularly grazing and grazing related weed infestation.	**Common and not locally restricted**	**Low**	**Good to Poor**	**Negligible**	**Low**
F3	*Acacia xiphophylla* low open woodland	Vadophytic	Ephemeral water availability Stony mantle type habitat. Relatively intact community, grazing impacts minimal.	**Common and not locally restricted**	**Low**	**Excellent to Very Good**	**Negligible**	**Low**
F4	CH Scattered trees/T. epactia Hummock grassland	Vadophytic	Ephemeral water availability. Floodplain type community with slightly elevated mesic flora species diversity. Minor mesic fauna habitats present. Elevated local avifauna diversity. Reduced value from direct and cumulative impacts, particularly grazing and grazing related weed infestation.	**Common and not locally restricted**	**Low**	**Very Good**	**Negligible**	**Low**
F5	*Acacia* spp. Tall Shrubland/*T. epactia* Hummock grassland	Vadophytic	Ephemeral water availability. Floodplain type community with slightly elevated mesic flora species diversity. Minor mesic fauna habitats present. Elevated local avifauna diversity. Reduced value from direct and cumulative impacts, particularly grazing and grazing related weed infestation.	**Common and not locally restricted**	**Low**	**Very Good**	**Negligible**	**Low**
F6	*Acacia* spp. open shrublands/*T. epactia* hummock grassland	Vadophytic	Ephemeral water availability. Floodplain type community with slightly elevated mesic flora species diversity. Minor mesic fauna habitats present. Elevated local avifauna diversity. Relatively intact community, grazing impacts minimal.	**Common and somewhat restricted locally**	**Minor**	**Excellent to Very Good**	**Negligible**	**Low**
H1	EL Scattered Trees/*T. wiseana* hummock grassland	Vadophytic	Ephemeral water availability. Rocky hillslope habitats. Relatively intact community.	**Common and not locally restricted**	**Low**	**Excellent**	**Negligible**	**Low**

Vegetation Code	Broad Vegetation Type	GDE Classification	Associated Ecological Values	Distribution/Representation/Rarity & Presence in the Pilbara environment	Initial Local Significance	Condition	Sensitivity to Relevant Impacts	Resultant Significance Rating
HD	Highly Disturbed Ground - Cleared	-	**Values present in the physical aspects of the land (namely soil profile) and biotic values mainly represented by the in the soil seed bank which remains.**	N/A		**Completely Degraded**	**N/A**	**N/A**

4.4 GDE SENSITIVITY AND RISK MAPPING

For the purpose of mapping the spatial distribution of risk within the study area, each community was attributed a risk rating. This process firstly involved providing an interpretation of the degree of sensitivity (or vulnerability) to hydrological change held by each community. From this a rating of the risk that "measurable" impact/change to a community could result from a significant degree of hydrological change was interpreted. This risk rating involved an initial consideration of 7 different factors to produce a rating. Then a residual risk rating was attributed through consideration of the significance and condition of the relevant community being considered. The steps, methods and definitions involved in this process are outlined in Section 3.3.

The final Residual risk ratings (similar to "Importance" ratings applied in SKM (2001)) attributed to each community are presented in Table 4-5. The spatial risk mapping created from this risk assessment process is presented in Figures 4-5 to 4-8.

Table 4-3: Risk ratings attributed to each community mapped in the study area and the associated GDE classification and sensitivity rating.

Vegetation Code	Broad Vegetation Type (MA = *Melaleuca argentea*, EC = *Eucalyptus camaldulensis*, EV = *Eucalyptus victrix*)	GDE Classification	Initial Sensitivity Rating
C1A	MA community - Low Open Forest	High to high (+)	High
C1b	MA community - Woodland	High	Moderate-High
C2AA	EC dominated Open Forest	Moderate to High	
C2AA-Cr	EC dominated woodland to open forest - Creek	Moderate (+) (to High in some places)	
C2A-SW	EC dominated woodland/Mesic open shrubland	Moderate to High	
C7-SW	Mesic Tall open scrub/ Scattered trees	Moderate (+) (potentially to High)	
C2A	EC dominated Open Forest	Moderate to High	Moderate (+)
C2A-B	EC dominated Woodland	Moderate	
C2A-Cr	EC dominated woodland to open forest - Creek	Moderate (+) (to High in some places)	
C2B	EC & EV co-dominated Open Forest	Moderate (+)	
C2BB-Cr	EC & EV dominated woodland - Creek	Moderate	
C2B-B	EC & EV co-dominated Woodland	Moderate	Moderate
C2B-Cr	EC & EV dominated woodland - Creek	Moderate	
C2C-SW1	EV dominated Woodland/Mesic Shrubland	Moderate	
C2C-SW2	EV & CH dominated Woodland/ Mesic open shrubland	Moderate (+)	

Vegetation Code	Broad Vegetation Type (MA = *Melaleuca argentea*, EC = *Eucalyptus camaldulensis*, EV = *Eucalyptus victrix*)	GDE Classification	Initial Sensitivity Rating
C2C	EV dominated Woodland	Low to Moderate	Low-Moderate
C2C-Cr	EV dominated Low Woodland - Creek	Low (+)	
C3A	EC & EV co-dominated Open Woodland	Low (+)	
C3B	EV dominated Open Woodland	Low (+)	Low
C3B-Cr	EV & CH dominated Low Open Woodland - Creek	Low	
C3C-Cr	CH scattered low trees/ Variable Open Shrubland	Low	
CL-SW	Mixed open shrublands on clay pans	Low (+)	
C4	Shrublands	Low	
C6	Shrublands	Very Low	Very Low
C5	Negligible vegetation	Negligible	Negligible
F1	CH Scattered trees/T. wiseana Hummock grassland	Negligible	
F2	*Acacia synchronicia* Tall open shrubland.	Negligible	
F3	*Acacia xiphophylla* low open woodland	Negligible	
F4	CH Scattered trees/T. epactia Hummock grassland	Negligible	
F5	*Acacia* spp. Tall Shrubland/TE Hummock grassland	Negligible	
F6	*Acacia* spp. open shrublands/T. epactia hummock grassland	Negligible	
H1	EL Scattered Trees/T. wiseana hummock grassland	Negligible	
HD	-	N/A	N/A

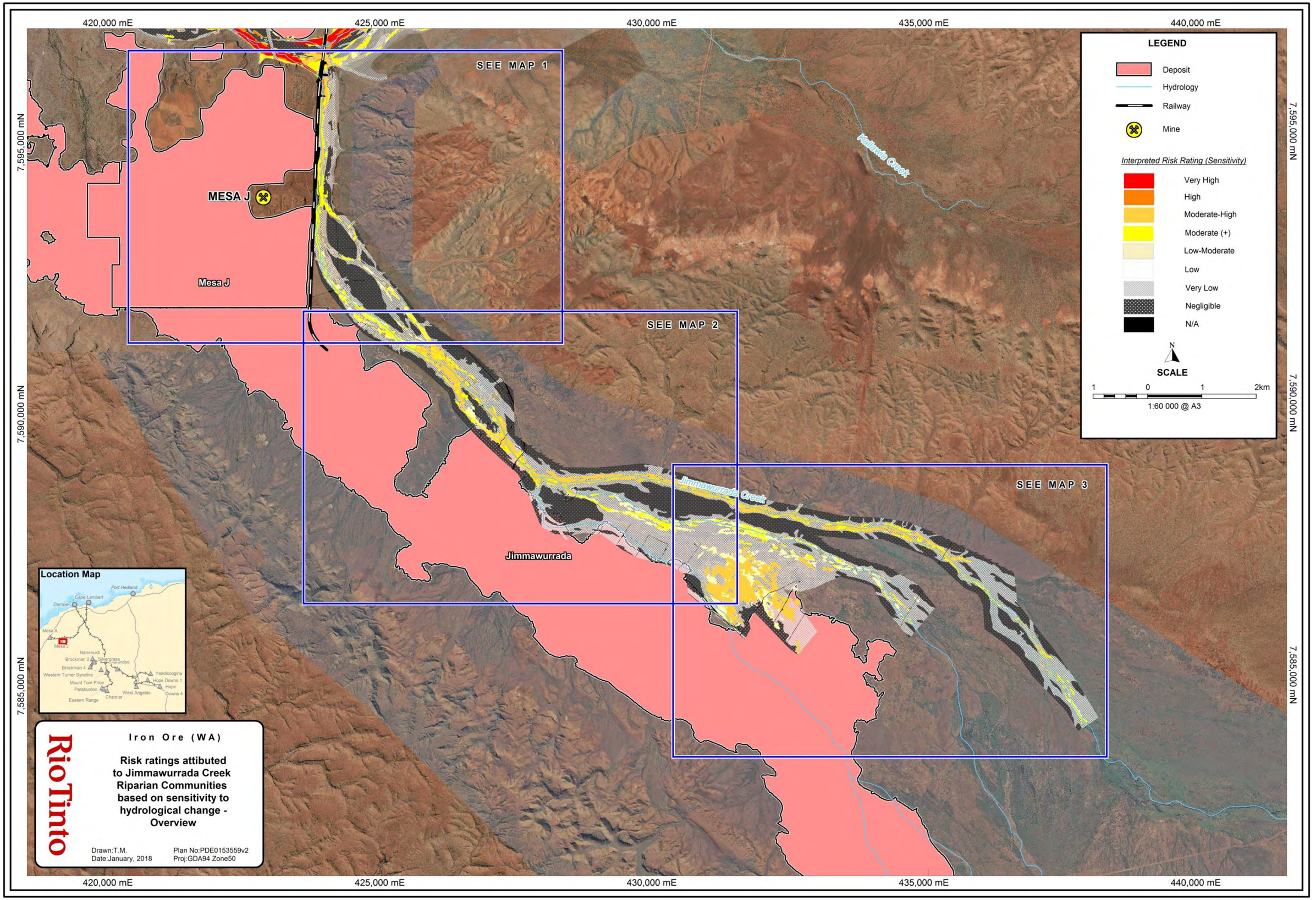


Figure 4-5: **Risk mapping depicting the inherent "Sensitivity" of Jimmawurrada Creek Riparian vegetation to hydrological change; Overview Map**

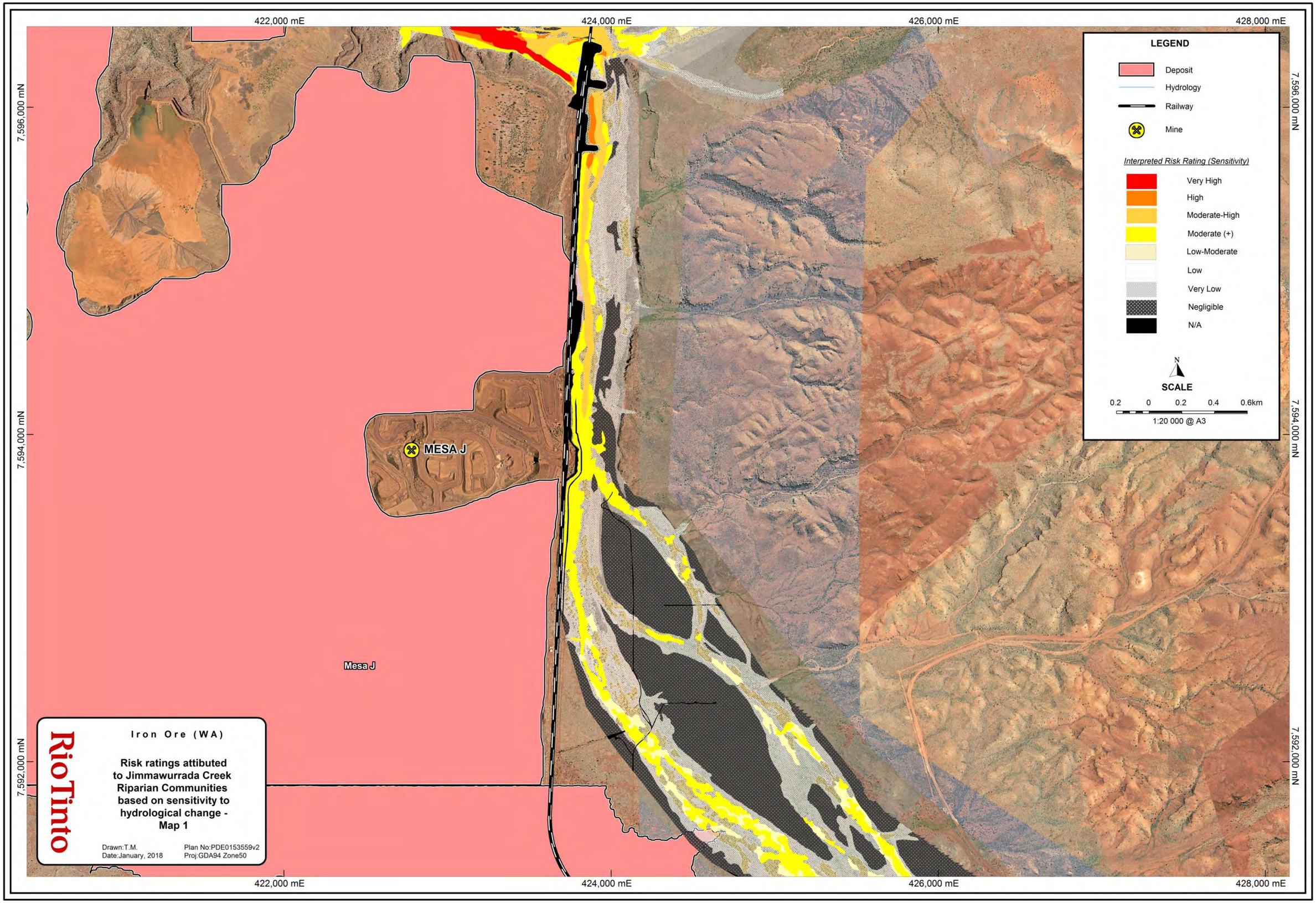


Figure 4-6: **Risk mapping depicting the inherent "Sensitivity" of Jimmawurrada Creek Riparian vegetation to hydrological change; Map 1 of 3**

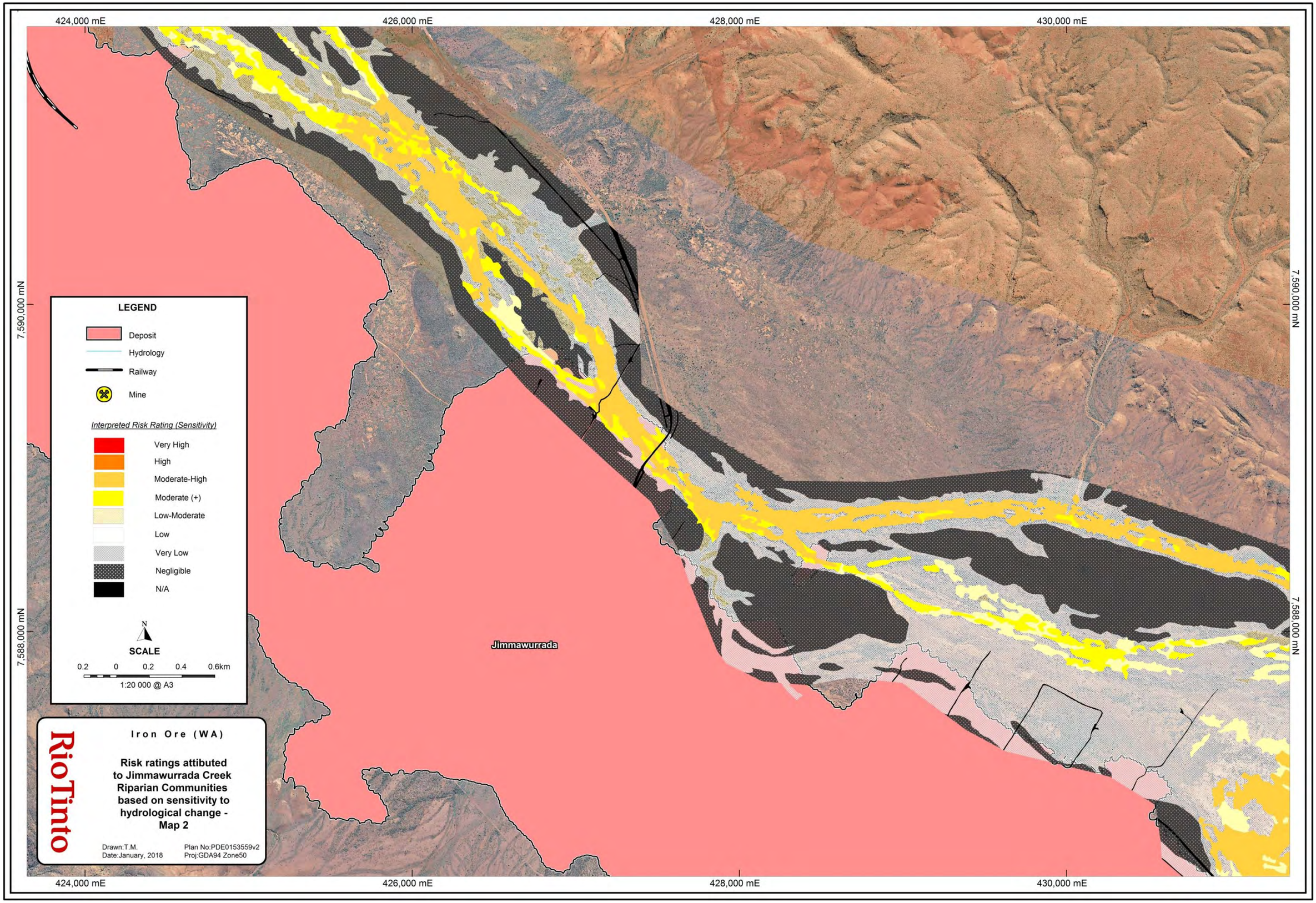


Figure 4-7: **Risk mapping depicting the inherent "Sensitivity" of Robe River Riparian vegetation to hydrological change; Map 2 of 3**

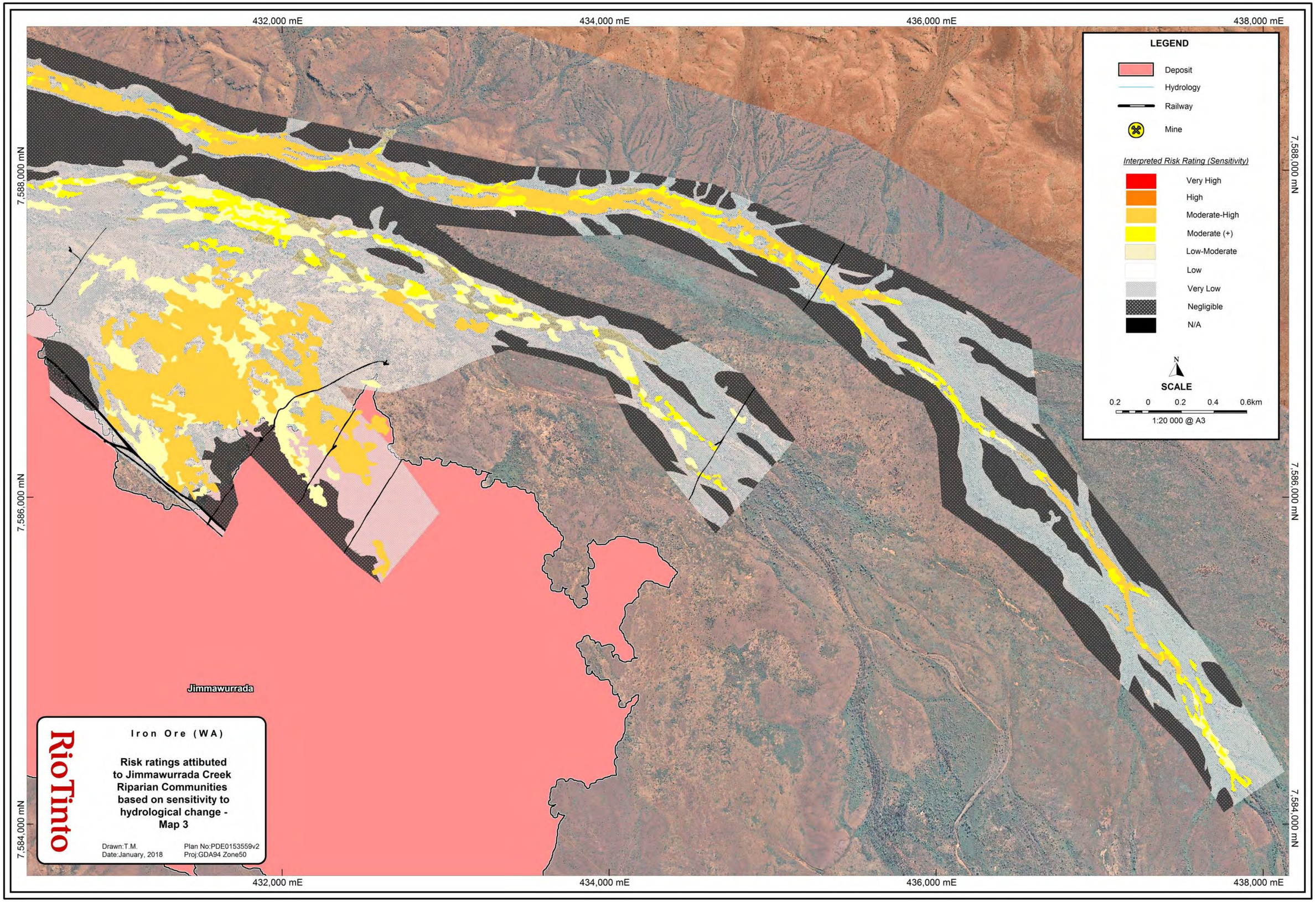


Figure 4-8: Risk mapping depicting the inherent "Sensitivity" of Robe River Riparian vegetation to hydrological change; Map 3 of 3

5 DISCUSSION

Jimmawurrada Creek Riparian Vegetation

Within the study area; in general, GDV in the form of OPV was relatively uncommon. Despite this, within the first 2-3 km stretch of Jimmawurrada Creek (from the confluence with the Robe River) the C1b community is relatively common (including a small stretch of C1bb) and consistently distributed along the low flow channel and some sections of the secondary or high flow channel. This distribution appears tightly aligned with the attenuation of Jimmawurrada Creek by the range (Hamersley Range) feature constricting the creek in this area, but also coincides with the local stretch of creek which receives discharge from the Mesa J mining operations. The consistent distribution of strips of *Melaleuca argentea* co-dominated vegetation (C1b), with quite narrow (uneven frequency distribution) and "semi-mature" age distributions, appears to be an indication that they have since established here, or were at least significantly augmented by the intermittent discharge which has occurred in this area for the last 15 years. Recent work (Rio Tinto 2015) suggests that the time period of discharge in this area is more than capable of accounting for the size distributions of *M. argentea* trees present in this area (generally less than 40cm DBH). Furthermore, the proximity to the Robe River and continuation of the Robe River alluvial aquifer into the Jimmawurrada Creek alluvium, in at least the first part of this stretch, (along with groundwater discharge from the Bungaroo valley, and proximity to the Mesa J pisolite aquifers) may also help account for the communities present.

The survey work conducted by Trudgen (1991) in this area (pre-discharge) indicated that only a small stretch of Jimmawurrada Creek near the confluence possessed occasional *Melaleuca argentea* individuals. Trudgen (1991) describes the remainder of woodlands within Jimmawurrada Creek as being dominated by riparian eucalypts (and being absent of *M. argentea*). In combination with present day observations of age structure, pre-discharge survey work has helped to conclude that baseline *Melaleuca argentea* populations and thus potential OPV distribution in Jimmawurrada Creek was most likely restricted to the first 500 m (but potentially as far as 800 m) along the creek. Groundwater modelling through this initial stretch of Jimmawurrada Creek suggests up to 10 m of drawdown (1-4 m in the first 200m and 4-10 m in the following 500 m) could potentially occur by 2030. However, while uncertainty remains, connectivity between the underlying formations and alluvium through this area is assumed to be low, and as such this degree of drawdown needs to be considered in light of such assumptions. Furthermore surface water influence on soil water and aquifer recharge along with groundwater influence from the Robe River alluvial aquifer and the Bungaroo valley aquifer mean that significant degrees of annual (or multiple times per year) recovery in groundwater heights have previously occurred (under influence from the Southern Cutback Borefield (**SCB**)) and are predicted to continue to occur (Rio Tinto 2018a) within the aquifers underlying Jimmawurrada Creek. Irrespective of the mitigating influence of such factors, modelled hydrological changes under Jimmawurrada Creek are likely to impact the more sensitive communities present in this stretch of the creek. However, the timing (and magnitude) of such groundwater changes in relation to seasonal water stress cycles and the potential onset of extended drought conditions will be the most influential factor determining whether significant impacts to OPV communities are realised. With intermittent discharge likely to continue within this stretch; demonstrated local cycles of groundwater recovery (driven by surface/groundwater flows from the Bungaroo Valley and Robe River) mean that more favourable growth conditions should regularly return to Jimmawurrada Creek. Cyclical restoration of more

favourable conditions should in-turn ensure that ongoing impacts will also regularly see some degree of amelioration which will likely ensure that continued and compounding hydrological stress and related changes is broadly absent in this zone of Jimmawurrada Creek.

While some pools were observed along parts of the Jimmawurrada Creek study area, the vast majority were confidently believed to be intermittent. Unlike the Robe River, relatively consistent and shallow groundwater base-flow within the alluvium is not believed to be present within Jimmawurrada Creek. While some permanent pools are known to occur further upstream in the Bungaroo Valley (such as the Old Yalleen Pool), no other similarly persistent pools were found or are considered likely to occur within the study area. In general permanent pools tend to be flanked by populations of Obligate Phreatophytic Species (**OPS**) whose presence generally corroborates with the consistency of water availability. Apart from the first 3 km stretch of Jimmawurrada Creek, the presence of *Melaleuca argentea* along Jimmawurrada creek was represented by a handful of recordings of no more than a couple young to semi-mature individuals. Interestingly, young to semi-mature populations of *M. argentea* are known from some of the relatively minor reticulating flowlines directly to the south (and outside of the study area) of the soak/wetland feature mapped in this study (see Plate 5-1 for the location of the *M. argentea* individual recorded south of the soak). The presence of obligate phreatophytes on almost plain like habitats within the valley floor, with no distinct drainage channel present and without a dense accompanying riparian community, is very unusual and potentially an indication of a shallow zone within the broader Bungaroo aquifer (or smaller independent, shallow aquifers). While more substantial and consistent populations of *Sesbania formosa* (and in some areas **Phoenix dactylifera*) were encountered on Jimmawurrada Creek from approximately 8.5-14 km upstream, their presence is not a reliable indicator of water permanence, but is instead a good indication of increasingly high water availability and surface water input; especially in the absence of *M. argentea* populations. Two pools were recorded in the upper parts of the study area as potentially being semi-permanent (located approximately 17 km and 18 km upstream from the confluence). This determination was based on a number of factors, including: the presence of single records of *M. argentea*, abnormally deep incisions of the channel into the local alluvium, and above average grazing disturbance indicating that such areas are consistently visited and that cattle-based erosion may also be helping maintain depth in the water hole. In these areas, high levels of in-pool cattle disturbance meant that the presence of semi-permanent, water-indicating macrophytes was unable to be interpreted. Visits by other surveyors to these locations late in 2017, anecdotally suggested that these pools were dry at this time of year. Despite this, the presence of relatively fine-sediment derived banks in such stretches of Jimmawurrada Creek increases the water holding capacity of the channel and thus the likelihood that some of the pools are at times, more consistently present. Beyond values for terrestrial fauna, the value of such pools for flora is difficult to define, due to the intense cattle activity and vegetation trampling.

The distribution of certain mesic indicator species within specific zones of Jimmawurrada Creek could be used as evidence to suggest that baseline moisture conditions through such zones were elevated in comparison to other areas. The mesic indicator species considered important in the locality include: *Melaleuca argentea, *Phoenix dactylifera, Sesbania formosa, Melaleuca bracteata, Phyllanthus baccatus, Ficus aculeata, *Passiflora foetida, Lobelia arnhemica*, and *Typha domingensis* (*T. domingensis* only relevant where consistent larger scale formations are present). Distribution of these species could be attributed to multiple factors, including:

- shallow groundwater (for whatever reason)
- intermittent disconnected surficial/alluvial aquifers;
- basement rock outcropping within the creek bed;
- incised channels and confinement of the fluvial system into a narrow corridor;
- fine sediment substrates and increased water holding capacity; and
- perched small scale aquifers linked to shallow basement material, or clay lenses.

Plate 5-1 displays the basic distribution of mesic indicator species within the Jimmawurrada Creek study area, where **Phoenix dactylifera*, *Sesbania formosa*, *Melaleuca bracteata* and *Melaleuca argentea* represent key mesic indicator species.

The presence of scattered (and clustered, mature) **Phoenix dactylifera* palms and consistently scattered *Sesbania formosa* through the central red polygon of Plate 1 suggests increasing water availability in this zone. While this type of mesic species distribution may partially be explained by generally shallow groundwater (baseline (pre-mining) groundwater levels in this zone were estimated at approximately 4-5 m), at the finer scale; confinement/incision of the channel along with seasonally intermittent (but likely disconnected) alluvial aquifers/through-flow is likely to also be playing a role in the establishment of vegetation associations recorded through this area. Furthermore; these same factors and potentially some influence from small scale perched aquifers (likely perched on clay lenses) could also explain the presence of isolated *Melaleuca argentea* individuals in the eastern orange polygon of Plate 5-1. Also of relevance were the observations that within this stretch of Jimmawurrada Creek; the low flow channel was relatively incised, bedrock was at times outcropping in and adjacent to the creek bed, surface water expressions were consistently intermittent, and mesic indicator species were relatively common.

Another area where mesic indicator species were prevalent and often formed a co-dominant component of vegetation, but which wasn't associated with a known drainage channel or fluvial system was the Soak/Wetland feature previously recorded in the south east of the study area. The vegetation associations in this area not only suggested quite shallow groundwater, or very consistent water availability, but also represented quite rare associations, especially in light of the landforms they were recorded on. The area, at over 200 ha seems to represent a large soak, which at times becomes part of the floodplain of the Bungaroo Creek arm of Jimmawurrada Creek; thus receiving and storing pooled water as a result of peak creek flows. While the presence of *Eucalyptus camaldulensis* woodlands over mesic shrublands on floodplain like features (C2A-SW), is quite rare in the Pilbara, the tall open scrub of *Melaleuca bracteata* and *Acacia ampliceps* (and *Melaleuca glomerata* and *Acacia sclerosperma*) over open hummock grasslands of *Triodia longiceps* and *Triodia angusta* (C7-SW) are extremely rare on similar landforms. With the dominant and co-dominant species present in this area suggesting a high degree of water availability, and with substantial surface water input events into this area likely to be uncommon, it is thought that either the broader groundwater table is quite locally shallow, or that clay lenses below it are facilitating the formation of a small perched aquifer in the area. Such factors suggest that this community is relatively sensitive to hydrological change. The highly restricted distribution of these communities (particularly C2A-SW, C7-SW, but also to a lesser degree C2C-SW1, C2C-SW2 & CL-SW) in combination with the likely hydrological sensitivity of vegetation in the soak/wetland area determines that their significance is likely to be relatively high.

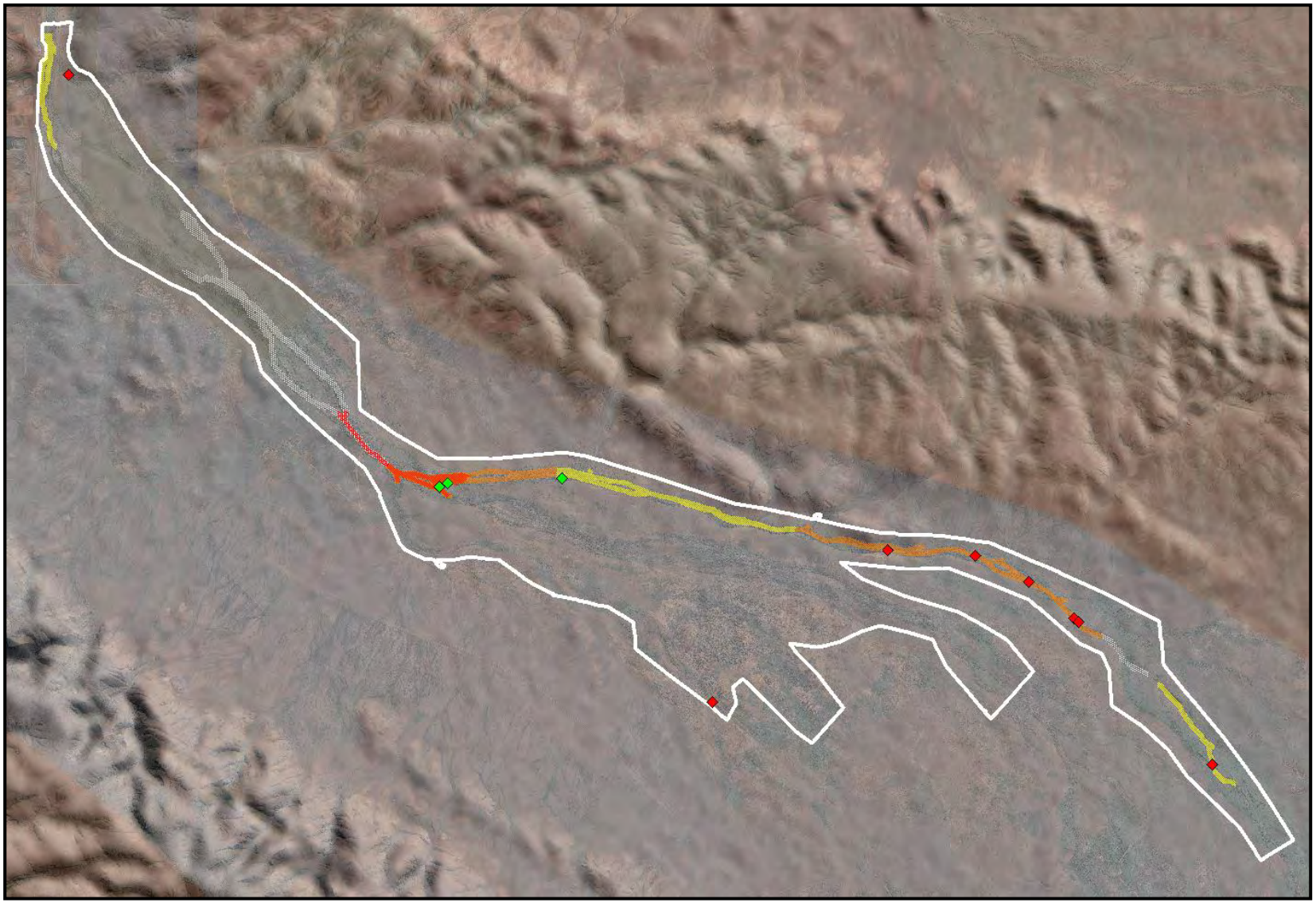


Plate 5-1: Basic distribution of mesic indicator species within the Jimmawurrada Creek study area (white outlined polygon).

Red polygon indicates where populations of nearly all mesic indicator species were recorded (except *Melaleuca argentea*), Orange polygns indicate where 3 key species were regularly recorded, Yellow indicates where 2 key species were regularly recorded, and white shaded polygons is where only one key mesic indicator species was regularly recorded. Green dots are where clusters of mature *Phoenix* palms were recorded, and Red dots are where 1-4 *Melaleuca argentea* individuals were recorded.

The vegetation communities within Jimmawurrada Creek, while generally representative of more typical mid to larger sized Pilbara creek systems, also possess some more mesic elements which are likely reflective of the substantial aquifer system which is present and discharging from the Bungaroo Valley towards the Jimmawurrada and the Robe River. From Jimmawurrada Creek at the confluence with the Robe River to the south eastern end of the study area; pre-mining groundwater levels in the first 2-3 km were in the vicinity of 2-3 meters below ground level (mbgl). From there groundwater depth increased to approximately 4-5 mbgl near the SCB and then fluctuated between 3 and 8 mbgl throughout the remainder. This suggests that groundwater has historically been somewhat shallow through parts of Jimmawurrada Creek. This is significant, given that groundwater modelling indicates that cumulative drawdown from Mesa J, H and the Coastal Water Supply Project will result in impacts to the aquifer underlying Jimmawurrada Creek riparian vegetation. Under such a scenario, factors affecting continued degrees of access to groundwater by resident vegetation will become important for determining the associated risk of impact to local GDV.

For Australian systems, evidence suggests that reliance on groundwater by terrestrial vegetation is greatly reduced in areas where the water table exceeds a threshold depth, likely to lie between 7 m and 12 m (Benyon, Theiveyanathan, and Doody 2006; Department of Water 2009; O'Grady, Carter, and Holland 2010; Zolfaghar et al. 2014), with 10 m suggested as a general threshold (Eamus, Froend, *et al*. 2006). However vegetation may potentially access groundwater when the water table is between 10 m and 20 m depth, although it is thought to be negligible in terms of contribution to total plant water use (Zencich *et al.* 2002). Beyond 20 m depth, the probability of groundwater as a water source for vegetation is regarded as being low. While meta-analyses by Canadell *et al.* (1996), Schenk & Jackson (2002) and Schenk & Jackson (2005), have shown maximum rooting depths across multiple biomes to extend 20-50m below ground, significant variation exists, and questions remain about the relative success of roots at this depth. Models of vertical root resource distribution (and water extraction) and field observations made by Schenk (2008), suggest that the percentage of root resources present below 10m is almost negligible, and likely to be less than 1% of all root resources available. A study by Kath *et al.* (2014) on groundwater decline and tree change in eastern Australian floodplain landscapes identified groundwater depth thresholds ranging from 12.1 m to 22.6 m for *Eucalyptus camaldulensis* (a dominant component of Jimmawurrada Creek vegetation); beyond which canopy condition declined abruptly. Statistical modelling conducted as part of this study indicated that 27% of variation was explained by survey year, 24% was explained by antecedent groundwater depths, 20% was explained by tree density, and 10% was explained by groundwater decline magnitude. It was hypothesised by Kath *et al.* (2014) that while maximum rooting depths in *E. camaldulensis* were unknown, critical groundwater depths identified in this study may represent a functional physiological limit to effective root growth and water extraction. In the Pilbara, the degrees of adaptation to aridity among local tree populations is thought to be higher (along with lower vegetation densities) and as such more importance tends to be placed on continued groundwater access beyond decline thresholds (associated with water table depths beyond 10 m). This continued access; while facilitating uptake of relatively negligible proportions of tree water use is considered highly important for the maintenance of turgor within trees and thus the avoidance of water stress induced mortality at key seasonal times.

Groundwater Modelling and Potential for Impacts Associated With Development of Mesa H

Modelled cumulative groundwater changes as a result of the ongoing operations at Mesa J (including the Southern Cutback Borefield) and the Coastal Water Project, combined with the development of Mesa H, are predicted to result in the initial 12 km stretch of Jimmawurrada Creek (from the confluence with the Robe River) experiencing significant groundwater height changes. Within the initial most sensitive stretch of Jimmawurrada Creek (approximately 3 km), this height change is modelled to be in the order of 1-8 m (increasing at distance from the confluence), with 4-10 m of groundwater drawdown experienced in the following 5 km stretch (i.e. from the vicinity of the corner of the creek closest to the SCB) (Rio Tinto 20189. Upstream of this stretch and away from discharge influence, modelled drawdown trends within the final approximate 4 km stretch of Jimmawurrada Creek are similar (4-8 m) depending on timing, with similar but generally greater drawdown than experienced in downstream reaches predicted for the year 2037. Beyond 2037, at the end of the Mesa H and Mesa J mine life and subsequent end of dewatering / water demand, groundwater levels in this area are expected to begin to recover. Plate 5-2 provides a spatial representation of some of the most relevant metrics from this groundwater modelling for local vegetation.

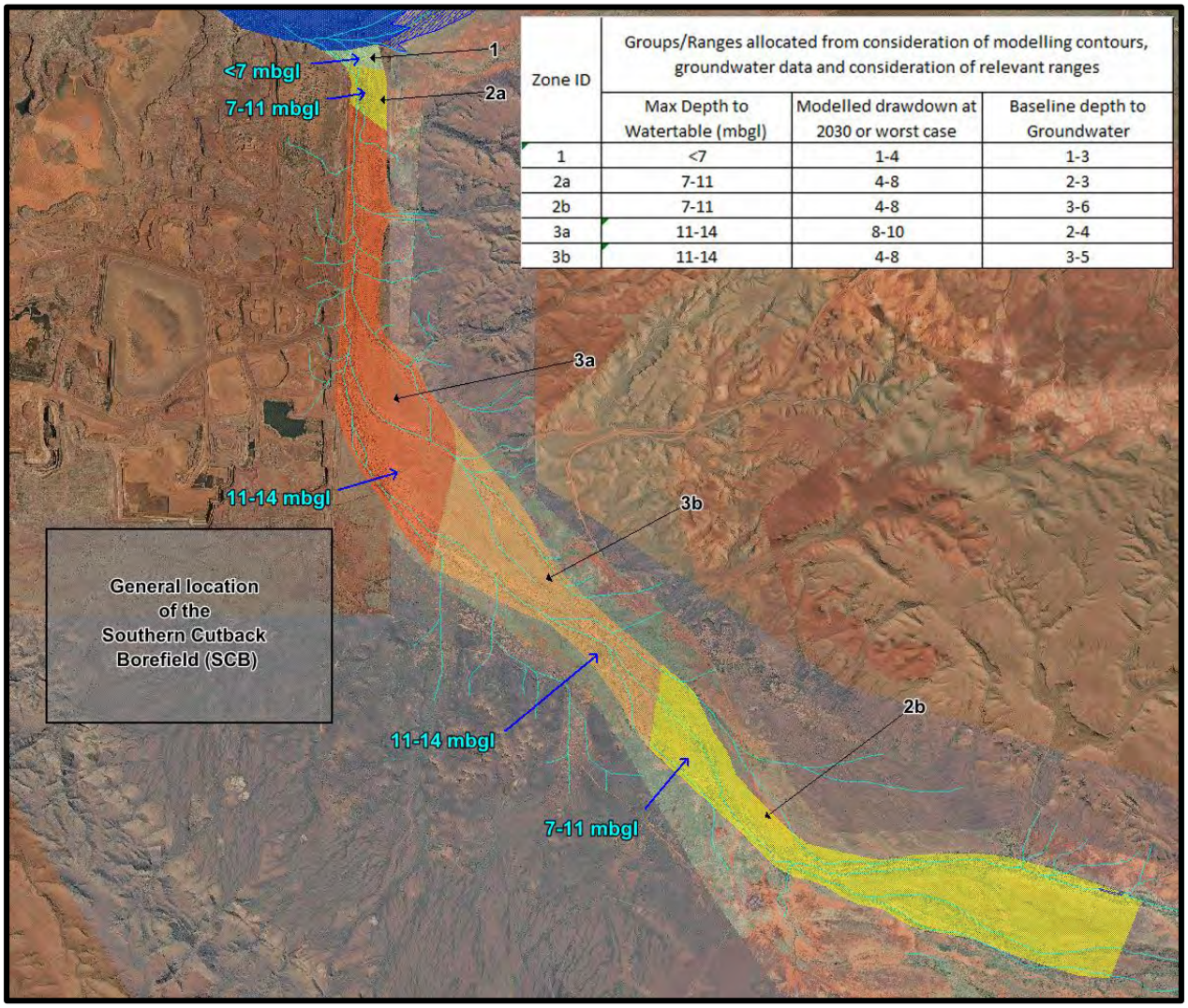
Based on current groundwater modelling (groundwater modelling from Rio Tinto 2019a), the first 0.2 km stretch of Jimmawurrada Creek from the confluence (represented by Zone 1 in Plate 5-2 and equating to approximately 2% of the modelled section of Jimmawurrada Creek), will experience a maximum depth to groundwater in 2030 of approximately <7 mbgl. Under such a scenario, groundwater should still be directly[3] and indirectly[4] accessible to overstorey vegetation, with some potential for indirect access by understorey constituents. However, some impacts are considered likely for smaller scale OPV communities present in this zone, irrespective of perceived degrees of groundwater access. See Plate 5-2 for approximate mapping of the maximum groundwater depth modelled to occur at 2030 (or the worst case scenario) within the relevant potential impact zones.

Approximately 43% of the modelled zone of Jimmawurrada Creek is represented by the following ~0.5 km creek stretch (0.2-0.7 km from the confluence) and the most upstream ~4.7 km stretch (7.3-12 km from the confluence) within the modelling area (Zone 2a & 2b in Plate 5-2). In this zone maximum depth to groundwater is modelled to be in the order of 7-11 mbgl at 2030. In addition, parts of the larger upstream stretch (7.3-12 km from the confluence) will also experience a similar depth to water later in the modelling period at 2037. Under such a scenario groundwater should still be directly and indirectly accessible to overstorey vegetation. Access for understorey vegetation is unclear, and while some understorey vegetation components may potentially maintain indirect access, this is dependent on multiple factors. Furthermore, the importance of the presence/absence of access to groundwater for understorey vegetation is not only very species dependent but is very dependent on antecedent conditions and generally this aspect of riparian ecology is poorly understood. In the case of Jimmawurrada Creek, it seems unlikely that groundwater access is a significant water source for understorey vegetation, but in some more mesic stretches it may play a role. Through the downstream

[3] Direct groundwater access is pertaining to roots directly in contact with the saturated zone of underlying aquifers.

[4] Indirect groundwater access is pertaining to roots being able to access water present in the soil profile but representing water sourced from the aquifer and forming the unsaturated zone directly above the underlying aquifer (including but not restricted to the capillary fringe) where varying degrees of capillary rise (or capillarity – forces influenced by matric and soil water potentials) can be present.

portion of this modelling group (0.2-0.7 km from the confluence) potential impacts are also likely for smaller scale OPV communities present in this area irrespective of perceived access.



Zone ID	Groups/Ranges allocated from consideration of modelling contours, groundwater data and consideration of relevant ranges		
	Max Depth to Watertable (mbgl)	Modelled drawdown at 2030 or worst case	Baseline depth to Groundwater
1	<7	1-4	1-3
2a	7-11	4-8	2-3
2b	7-11	4-8	3-6
3a	11-14	8-10	2-4
3b	11-14	4-8	3-5

Plate 5-2: Approximate mapping of the modelled maximum depth to groundwater groups (meters below ground (mbgl)) at 2030 (blue labels and arrows) for the relevant stretch of Jimmawurrada Creek*.

*** Includes delineation of the relevant potential impact zones (1-3) and table of other relevant hydrological modelling data for each zone such as; grouped maximum depth to water-table below ground level, groupings for modelled drawdown and groupings for approximate baseline (pre-mining) depth to water-table below ground level.**

Of the remainder of the drawdown modelled section of Jimmawurrada Creek (~55% or 6.6 km), and representing the central stretch, broadly located adjacent to Mesa J and the SCB (Zone 3; Plate 5-2), the maximum depth to water table is modelled as being between 11-14 mbgl at 2030. Under such a scenario, direct groundwater access is likely to be maintained by at least a portion (the more mature portion) of the overstorey riparian components. Furthermore indirect[5] access to groundwater should

[5] Indirect groundwater access is pertaining to roots being able to access water present in the soil profile but representing water sourced from the aquifer and forming the unsaturated zone directly above the underlying aquifer (including but not restricted to the capillary fringe) where varying degrees of capillary rise (or capillarity – forces influenced by matric and soil water potentials) and water delivery can be present.

be maintained by most riparian trees. However regardless of the maintenance of indirect or direct groundwater access; its acknowledged than where the water table is deeper than 10-12 mbgl, the relative contribution of groundwater to the environmental water requirements of overstorey phreatophytes is thought to be limited.

Limitations on groundwater access applied by the dimensions of local alluvial formations is also an important factor to consider in relation to the maintenance of groundwater access by GDV. At the deepest part of the Jimmawurrada Creek Alluvial Aquifer channel (the thalweg), alluvial depths are interpreted from borehole data, where available, to range from 28-40m deep. However; the denser riparian vegetation communities are not necessarily aligned with the thalweg of the alluvial aquifer channel. Based on available borehole data, the flanks of the alluvial formation ranges from 14-28m deep, and on the periphery of these outer zones, alluvial depths may be even shallower..

Based on the above observed ranges in alluvial depth, an ultimate depth to groundwater in the realm of 15m, while temporary, would broadly coincide with areas where alluvial formations extend deeper than the maximum water table depth. This means that vegetation should not experience a situation where their root systems no longer have access to groundwater saturated alluvials, notwithstanding the potential that root access to this depth may be constrained by other factors (i.e. lack of an inherent capability to or available stimuli to root that deep). Despite this; variability in channel morphology and vegetation distribution does determine that if modelled drawdown in this stretch is realised and does lead to groundwater levels extending as deep as 14 mbgl (or greater), stress associated with complete groundwater access removal from vegetation may occur in localised areas. However; this is considered unlikely based on the estimates of alluvium thickness. While this is a potential issue (but considered unlikely) for vegetation overlying some small stretches within approximately 8 km of the modelled zone, the remainder of the modelling area will not be exposed to this issue as it is also proven to have a greater alluvial sediment thickness than 15m on the creek flanks surrounding the thalweg. In addition to this; approximately 90 % of the alluvial layers in the modelled stretch of Jimmawurrada creek overlie a basement lithology of Channel Iron Deposit (**CID**), and as such, the degree of porosity, structural complexity, and inherent water holding capacity of both the lithology and sediments, may positively influence water availability at the alluvial-CID interface.

While there is limited information regarding the interface between the alluvial basement and the underlying formations, clay formations are known to be common in the area, and the potential for fine, moisture holding formations at the alluvial basement are elevated. Such formations may not only be important for holding water through dry periods, but may also be important for reducing the influence of aquifers in the underlying rock layers on those present in the alluvium. Dell et al., (1983) explored the role of root channels in deep soil profiles through coring and excavation methods in the jarrah forest of South West Western Australia. Fine Roots of *Eucalyptus marginata* were shown to penetrate the clay matrix and occupy the entire profile down to weathered basement at depths of up to 40 m. Such root channels were found to extend vertically from fissures and conduits in the shallow subsurface caprock layer deep in the clay subsoil. The channels are considered permanent features of the profile and are occupied by successive generations of trees (Dell *et al.* 1983). For roots to form channels this deep and into the fissures of basement lithologies and over successive generations, moisture sources (likely from fractured rock aquifers) in these zones must be important, and are potentially what is enticing roots down to such depths (rather than random establishment). It is for the same reason that potential moisture sources in the weathered bedrock interface between the alluvium and the porous CID layer in Jimmawurrada Creek may also represent relevant water source for trees if groundwater levels are significantly reduced.

Despite the potential for the formation of accessible fractured rock aquifers in the interface between the alluvial basement and weathered bedrock zone; information on such characteristics are minimal and thus unable to be considered as an important alternative water source. This is also compounded by the potential, in some small areas, for the groundwater table to recede down to the base of the local alluvial formations. In such situations, however spatially small they may be; the potential for impacts to overlying GDV increase substantially given that groundwater access may be removed altogether. Regardless of the presence of periods of negligible access, or degrees of groundwater access removal, the overriding factor of importance is that at least partial recovery of groundwater tables has been shown to occur annually (and at times more frequently). As a consequence, cycles of exposure to water stress and return to more acceptable conditions, have been and will be (and will continue to be) facilitating some degree of hydraulic adaptation within local vegetation communities to periodic water stress.

In situations where groundwater contact with tree roots may be removed through the general drop of water tables below existing root systems (however deep they may range), the rate of drawdown is modelled to be slow enough (average < 1 m per year, but at times greater and accompanied by short term recovery cycles as shown in Figure 5-1) in order for roots to successfully follow groundwater as it declines. This process will increase the ability of trees (particularly young to semi-mature trees) to be able to slowly adapt and potentially establish larger root masses. The development of larger root masses than previously held will help increase the ability of trees to rely more heavily on sourcing water needs from the vadose zone and associated surface water driven replenishment events.

As addressed earlier; some understorey changes are likely as a result of changes predicted by the groundwater modelling. However it is important to point out that the majority of mesic understorey components within Jimmawurrada Creek are crowded around the low flow channels where surface water inputs are generally focused. The regular surface water inputs present in these zones (along with intermittent discharge in the downstream stretches) should therefore go some way to minimising changes within the more sensitive understorey components. Despite this; structural and potentially compositional changes in the understorey vegetation are possible in the historically mesic zones experiencing the higher degrees of aquifer drawdown.

General Responses of Riparian Vegetation in Jimmawurrada Creek through Anthropogenic and Climatic Influences

As is typical in the overstorey of any woodland community when groundwater access and thus water availability is reduced, assuming the rate and severity of change stay below certain thresholds; trees will typically respond[6] by reducing their Huber value (ratio of leaf area to sapwood area) in the form of reductions in canopy leaf area (Carter & White 2009). In various locations/cases this can ultimately lead to tree mortality as a result of spatial spikes in soil dryness and the resulting competition for water resources. While mechanisms surrounding water stress induced mortality are many and often hard to attribute, the distribution and extent of mortality linked to water stress are likely to come in two key forms (assuming more extended drought conditions are not in effect). Spatial clusters of elevated mortality occurring more sporadically and which depend on smaller scale edaphic

[6] Use of the term respond is used loosely here, as this may more accurately be described as a flow on effect from multiple feedback loops within the physiology of a plant. In the shorter term this may result in leaf drop, and reductions in LAI without obvious changes in sapwood resources.

characteristics interacting with areas of elevated competition for water resources. Such clusters are generally not very obvious, as they tend to be scattered among more average conditioned vegetation. Alternatively, in arid environments such as the Pilbara, mortality events are likely to eventuate as a result of increased amounts of dead wood in canopies (from cavitation and death of some branches), increasing the susceptibility of trees to succumb to fire. These mortality events tend to convert overall to reductions in basal area over certain communities as tree density (along with leaf area per hectare) transitions to a value which the new soil moisture regime can support in the short to long term.

Current modelling (Rio Tinto 2019) suggests that the greatest rate of change in groundwater height along the creek is predicted to occur between 2027 and 2030 with a cumulative drawdown rate of approximately 2.5 m/year. However, drawdown and aquifer recovery rates of 2m/year will happen frequently depending on duration of the dry season and the frequency of rainfall events (Figure 5-1). Between 2023 and 2036 the average linear rate of drawdown during this entire period is predicted to be approximately 0.2 m/year.

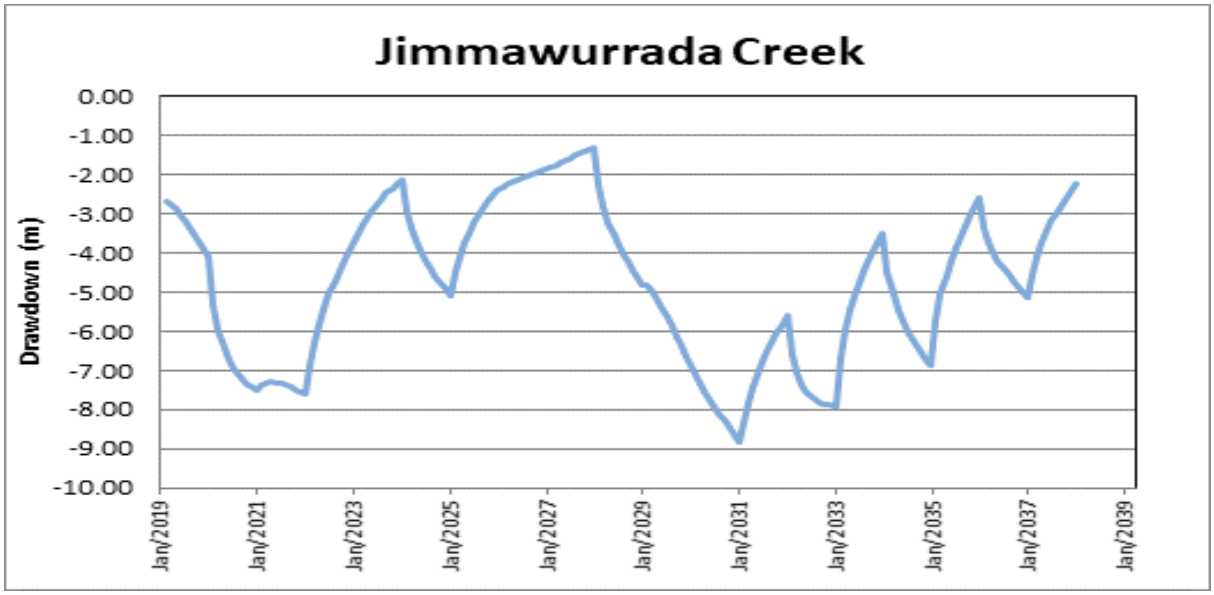


Figure 5-1: Graph showing the maximum rates of drawdown modelled to occur along the stretch of Jimmawurrada creek where groundwater heights are influenced by the Mesa H proposal.

The modelled degree of vertical change to groundwater levels is generally thought to be within ranges which local facultative phreatophytes can successfully adapt to (i.e. 1 cm per day which translates to more than 3 meters per year; Kranjcec, Mahoney and Rood 1998; Scott, Shafroth, and Auble 1999; Horton and Clark 2001; and Canham 2011). This suggests that, assuming an extreme drought does not temporally align with spikes in drawdown induced water stress; rates of change are unlikely to bring about significant threshold induced mortality events and extreme canopy decline. Furthermore, such rates of groundwater table decline are considered well within the range with which tree root growth is thought capable of tracking down through the alluvial profile in order to maintain contact and groundwater access. However, it is acknowledged that aquifer drawdown based on groundwater modelling does not accurately predict rates of drawdown at a smaller scale. Instead, as the degrees of drawdown predicted are realised in the environment, cycles of fluctuation in the water table (as depicted in Figure 5-1) will be likely and as such there will be periods of slower change and periods of accelerated change, often followed by some level of recovery in the shorter term. As a result and also through consideration of the historical groundwater levels in the area; small sections of

Jimmawurrada Creek such as the area adjacent to and further upstream of the SCB (see Plate 5-2; where drawdown of 4-8 and 8-9 m may be experienced), also have the potential to experience threshold-induced mortality events and significant canopy decline as a result of water stress. However, this same area is also where significant changes in groundwater height, in the order of that predicted to occur as a result of the proposal, have already been experienced (along with subsequent recovery) due to climatic changes and historical dewatering of local aquifers. Therefore, it is assumed that these riparian communities have already undergone some degree of adaptation to hydrological change and as such should possess increased resilience to future hydrological change of a similar magnitude.

So far, groundwater changes broadly linked to climatic shifts, but also partly attributable to local bore fields have seen canopy cover changes in the order of 10-40 % in communities surrounding the low flow channel (Rio Tinto 2018c). However; baseline monitoring in the area of interest along Jimmawurrada Creek is limited to 2017 onwards, and as a result, does not provide a full context with which to quantify the impact of recent hydrological changes experienced in the study area. This means that the following changes are summarised from a limited number of tree health sites (monitored back to 2012), some located near to, but all positioned upstream of the modelled influence of the SCB and Mesa H/J. In addition, some localised increases in mortality (patchy, and generally not coinciding spatially with monitoring sites), likely to be in the order of 1-5 % of local overstorey populations have also been observed, but not monitored.

Based on the hydrogeological modelling results, there is a risk that certain riparian zones within Jimmawurrada Creek may suffer impacts to overstorey and some understorey components. Such impacts are most likely to be a result of reduced access to groundwater in combination with increased competition for water. Increased competition for water is thought to be linked to elevated tree stand densities which appear to have established as a result of historical groundwater access, discharge and the climatically wet period appearing in the rainfall records between 1988 and 2011. However; certain local conditions may also determine that the riparian systems in the area possess an increased degree of resilience to changes in the broader groundwater table.

Sediments in the Jimmawurrada Creek area appear to be relatively fine, so the alluvial deposits below creek bed and bank communities are likely to possess relatively high soil matric potentials. Water in soil profiles typically moves from areas of high water potential to areas of low water potential (i.e. wet soil to dry soil), with such water potential gradients often formed by root zones drying the soil in their areas of influence (Hillel 1998). While the force of gravity generally restricts water moving too far along such gradients against this force (i.e. vertically up), soil matric potentials (broadly a product of soil particle sizes and surface characteristics) essentially influence the size of capillary forces and have the power to draw water up from saturated/unsaturated areas along water potential gradients (Hillel 1998). For this reason soil matric potentials and processes which set up soil water potential gradients in the soil, have an ability to influence the distance over which water can be transported vertically (up) from the saturated zones associated with local aquifers. As a result wetting and drying cycles in the soil profile down to average rooting depths have a tendency to create underlying gradients of soil water potential capable of drawing moisture up from the unsaturated zone above the broader water table through capillary rise (via the forces of capillarity (unsaturated soil water movement)). Where soil matric potentials are high and barriers to capillary rise are not present (such as clay lenses), capillary rise can be substantial, and potentially in the order of 2-6 m above the actual water table

height[7]. In arid climates the water delivered by transfer along such gradients is potentially as important as direct connection to the groundwater as it serves the same purpose of maintaining turgor within plant tissues through drought and seasonal water stress periods. As a result groundwater supplementation to the vadose zone along gradients of matric potential has the potential to prevent/diminish substantial decline/mortality events. The potential extent of this type of moisture supplementation to the vadose zone in riparian environments is clearly relatively unknown, but may also represent a key mechanism driving the resilience shown by established arid-zone riparian communities to recorded groundwater changes.

The Robe Valley has recently transitioned from a medium term period (approximately 15+ years) of above average rainfall to a five year period of average to slightly below average rainfall (from 2012) which appeared to be broken by an above average 2016/2017 wet season (See Figure 5-1). A significant drying trend was also noted to reach a peak in 2016 as part of long-term pool monitoring conducted within the Robe River (Streamtec 2017), and within riparian tree canopies monitored as part of a suite of tree health sites within Jimmawurrada Creek (Rio Tinto 2018c). In the section of Jimmawurrada Creek where a good number of bores are located relatively close to the creek (broadly equivalent to zones 2b & 3b in Plate 5-2), bore data has shown that groundwater has dropped between 2-6 m in various locations, with change in the order of 5m and greater located in the creek section closest to the southern cut back Borefield (Rio Tinto 2018d). While a significant component (probably the most substantial component) of the drying trend detected is likely attributable to the climatic influence recorded (and importantly a significant reduction in surface water flows within Jimmawurrada Creek prior to 2016), it is not yet clear how much of this trend is also associated with local anthropogenic groundwater pressures. What is clear is that in the zone where greatest recent groundwater height change has been experienced, beyond a general trend of canopy decline and some patchy clustering of more substantial canopy decline, no significant increases in tree mortality were noticed at the time of survey (and more generally by Rio Tinto monitoring staff). However it is important to note that similar levels of groundwater height change have not been confirmed in the alluvium of Jimmawurrada Creek due to a limited number of bores located directly in this zone. Despite this, it is assumed that a similar degree of change has also occurred in the alluvium. If not, this may be testament to the influence of local surface water regimes, the water holding capacity of alluvial formations in this area and the reduced potential for groundwater changes in the basement to transfer through to the potentially dense alluvial formations above.

When considered in light of the magnitude of hydrological change experienced through the 2014-2018 period (up to 6 m of groundwater drawdown in some areas); the magnitude of canopy decline and particularly mortality observed along key sections of Jimmawurrada Creek appears relatively low. If this is also considered in light of the 2017 canopy regrowth and some recovery within riparian vegetation through such areas; the evidence suggests that at least partial groundwater recovery events are regular, vegetation in the area is relatively robust, and a significant degree of adaptation to new hydrological conditions, particularly within the root-zone may have already occurred and will likely continue to occur.

[7] Estimated based on theoretical graphs provided in various literature, but not backed by good empirical data, rather a guide from theoretical models. This should be assumed to give some indication of hydraulic uplift could be achieved via such pathways rather than suggesting what's occurring in this situation.

Despite more positive rainfall and recharge conditions during the 2016/2017 wet season and some positive 2018 winter rainfall events, 2017/2018 rainfall has generally been below average, with similar trends seen in the creek flow data for Jimmawurrada Creek. This is an important trend given how important groundwater in the Bungaroo valley is, and how tightly linked aquifer recharge is to rainfall/stream-flow in the locality.

If an extended period of drought and a lack of cyclonic events (and associated stream flows) is experienced; natural recharge and thus recovery of the local Bungaroo aquifer and groundwater heights under Jimmawurrada creek; may be heavily reduced. Hydrogeological modelling based on a simulated 50% reduction of natural recharge (Uncertainty run 2; Rio Tinto 2019), suggested that the water table along the Jimmawurrada Creek could be reduced by a further 3m on top of current modelling. However; this does assume below average rainfall/cyclonic events occur and persist for an extended period, which while possible, is relatively unlikely under current short term climate change predictions. Importantly, the nature of the hydrogeological environment of the Bungaroo valley determines that recharge rates per unit area appear broadly high, when compared to other Pilbara aquifer systems. As a result, any decline in water levels brought about by such climatic changes, also have the potential to be ameliorated relatively rapidly under the influence of a cyclone or multiple large tropical rainfall events. However the modelling conducted in the H3 report (Rio Tinto 2019) generally suggests recovery rates of 2m/year will happen frequently depending on the duration of dry season and frequency of rainfall events. This is supported by airborne geophysical data interpretation which suggests that there is a fair degree of hydraulic connectivity between the Jimmawurrada Creek sediments and Bungaroo palaeochannel aquifer in the upper Jimmawurrada area (Rio Tinto 2019).

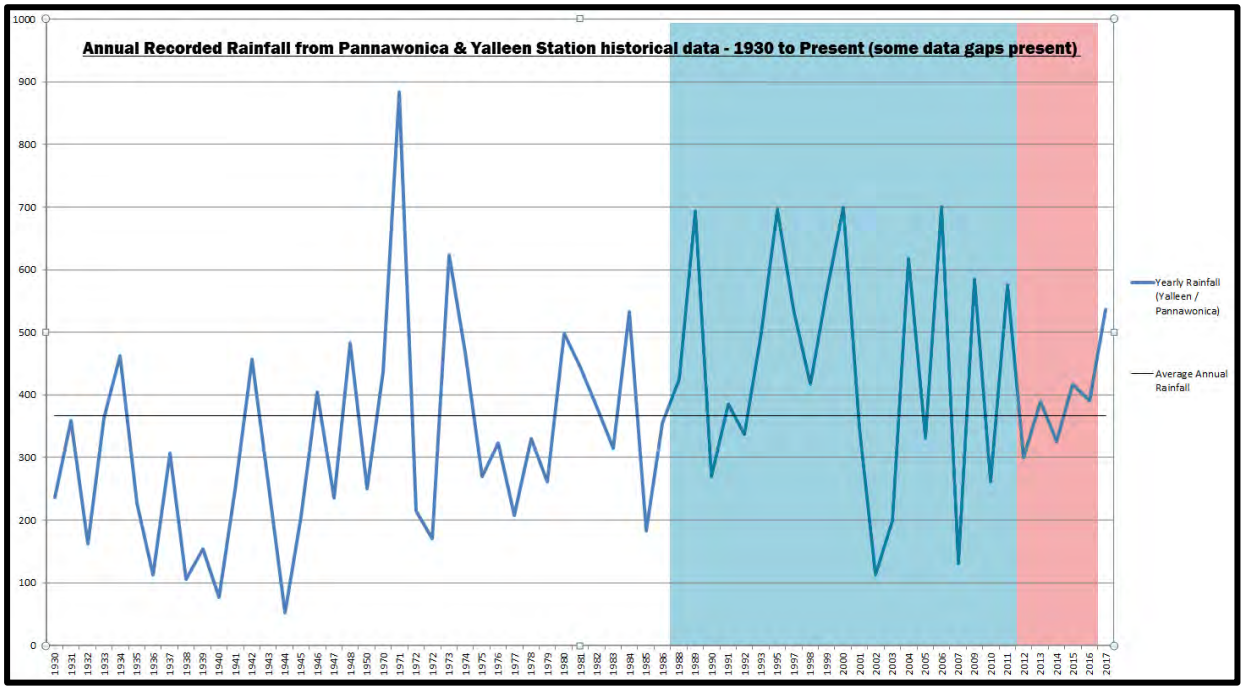


Figure 5-2: Graph of the long term annual rainfall records for Pannawonica and Yalleen Station combined*

*takes advantage of mid-late 1900's Yalleen station data and gaps in this data filled by the Pannawonica data.

6 CONCLUSIONS

Broadly speaking; vegetation communities mapped within the Jimmawurrada Creek study area and excluding communities in the sump/wetland, are relatively equivalent to typical medium to larger sized creekline communities which are well represented throughout the Pilbara. Despite the presence of some atypical mesic floristic components and associations within the upstream reaches of Jimmawurrada Creek (likely associated with hydrological influence form the Bungaroo valley aquifer, the high degree of grazing related disturbance and weed infestation led to the ultimate significance attributed to these communities being reduced. As a result, the key riparian communities which are distributed on and around the main low and high flow channels of the creek are estimated to possess a "Moderate" to "Minor" range of significance. In addition to this, some small areas of C1b/C1bb coded vegetation (OPV), where *Melaleuca argente*a forms a co-dominant component, are present at the Robe River end (Jimmawurrada Creek – Robe River confluence) of the study area. In addition to these areas being quite sensitive to hydrological change, they are also of elevated significance having been attributed a "Moderate-high" significance (where present at baseline) rating as part of this study.

Significant impacts to the more sensitive C1bb community (~0.5 ha interpreted present at baseline) within Jimmawurrada Creek are unlikely but possible given the inherent vulnerability of the resident obligate phreatophytes and the degree of consistency of water access they are likely accustomed to. Significant impacts/changes to the C1b community within Jimmawurrada Creek are likely based on groundwater modelling, but together with the mitigating influence of discharge, surface water inputs, and groundwater recovery cycles, such impacts if realised are unlikely to persist over short to medium time scales. Furthermore this community appears to have established under the influence of discharge and as a result, any transition to a more ephemeral type riparian community is potentially insignificant. Upstream of these communities where greater magnitude drawdown is likely; a slow transition to smaller canopies (i.e. reduced Leaf Area Index) and reduced tree densities (or basal areas) within communities currently accessing and relying upon groundwater is likely. The Facultative phreatophytic type vegetation communities present in such zones of the creek are generally known to be more resistant to hydrological change and much better at transitioning to utilising alternative water sources for the vast majority of their requirements. As a result, it is predicted that some level of change (minimal compositional changes (understorey) and potentially some structural change (reduced cover) in overstorey/understorey components) is likely within riparian vegetation communities within Zones 1 – 3 along Jimmawurrada Creek, but that there is potential for more pronounced change in certain zones (particularly Zone 3a (southern half), and 3b, and the western half of 2b south (Plate 5-2)), where elevated stand densities occur adjacent to the Mesa J SCB.

Within the Sump/Wetland area, communities were attributed a "Moderate-High" significance and were also determined to possess "Medium (+) to High" sensitivity to hydrological change. While the Sump/Wetland communities may be dependent on small perched aquifers and therefore potentially exist independent of the broader groundwater table, the cumulative drawdown modelled as part of the Mesa H Proposal is not predicted to have a detectable influence that far to the east.

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7 APPENDICES

Appendix 1: Vegetation structure and condition scale used for vegetation description and mapping formulated within this study.

Vegetation Structure and Condition Scale

Vegetation Structural Classes*

Stratum	Canopy Cover (%)				
	70-100%	30-70%	10-30%	2-10%	<2%
Trees over 30 m	Tall closed forest	Tall open forest	Tall woodland	Tall open woodland	Scattered tall trees
Trees 10-30 m	Closed forest	Open forest	Woodland	Open woodland	Scattered trees
Trees under 10 m	Low closed forest	Low open forest	Low woodland	Low open woodland	Scattered low trees
Shrubs over 2 m	Tall closed scrub	Tall open scrub	Tall shrubland	Tall open shrubland	Scattered tall shrubs
Shrubs 1-2 m	Closed heath	Open heath	Shrubland	Open shrubland	Scattered shrubs
Shrubs under 1 m	Low closed heath	Low open heath	Low shrubland	Low open shrubland	Scattered low shrubs
Hummock grasses	Closed hummock grassland	Hummock grassland	Open hummock grassland	Very open hummock grassland	Scattered hummock grasses
Grasses, Sedges, Herbs	Closed tussock grassland / bunch grassland / sedgeland / herbland	Tussock grassland / bunch grassland / sedgeland / herbland	Open tussock grassland / bunch grassland / sedgeland / herbland	Very open tussock grassland / bunch grassland / sedgeland / herbland	Scattered tussock grasses / bunch grasses / sedges / herbs

* Based on Muir (1977), and Aplin's (1979) modification of the vegetation classification system of Specht (1970): Aplin T.E.H. (1979). The Flora. Chapter 3 In O'Brien, B.J. (ed.) (1979). *Environment and Science*. University of Western Australia Press; Muir B.G. (1977). Biological Survey of the Western Australian Wheatbelt. Part II: Vegetation and habitat of Bendering Reserve. *Records of the Western Australian Museum*, Suppl. No. 3; Specht R.L. (1970). Vegetation. In: *The Australian Environment*. 4th edn (Ed. G.W. Leeper). Melbourne.

Vegetation Condition Scale*

E = Excellent (=Pristine of BushForever) Pristine or nearly so; no obvious signs of damage caused by the activities of European man.
VG = Very Good (= Excellent of BushForever) Some relatively slight signs of damage caused by the activities of European man. For example, some signs of damage to tree trunks caused by repeated fire, the presence of some relatively non-aggressive weeds such as **Sonchus oleraceus* or **Cucumis* spp., or occasional vehicle tracks.
G = Good (= Very Good of BushForever) More obvious signs of damage caused by the activities of European man, including some obvious impact on the vegetation structure such as that caused by low levels of grazing or by selective logging. Weeds as above, possibly plus some more aggressive ones such as **Cenchrus* spp.
P = Poor (= Good of BushForever) Still retains basic vegetation structure or ability to regenerate to it after very obvious impacts of activities of European man, such as grazing, partial clearing (chaining) or frequent fires. Weeds as above, probably plus some more aggressive ones such as **Cenchrus* spp.
VP = Very Poor (= Degraded of BushForever) Severely impacted by grazing, very frequent fires, clearing or a combination of these activities. Scope for some regeneration but not to a state approaching good condition without intensive management. Usually with a number of weed species including very aggressive species such as **Prosopis* spp.
D = Completely Degraded (= Completely Degraded of BushForever) Areas that are completely or almost completely without native species in the structure of their vegetation; ie. areas that are cleared or 'parkland cleared' with their flora comprising weed or crop species with isolated native trees or shrubs.

* Based on Trudgen M.E. (1988). A Report on the Flora and Vegetation of the Port Kennedy Area. Unpublished report prepared for Bowman Bishaw and Associates, West Perth.

Appendix 2: Associated species recorded in each mapped vegetation type.

Veg Code	GDE / Community Summary Info	GDE Type	Vegetation Description	Equivalent Astron 2015, or Biota 2012 code.
C1A (Only present at confluence with the Robe River)	Mature MA and EC dominated Open forest to Low Woodland	**OPV-B**	*Acacia ampliceps, Acacia trachycarpa, Acacia tumida* var. *pilbarensis, Alternanthera nana, Amaranthus undulatus, Amaranthus cuspidifolius, Argemone ochroleuca* subsp. *ochroleuca*, Boerhavia coccinea, Capparis spinosa* var. *nummularia, Cenchrus ciliaris*, Centipeda minima* subsp. *macrocephala, Cleome viscosa, Clerodendrum tomentosum* var. *lanceolatum, Crotalaria medicaginea* var. *neglecta, Cucumis melo, Cymbopogon ambiguus, Cyperus iria, Cyperus vaginatus, Echinochloa colona*, Euphorbia australis, Gomphrena cunninghamii, Cyperus vaginatus, Eucalyptus victrix, Goodenia lamprosperma, Gossypium robinsonii, Ipomoea muelleri, Juncus kraussii, Notoleptopus decaisnei, Passiflora foetida* subsp. *hispida*, Petalostylis labicheoides, Pluchea rubelliflora, Ptilotus gomphrenoides, Rhynchosia minima, Schenkia clementii, Sesbania cannabina, Sesbania formosa, Sporobolus australasicus, Stemodia grossa, Tinospora smilacina, Sonchus oleraceus*, Tephrosia rosea* var. *Fortescue Creeks (M.I.H. Brooker 2186), Vigna lanceolata, Waltheria indica,* and **Vachellia farnesiana.*	*EcMaCvCspp (Astron 2015) or MaEcCv (Astron 2016*)*
C1b	Semi-Mature MA and EC dominated Low Woodland	**OPV-C**	*Acacia ampliceps, Acacia colei var. ileocarpa, Acacia trachycarpa, Acacia tumida* var. *pilbarensis, Alternanthera nana, Argemone ochroleuca* subsp. *ochroleuca*, Capparis spinosa* var. *nummularia, Cenchrus ciliaris*, Cleome viscosa, Clerodendrum tomentosum* var. *lanceolatum, Cucumis melo, Cymbopogon ambiguus, Cynodon dactylon*, Cyperus vaginatus, Echinochloa colona*, Eucalyptus victrix, Ficus aculeata, Flueggea virosa* subsp. *melanthesoides, Gossypium robinsonii, Ipomoea muelleri, Juncus kraussii, Passiflora foetida* subsp. *hispida*, Petalostylis labicheoides, Rhynchosia bungarensis, Sesbania formosa, Sesbania cannabina, Sonchus oleraceus*, Tephrosia rosea* var. *Fortescue Creeks (M.I.H. Brooker 2186) , Vachellia farnesiana*,* and *Vigna lanceolata.*	*Similar to EcMaCvCspp (Astron 2015) or similar to MaEcCv (Astron 2016*)*
C2AA	Large Mesic EC dominated Open Forest representations	**FPV-A**	*Acacia ampliceps, Acacia bivenosa, Acacia colei var. colei, Acacia trachycarpa, Acacia ancistrocarpa, Acacia maitlandii, Acacia pyrifolia* var. *pyrifolia, Acacia tumida* var. *pilbarensis, Argemone ochroleuca* var. *ochroleuca*, Cenchrus setiger*, Cenchrus ciliaris*, Cleome viscosa, Crotalaria medicaginea var. neglecta, Cucumis variabilis, Cucumis melo, Cyperus vaginatus, Eucalyptus victrix, Eulalia aurea, Euphorbia schultzii, Hybanthus aurantiacus, Ipomoea muelleri, Melaleuca glomerata, Melaleuca argentea, Petalostylis labicheoides, Phyllanthus maderaspatensis, Senna notabilis, Sesbania cannabina, Sesbania formosa, Stemodia grossa, Tephrosia rosea* var. *Fortescue creeks* (M.I.H. Brooker 2186), *Trachymene oleracea* subsp. *Oleracea, Triodia epactia, Typha domingensis, Vachellia farnesiana** and *Vigna lanceolata* var. *lanceolata.*	*Similar to EcCv (Astron 2015) or EcEvAtrApyPlTw (Astron 2016*)*

Veg Code		GDE / Community Summary Info	GDE Type	Vegetation Description	Equivalent Astron 2015, or Biota 2012 code.
C2A		EC dominated Open Forest	**FPV-A**	*Acacia ampliceps, Acacia bivenosa, Acacia colei* var. *colei, Acacia trachycarpa, Acacia ancistrocarpa, Argemone ochroleuca var. ochroleuca*, Cenchrus setiger*, Cenchrus ciliaris*, Cleome viscosa, Cucumis variabilis, Cyperus vaginatus, Eucalyptus victrix, Eulalia aurea, Euphorbia schultzii, Hybanthus aurantiacus, Melaleuca glomerata, Melaleuca argentea, Petalostylis labicheoides, Phyllanthus maderaspatensis, Sesbania formosa, Sesbania cannabina, Stemodia grossa, Trachymene oleracea* subsp. *Oleracea, Typha domingensis,* and *Vigna lanceolata* var. *lanceolata.*	*Similar to EcCv (Astron 2015) or EcEvAtrApyPlTw (Astron 2016*)*
C2A-Cr	**C2AA-Cr**	EC dominated woodland to open forest - Creek	**FPV-A**	*Acacia bivenosa, Acacia colei var. colei, Acacia sclerosperma, Acacia trachycarpa, Acacia ancistrocarpa, Argemone ochroleuca var. ochroleuca*, Cenchrus setiger*, Cenchrus ciliaris*, Cleome viscosa, Corchorus sidoides, Cucumis variabilis, Cyperus vaginatus, Eucalyptus victrix, Eulalia aurea, Euphorbia schultzii, Gymnanthera cunninghamii, Hybanthus aurantiacus, Lobelia arnhemica, Malvastrum americanum*, Melaleuca glomerata, Melaleuca argentea, Melaleuca bracteata, Petalostylis labicheoides, Phyllanthus maderaspatensis, Phoenix dactylifera, Rhynchosia minima, Sesbania formosa, Sesbania cannabina, Stemodia grossa, Stylobasium spathulatum, Themeda triandra, Trachymene oleracea subsp. Oleracea, Typha domingensis, Vachellia farnesiana, and Vigna lanceolata var. lanceolata.*	EcEvMgCYPvCEc (Biota 2012)
	C2A-Cr	EC dominated woodland to open forest - Creek	**FPV-A**	*Acacia bivenosa, Acacia colei var. colei, Acacia trachycarpa, Acacia ancistrocarpa, Acacia sclerosperma, Argemone ochroleuca var. ochroleuca*, Cenchrus setiger*, Cenchrus ciliaris*, Cleome viscosa, Corchorus sidoides, Cucumis variabilis, Cyperus vaginatus, Eucalyptus victrix, Eulalia aurea, Euphorbia schultzii, Hybanthus aurantiacus, Malvastrum americanum, Melaleuca glomerata, Melaleuca bracteata, Petalostylis labicheoides, Phyllanthus maderaspatensis, Rhynchosia minima, Sesbania formosa, Sesbania cannabina, Stemodia grossa, Stylobasium spathulatum, Themeda triandra, Trachymene oleracea subsp. Oleracea, Typha domingensis, Vachellia farnesiana, and Vigna lanceolata var. lanceolata.*	EcEvMgCYPvCEc (Biota 2012)
C2A-SW		EC dominated woodland/Mesic open shrubland	**FPV-A**	*Eucalyptus victrix, Acacia sclerosperma, Acacia colei var. colei, Acacia pruinocarpa, *Cenchrus setiger, Centaurium spicatum, Cynodon dactylon, Eragrostis surreyana, *Flaveria trinervia, *Lactuca serriola, *Malvastrum americanum, Melaleuca glomerata, Melaleuca bracteata, *Passiflora foetida var. hispida, Pluchea rubelliflora, Rhynchosia minima, and Setaria dielsii, Stylobasium spathulatum, Triodia angusta, and Vachellia farnesiana.*	Wetland-Mosiac (Biota 2012)

Veg Code		GDE / Community Summary Info	GDE Type	Vegetation Description	Equivalent Astron 2015, or Biota 2012 code.
C2B		EC & EV co-dominated Open Forest	**FPV-B**	*Acacia ampliceps, Acacia bivenosa, Acacia colei, Acacia trachycarpa, Acacia ancistrocarpa, Acacia pyrifolia* var. *pyrifolia, Cenchrus setiger*, Cenchrus ciliaris*, Cleome viscosa, Cyperus vaginatus, Eulalia aurea, Gossypium robinsonii, Indigofera colutea, Ipomoea muelleri, Melaleuca glomerata, Melaleuca argentea, Petalostylis labicheoides, Sesbania cannabina, Triodia epactia, Typha domingensis,* and *Vachellia farnesiana**	*Similar to EcEvCspp (Astron 2015) or EcEvAtrApyPlTw (Astron 2016*)*
C2B-Cr	**C2BB-Cr**	EC & EV dominated woodland - Creek	**FPV-B**	*Acacia bivenosa, Acacia colei var. colei, Acacia trachycarpa, Acacia ancistrocarpa, Acacia pyrifolia* var. *pyrifolia, Cenchrus setiger*, Cenchrus ciliaris*, Cleome viscosa, Cyperus vaginatus, Eulalia aurea, Ficus aculeata, Gossypium robinsonii, Indigofera colutea, Ipomoea muelleri, Melaleuca bracteata, Melaleuca glomerata, Petalostylis labicheoides, Phyllanthus baccatus, Phoenix dactylifera, Sesbania formosa, Sesbania cannabina, Stylobasium spathulatum, Triodia epactia, Typha domingensis,* and *Vachellia farnesiana*.*	EcEvMgCYPvCEc (Biota 2012)
	C2B-Cr	EC & EV dominated woodland - Creek	**FPV-B**	*Acacia bivenosa, Acacia colei var. colei, Acacia trachycarpa, Acacia ancistrocarpa, Acacia pyrifolia* var. *pyrifolia, Cenchrus setiger*, Cenchrus ciliaris*, Cleome viscosa, Cyperus vaginatus, Eulalia aurea, Gossypium robinsonii, Indigofera colutea, Ipomoea muelleri, Melaleuca glomerata, Petalostylis labicheoides, Sesbania cannabina, Stylobasium spathulatum, Triodia epactia,* and *Vachellia farnesiana*.*	EcEvMgCYPvCEc (Biota 2012)
C2A-B		EC dominated Woodlands	**FPV-A**	*Acacia bivenosa, Acacia colei* var. *colei, Acacia trachycarpa, Acacia ancistrocarpa, Acacia trachycarpa, Argemone ochroleuca* var. *ochroleuca*, Cenchrus setiger*, Cenchrus ciliaris*, Cleome viscosa, Cucumis variabilis, Cyperus vaginatus, Eucalyptus victrix, Eulalia aurea, Euphorbia schultzii, Hybanthus aurantiacus, Melaleuca glomerata, Melaleuca argentea, Petalostylis labicheoides, Phyllanthus maderaspatensis, Sesbania cannabina, Stemodia grossa, Trachymene oleracea* subsp. *Oleracea, Typha domingensis,* and *Vigna lanceolata* var. *lanceolata.*	*EcCv (Astron 2015) or EcEvAtrApyPlTw (Astron 2016*)*
C2B-B		EC & EV co-dominated Woodland	**FPV-B**	*Acacia bivenosa, Acacia colei, Acacia trachycarpa, Acacia ancistrocarpa, Acacia pyrifolia* var. *pyrifolia, Cenchrus setiger*, Cenchrus ciliaris*, Cleome viscosa, Cyperus vaginatus, Cyperus vaginatus, Eulalia aurea, Gossypium robinsonii, Indigofera colutea, Ipomoea muelleri, Melaleuca argentea, Melaleuca glomerata, Petalostylis labicheoides, Sesbania cannabina, Triodia epactia, Typha domingensis,* and *Vachellia farnesiana**	*EcEvCspp (Astron 2015) or EcEvAtrApyPlTw (Astron 2016*)*

Veg Code	GDE / Community Summary Info	GDE Type	Vegetation Description	Equivalent Astron 2015, or Biota 2012 code.
C2C	EV Dominated Woodland	**FPV-C**	*Acacia pyrifolia* var. *pyrifolia, Acacia bivenosa, Acacia maitlandii, Acacia pyrifolia* var. *pyrifolia, Acacia trachycarpa, Boerhavia coccinea, Cenchrus setiger*, Cenchrus ciliaris*, Cleome viscosa, Crotalaria medicaginea* var. *neglecta, Gossypium robinsonii, Hybanthus aurantiacus, Ipomoea muelleri, Rhynchosia minima, Senna notabilis, Stemodia grossa, Tephrosia rosea* var. *Fortescue creeks* (M.I.H. Brooker 2186), *Triodia epactia, Triumfetta appendiculata, Vachellia farnesiana*,* and *Waltheria indica.*	*EvMgCv (Astron 2015) or EvAtrTwCspp (Astron 2016*)*
C2C-Cr	EV dominated Low Woodland - Creek	**FPV-C**	*Acacia pyrifolia var. pyrifolia, Acacia bivenosa, Acacia pyrifolia var. pyrifolia, Acacia trachycarpa, Boerhavia coccinea, Cenchrus setiger*, Cenchrus ciliaris*, Cleome viscosa, Corchorus sidoides, Crotalaria medicaginea var. neglecta, Gossypium robinsonii, Grevillea pyramidalis, Hybanthus aurantiacus, Ipomoea muelleri, *Malvastrum americanum, Rhynchosia minima, Senna notabilis, Stemodia grossa, Themeda triandra, Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186), Triodia epactia, Triumfetta appendiculata, Vachellia farnesiana*, and Waltheria indica.*	EcEvMgCYPvCEc (Biota 2012)
C2C-SW1	EV dominated Woodland/Mesic Shrubland	**FPV-C**	*Acacia pruinocarpa, *Cenchrus setiger, Centaurium spicatum, Cynodon dactylon, Cyperus vaginatus, Eragrostis surreyana, *Flaveria trinervia, Grevillea pyramidalis, *Malvastrum americanum, Pluchea rubelliflora, Rhynchosia minima, and Setaria dielsii, Stylobasium spathulatum, Themeda triandra, Chrysopogon fallax, Triodia angusta, and Vachellia farnesiana.*	Wetland-Mosiac (Biota 2012)
C2C-SW2	EV & CH dominated Woodland/ Mesic open shrubland	**FPV-C**	*Acacia pruinocarpa, *Cenchrus setiger, Centaurium spicatum, Cynodon dactylon, Eragrostis surreyana, *Flaveria trinervia, *Malvastrum americanum, Melaleuca glomerata, Pluchea rubelliflora, Rhynchosia minima, and Setaria dielsii, Triodia angusta, and Vachellia farnesiana.*	Wetland-Mosiac (Biota 2012)
C3A	EC & EV co-dominated Open woodland	**FPV-B**	*Acacia bivenosa, Acacia colei, Acacia trachycarpa, Acacia ancistrocarpa, Acacia pyrifolia* var. *pyrifolia, Cenchrus setiger*, Cenchrus ciliaris*, Cleome viscosa, Cyperus vaginatus, Cyperus vaginatus, Eulalia aurea, Gossypium robinsonii, Indigofera colutea, Ipomoea muelleri, Melaleuca argentea, Melaleuca glomerata, Petalostylis labicheoides, Sesbania cannabina, Triodia epactia, Typha domingensis,* and *Vachellia farnesiana**	*EcEvCspp (Astron 2015) or similar to EcEvAtrApyPlTw (Astron 2016*)*
C3B	EV Dominated Open Woodland	**FPV-C**	*Acacia pyrifolia* var. *pyrifolia, Acacia bivenosa, Acacia maitlandii, Acacia trachycarpa, Boerhavia coccinea, Cenchrus setiger*, Cenchrus ciliaris*, Cleome viscosa, Crotalaria medicaginea* var. *neglecta, Gossypium robinsonii, Hybanthus aurantiacus, Ipomoea muelleri, Rhynchosia minima, Senna notabilis, Stemodia grossa, Tephrosia rosea* var. *Fortescue creeks (M.I.H. Brooker 2186), Triodia epactia, Triumfetta appendiculata, Vachellia farnesiana*,* and *Waltheria indica*	*EvMgCv (Astron 2015) or EvAtrTwCspp (Astron 2016*)*

Veg Code	GDE / Community Summary Info	GDE Type	Vegetation Description	Equivalent Astron 2015, or Biota 2012 code.
C3B-Cr	EV & CH dominated Low Open Woodland - Creek	**FPV-C**	*Acacia pyrifolia var. pyrifolia, Acacia bivenosa, Acacia sclerosperma, Acacia trachycarpa, Boerhavia coccinea, Cenchrus setiger*, Cenchrus ciliaris*, Cleome viscosa, Crotalaria medicaginea var. neglecta, Gossypium robinsonii, Grevillea pyramidalis, Hybanthus aurantiacus, Ipomoea muelleri, Malvastrum americanum, Rhynchosia minima, Senna notabilis, Themeda triandra, Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186), Triodia epactia, Triumfetta appendiculata, Vachellia farnesiana*, and Waltheria indica.*	EcEvMgCYPvCEc (Biota 2012)
C3C-Cr	CH scattered low trees/ Variable Open Shrubland	**FPV-C**	*Acacia pyrifolia var. pyrifolia, Acacia trachycarpa, Boerhavia coccinea, Cenchrus setiger*, Cenchrus ciliaris*, Cleome viscosa, Corchorus sidoides, Crotalaria medicaginea var. neglecta, Gossypium robinsonii, Grevillea pyramidalis, Hybanthus aurantiacus, Ipomoea muelleri, Malvastrum americanum, Petalostylis labicheoides, Rhynchosia minima, Senna notabilis, Themeda triandra, Triodia epactia, Vachellia farnesiana*, and Waltheria indica.*	EcEvMgCYPvCEc (Biota 2012)
C4	Shrublands	**Vadophytic**	*Acacia bivenosa, Acacia pyrifolia* var. *pyrifolia, Abutilon otocarpum, Acacia ancistrocarpa, Aerva javanica*, Argemone ochroleuca* subsp. *Ochroleuca*, Boerhavia coccinea, Cenchrus ciliaris*, Crotalaria cunninghamii, Eriachne pulchella* subsp. *dominii, Euphorbia schultzii, Gomphrena cunninghamii, Gossypium australe, Ipomoea muelleri, Notoleptopus decaisnei* var. *Orbicularis (A.B. Craig 428), Ptilotus astrolasius* var. *astrolasius, Ptilotus nobilis, Senna notabilis , Triodia epactia, Tephrosia rosea* var. *Fortescue Creeks (M.I.H Brooker 2186), Trachymene oleracea* subsp. *Oleracea,* and *Triodia wiseana.*	*Similar to AtrEs & AtTeCc (Astron 2015) or AtrPl (Astron 2016*)*
C5	Beds with minimal vegetation	**Vadophytic**	*Acacia trachycarpa, Argemone ochroleuca* subsp. *ochroleuca*, Boerhavia coccinea, Eriachne pulchella* subsp. *dominii, Gomphrena cunninghamii, Hybanthus aurantiacus, Ipomoea muelleri, Ipomoea muelleri, Ptilotus incanus, Ptilotus nobilis, Rhynchosia minima, Senna notabilis, Trichodesma zeylanicum* var. *zeylanicum,* and *Trachymene oleracea* subsp. *Oleracea.*	*AtrEs (Astron 2015) or Es (Astron 2016*)*

Veg Code	GDE / Community Summary Info	GDE Type	Vegetation Description	Equivalent Astron 2015, or Biota 2012 code.
C6	Shrublands	Vadophytic / Xerophytic	*Acacia ancistrocarpa, Acacia bivenosa, Acacia inaequilatera, Acacia trachycarpa, Acacia tumida* var. *pilbarensis, Acacia colei* var. *ileocarpa, Acacia inaequilatera, Acacia maitlandii, Acacia monticola, Acacia pyrifolia* var. *pyrifolia, Acacia synchronicia, Acacia trachycarpa* x *tumida* var. *pilbarensis, Acacia tumida* var. *pilbarensis, Acacia wanyu, Abutilon otocarpum, Aerva javanica*, Boerhavia coccinea, Bonamia erecta, Cajanus cinereus, Cenchrus ciliaris*, Corchorus lasiocarpus* subsp. *parvus, Crotalaria cunninghamii, Cymbopogon ambiguous, Grevillea pyramidalis* subsp. *leucadendron, Gossypium australe, Gossypium robinsonii, Hybanthus aurantiacus, Indigofera monophylla, Jasminum didymum* subsp. *lineare, Malvastrum americanum*, Notoleptopus decaisnei* var. *Orbicularis* (A.B. Craig 428), *Pentalepis trichodesmoides, Rhynchosia minima, Senna artemisioides* subsp. *oligophylla, Senna notabilis,* and *Trichodesma zeylanicum* var. *zeylanicum.*	*Similar to AtTeCc & ChAsppTwTe (Astron 2015) or ChAsppGOrGsppPlSsTeTw & ChPlAbGOrTw (Astron 2016*)*
C7-SW	Mesic Tall open scrub/ Scattered trees	FPV-C	*Acacia colei, var. colei, *Cenchrus setiger, Chrysopogon fallax, Centaurium spicatum, Cyperus vaginatus, Eragrostis surreyana, *Flaveria trinervia, Gossypium robinsonii, Petalostylis labicheoides, *Passiflora foetida var. hispida, Pluchea rubelliflora, Setaria dielsii, Stylobasium spathulatum, and Themeda triandra.*	Wetland-Mosaic (Biota 2012)
CL-SW	Mixed open shrublands on clay pans	Vadophytic	*Acacia colei, var. colei, *Cenchrus setiger, Chloris barbata, Chrysopogon fallax, Centaurium spicatum, Cyperus vaginatus, Eragrostis surreyana, *Flaveria trinervia, Gossypium robinsonii, Petalostylis labicheoides, *Passiflora foetida var. hispida, Pluchea rubelliflora, Setaria dielsii and Themeda triandra.*	Wetland-Mosaic (Biota 2012)
F1	CH Scattered trees/T. wiseana Hummock grassland	Vadophytic	*A. ancistrocarpa, Acacia bivenosa, Acacia inaequilatera, , A. synchronicia, Trianthema triquetra, *Cenchrus setiger, Eriachne pulchella, Stemodia grossa, Cassia glutinosa, Corchorus sidoides, and Dysphania rhadinostachya.*	**ChAspp.Tw (Biota 2012)**
F2	A. Synchronicia Tall open shrubland.	Vadophytic	**Cenchrus ciliaris and Corchorus crozophorifolius Goodenia microptera, Hakea chordophylla, Indigofera colutea, Maireana planifolia, Paraneurachne muelleri, Polycarpaea corymbosa, and Salsola tragus.*	**AsyTeCEs (Biota 2012)**
F3	A. xiphophylla low open woodland	Vadophytic	*Acacia synchronicia, Cassia notabilis, *Cenchrus ciliaris, *C. setiger, Cleome viscosa, Sporobolus australasicus, Pterocaulon sphaeranthoides and *Vachellia farnesiana.*	**AxTe (Biota 2012)**

Veg Code	GDE / Community Summary Info	GDE Type	Vegetation Description	Equivalent Astron 2015, or Biota 2012 code.
F4	C.H. Scattered trees/T. epactia Hummock grassland	**Vadophytic**	*Acacia elachantha, Alternanthera nana, Boerhavia coccinea, Bulbostylis barbata, Chrysopogon fallax, Dysphania rhadinostachya, Evolvulus alsinoides var. villosicalyx, Gossypium australe, Goodenia microptera, Hakea chordophylla, Indigofera colutea, Maireana planifolia, *Malvastrum americanum, Paraneurachne muelleri, Polycarpaea corymbosa, *Portulaca oleracea, Pterocaulon sphaeranthoides, Ptilotus astrolasius, Salsola tragus, Sclerolaena densiflora and Sida arsiniata.*	**ChAiTe (Biota 2012)**
F5	Acacia spp. Tall Shrubland/T. epactia Hummock grassland	**Vadophytic**	*Acacia pyrifolia, Bulbostylis barbata, Cassia notabilis, Chrysopogon fallax, Cleome viscosa, Dysphania rhadinostachya, Goodenia forrestii, G. microptera, Gossypium australe, Hakea lorea, Ptilotus astrolasius, Salsola tragus, Sida arsiniata, Sporobolus australasicus and Trichodesma zeylanicum var. zeylanicum.*	**ChAsyAbTe (Biota 2012)**
F6	Acacia spp. open shrublands/T. epactia hummock grassland	**Vadophytic**	**Cenchrus ciliaris and Corchorus crozophorifolius Goodenia microptera, Hakea chordophylla, Indigofera colutea, Maireana planifolia, Paraneurachne muelleri, *Portulaca oleracea, Pterocaulon sphaeranthoides, Ptilotus astrolasius and Salsola tragus.*	**AsclAsyTe (Biota 2012)**
H1	EL Scattered Trees/T. wiseana hummock grassland	**Vadophytic**	*Corymbia hamersleyana, Hakea chordophylla, Gossypium robinsonii, Ptilotus calostachyus, Ptilotus exaltatus var. exaltatus, Pterocaulon sphaeranthoides, Goodenia stobbsiana, Triodia sp. Robe River (M.E. Trudgen et al. MET 12367).*	**ElAiAbTw (Biota 2012)**
HD	Highly Disturbed Ground - Cleared	-	*Various regrowth related taxa.*	N/A

Appendix 3: Representative photographs of the key riparian vegetation units mapped to occur within the study area

New Veg code	Vegetation Type and Description	Representative Photos
C1A (Only present at confluence with the Robe River)	Mature MA and EC dominated Open forest to Low Woodland	

New Veg code	Vegetation Type and Description	Representative Photos
C1b	MA (Young) and EC dominated Low Woodland Apparent discharge established community within Jimmawurrada Creek	

New Veg code	Vegetation Type and Description	Representative Photos

New Veg code	Vegetation Type and Description	Representative Photos
C1bb	MA (Young) and EC dominated Low Woodland Potentially baseline community; discharge appears to have influenced community	
C2A	EC dominated Open Forest	

New Veg code	Vegetation Type and Description	Representative Photos

C2AA-Cr	Mesic EC dominated woodland to open forest - Creekline	

New Veg code	Vegetation Type and Description	Representative Photos

New Veg code	Vegetation Type and Description	Representative Photos
C2A-Cr	EC dominated woodland to open forest - Creekline	

C2A-SW	EC dominated woodland/Mesic open shrubland - Floodplain	

New Veg code	Vegetation Type and Description	Representative Photos

New Veg code	Vegetation Type and Description	Representative Photos
C2B	EC & EV co-dominated Open Forest	

New Veg code	Vegetation Type and Description	Representative Photos
C2BB-Cr	Mesic EC & EV dominated woodland - Creek	

New Veg code	Vegetation Type and Description	Representative Photos
C2B-Cr	EC & EV dominated woodland - Creek	

New Veg code	Vegetation Type and Description	Representative Photos

New Veg code	Vegetation Type and Description	Representative Photos
C2A-B	EC dominated Woodlands	

New Veg code	Vegetation Type and Description	Representative Photos
C2B-B	EC & EV co-dominated Woodland	

New Veg code	Vegetation Type and Description	Representative Photos
C2C	EV Dominated Woodland	

New Veg code	Vegetation Type and Description	Representative Photos
C2C-Cr	EV dominated Low Woodland - Creek	

New Veg code	Vegetation Type and Description	Representative Photos
C2C-SW1	EV dominated Woodland/Mesic Shrubland	

New Veg code	Vegetation Type and Description	Representative Photos
C2C-SW2	EV & CH dominated Woodland/ Mesic open shrubland	

New Veg code	Vegetation Type and Description	Representative Photos
C3A	EC & EV co-dominated Open woodland	

New Veg code	Vegetation Type and Description	Representative Photos
C3B	EV Dominated Open Woodland	

New Veg code	Vegetation Type and Description	Representative Photos
C3B-Cr	EV & CH dominated Low Open Woodland - Creek	

New Veg code	Vegetation Type and Description	Representative Photos
C3C-Cr	CH scattered low trees/ Variable Open Shrubland	

New Veg code	Vegetation Type and Description	Representative Photos
C4	Shrublands	

New Veg code	Vegetation Type and Description	Representative Photos
C5	Beds with minimal vegetation	

New Veg code	Vegetation Type and Description	Representative Photos
C6	Shrublands	

C7-SW	Mesic Tall open scrub/ Scattered trees	

New Veg code	Vegetation Type and Description	Representative Photos

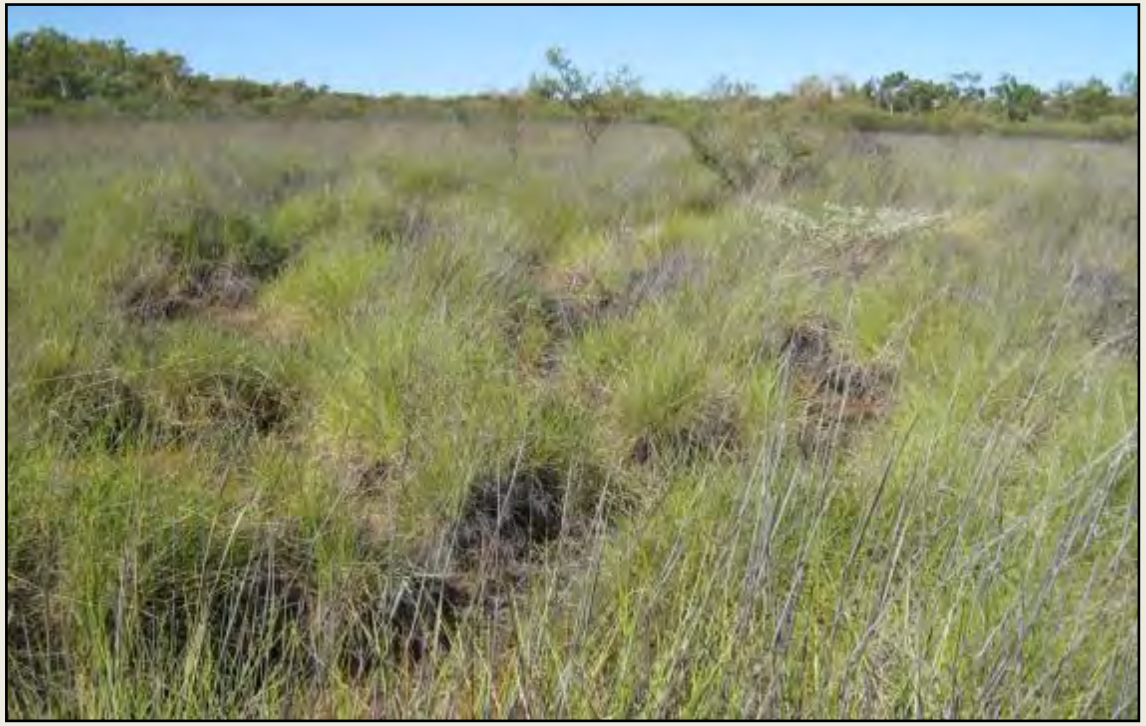
New Veg code	Vegetation Type and Description	Representative Photos
CL-SW	Mixed open shrublands on clay pans	

New Veg code	Vegetation Type and Description	Representative Photos
F1	CH Scattered trees/T. wiseana Hummock grassland	
F2	A. Synchronicia Tall open shrubland.	

New Veg code	Vegetation Type and Description	Representative Photos
F3	A. xiphophylla low open woodland	

New Veg code	Vegetation Type and Description	Representative Photos
F4	CH Scattered trees/T. epactia Hummock grassland	

New Veg code	Vegetation Type and Description	Representative Photos
F5	Acacia spp. Tall Shrubland/T. epactia Hummock grassland	

New Veg code	Vegetation Type and Description	Representative Photos
F6	Acacia spp. open shrublands/T. epactia hummock grassland	

New Veg code	Vegetation Type and Description	Representative Photos
H1	EL Scattered Trees/T. wiseana hummock grassland	

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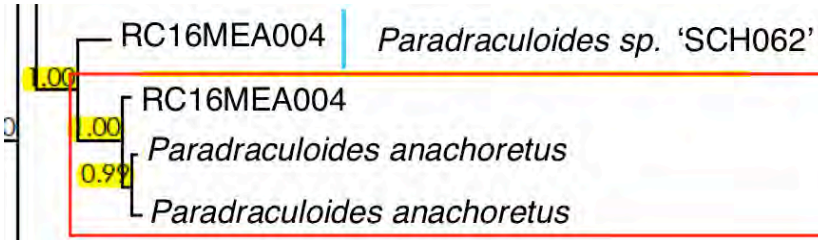
Mesas A and K Targeted Troglofauna Survey



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Mesa A and K Targeted Troglofauna Survey

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1.0 Project Summary

In accordance with the Rio Tinto scope of work, Table 1.1 presents a summary of survey and project information.

Table 1.1: Summary of project specifications and limitations.

Project Name	Mesas A and K Targeted Troglofauna Survey			
Level of Survey	Targeted survey			
Location	Approximately 38 km west of Pannawonica township			
Survey Area Size	Mesa A	20 km^2	Mesa K	6.3 km^2
Survey Timing	Surveys completed between December 2016 – March 2017			
Relevant Regulatory Guidance Documents and Applicable Legislation	• EPA Statement of Environmental Principles, Factors and Objectives (EPA 2016a); • Environmental Factor Guideline – Subterranean Fauna (EPA 2016b); • Technical Guidance - Subterranean fauna survey (EPA 2016c); and • Technical Guidance - Sampling methods for subterranean fauna (EPA 2016d).			
Key Survey Limitations	• Sampling for troglofauna in the Robe Valley and wider Pilbara region relies on the use of drill holes, which are almost always installed as part of exploration drilling and thus focus on geological units of economical importance. This creates a bias in availability of drill holes for troglofauna sampling, as sampling tends to not extend far beyond the footprint of the target ore body and is focussed on particular rock types. This places limitations on determining wider species distributions and whether there are potential barriers to dispersal. • For most taxa, only adult specimens have diagnostic morphological characteristics necessary to be identified to species level. As juvenile specimens are often collected, this limited the level to which many specimens could be identified. These specimens, as well as those too damaged to identify have been classified as indeterminate species (sp. 'indet'). Indeterminate species (e.g. *Paradraculoides* sp. 'indet' and Thysanura sp. 'indet'), while reported on for transparency within the results, were removed from the discussion analysis since these specimens may represent multiple species or may equate to a species already known elsewhere. • A relatively small number of sampling locations were available to investigate the subterranean fauna habitat questions considered by this study (only a single site in the case of the low grade waste dump at Mesa A). With the high degree of ecological sampling effects and intra-site variation inherent in troglofauna data sets, this limits the power of the sampling design and thereby the conclusiveness with which this study can resolve habitat utilisation.			

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2.0 Executive Summary

Rio Tinto wishes to improve knowledge on the persistence of troglobitic communities within historically disturbed habitats at Mesa A and Mesa K. The target habitats in this respect include substrate beneath existing mine pits and habitat beneath or within waste dumps.

Biota Environmental Sciences (Biota) was commissioned to undertake targeted troglofauna sampling at Mesa A and K to build upon data from previous surveys in each area and investigate whether troglofauna communities still persist beneath the pit floors, the extent of these communities, and whether they have become established within, or still persist beneath, waste dumps.

Two phases of troglofauna sampling involving three field mobilisations were conducted at Mesa A and K between December 2016 and March 2017. A total of 19 drill holes were successfully sampled within the Mesa A and Mesa K survey areas (14 and 5 sites respectively). Fifteen sites were sampled in consecutive phases and four sites sampled once. A total of 86 troglofauna traps were installed with 79 traps recovered. The number of traps installed per site varied from 1 – 3 traps depending on hole depth. Haul net scraping was completed for 16 of the 19 sites during Phase 1. No haul net scraping was conducted during Phase 2.

A total of 383 specimens, representing 44 taxa across 11 orders were documented for the Mesa A search area during the desktop review. Of these, 22 taxa could not be identified to species level. Six of the remaining 22 taxa represent formally described species and the remaining 16 taxa are undescribed. The most commonly collected species was the schizomid *Paradraculoides anachoretus*, representing over 32% of specimens. This species, as well as four pseudoscorpion species, *Lagynochthonius asema*, *Tyrannochthonius* sp. 'Mesa A', *Ideoblothrus linnaei* and *Ideoblothrus* sp. 'Mesa A', are all listed as conservation significant.

The Mesa K desktop review yielded 363 past specimen records representing 29 taxa across 14 orders. Seven taxa were unable to be identified to species level and four taxa aligned with formally described species. The remaining 18 taxa are currently undescribed. The schizomid species *Paradraculoides kryptus* was most commonly recorded, representing over 38% of Mesa K collections. This species is the only listed conservation significant fauna species identified from the desktop review for Mesa K.

During the current survey, four schizomid specimens were recorded from drillhole RC16MEA004 at Mesa A, all of which were recorded during Phase 2. Genetic analysis of the collected Schizomida determined the presence of two distinct lineages, equating to two species for the purpose of this report, *Paradraculoides anachoretus* and *Paradraculoides* sp. 'SCH034'.

Paradraculoides anachoretus has been widely recorded from Mesa A in the past and is considered to be endemic to the mesa. *Paradraculoides* sp. 'SCH034' was recorded from RC16MEA004 during the current sampling, which is located within the pit and drilled through a low-grade waste dump, and has previously been recorded from two sites within the Mesa A Mining Exclusion Zone (MEZ).

No troglomorphic specimens were collected from Mesa K during the current survey, and no additional information on habitat utilisation by troglofauna at this site is therefore available.

Currently, insufficient data exist to allow for a robust analysis comparing results of sampling in-pit at Mesa A with the results of sampling within the MEZ and prior to mining operations, but both schizomid species recorded in-pit have been demonstrated to also occur within the MEZ. Most sampling effort since operations commenced has focused on reference area sampling. However some observations can still be made from the results of the in-pit sampling. From the very limited data available, it is possible troglofauna may be utilising the low-grade waste dump at Mesa A as habitat. However, information provided by Rio Tinto indicates that the sampled drill hole

(RC16MEA004) was also drilled beyond the base of the waste dump and into intact troglofauna habitat below. This introduces the possibility that the troglobites recorded from this site may have entered the drillhole from intact habitat at depth, rather than truly utilising the waste dump as habitat.

3.0 Introduction

Rio Tinto wishes to improve knowledge on the persistence of troglobitic communities within historically disturbed habitats at Mesa A and Mesa K (Figure 3.1). The target habitats in this respect include substrate beneath existing mine pits and habitat beneath or within waste dumps.

Previous studies in the vicinity of Mesa A and elsewhere in the Robe Valley have documented troglofauna species that are isolated to individual mesas, demonstrating extreme short-range endemism, which has implications for environmental impact assessment (EIA). Biota Environmental Sciences (Biota) was commissioned to undertake troglofauna sampling at Mesa A and K, as part of prefeasibility studies to further inform EIA. The purpose of this work is to build upon previous surveys in each study area and investigate whether troglofauna communities still persist beneath the pit floors and waste dumps, the nature and extent of these communities, and whether they have also become established within waste dumps.

3.1 Project Background

Biota conducted sampling for stygobitic fauna at Mesa A in 2003 and recorded four troglobitic taxa within the voids in the pisolitic mesa (Biota 2004). Prior to this, troglofauna had not been recorded from the Pilbara region (Biota 2004). Since this discovery, further sampling has demonstrated that troglofauna are widely distributed within the Robe Valley (Biota 2006a, 2007, 2011a, 2017) and elsewhere in the Pilbara (Biota 2016). However, previous sampling within the Robe Valley mesas has demonstrated that each mesa provides habitat for a unique assemblage of troglofauna (Biota 2006a, 2007, 2011a, 2017). A total of 10 phases of sampling has been completed at Mesa A and 12 phases at Mesa K.

3.2 Objectives and Scope

The scope of this study was two-fold:

- to undertake troglofauna sampling at Mesas A and K to build upon the knowledge gathered during previous surveys in the Robe Valley area; and
- to investigate whether a troglofauna community is present within previously disturbed parts of Mesa A and K.

The key objectives of this study were to:

1. conduct a two-phase targeted troglofauna survey at Mesas A and K;
2. document the recorded fauna to the lowest level of identification possible, including alignment and comparison with previously collected taxa;
3. complete molecular analysis of troglobitic specimens that are not able to be adequately identified morphologically;
4. discuss the distribution of taxa recorded during this survey;
5. discuss the conservation significance of the species recorded during the survey in both a local and regional context; and
6. compare the troglofauna community recorded during this targeted survey with the communities recorded previously at Mesas A and K, and elsewhere in the Robe Valley.

The study was planned and implemented as close as practicable in accordance with:

- EPA Statement of Environmental Principles, Factors and Objectives (EPA 2016a);
- Environmental Factor Guideline – Subterranean Fauna (EPA 2016b);
- Technical Guidance - Subterranean fauna survey (EPA 2016c); and
- Technical Guidance - Sampling methods for subterranean fauna (EPA 2016d).

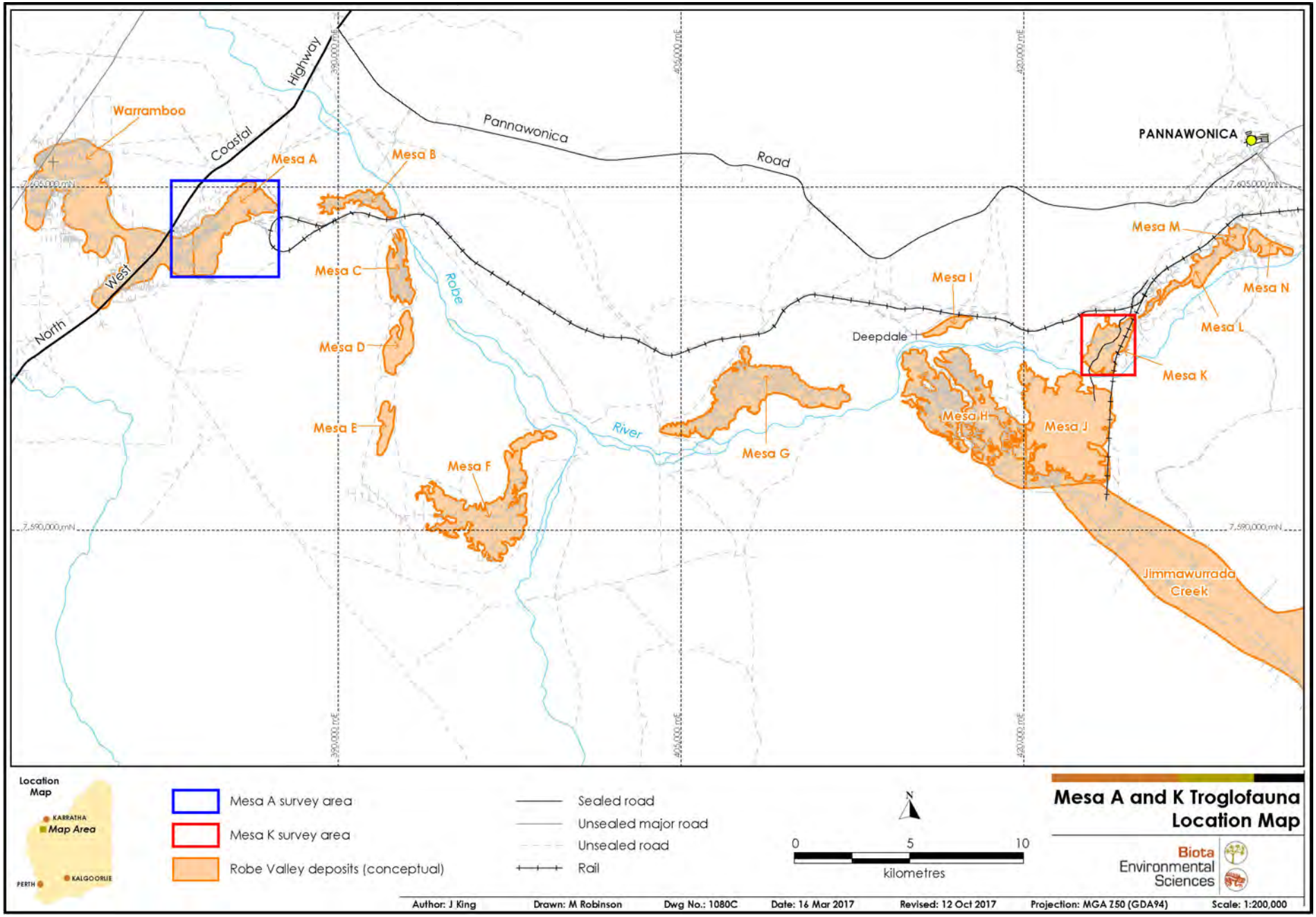

Figure 3.1: Location of the Mesa A and Mesa K survey areas.

3.3 Terminology

For the purpose of this report, the following terms are used as defined below:

Survey area – Refers to the extents of Mesa A and Mesa K that were surveyed as part of the current scope (Figure 3.1).

MEZ – Mining Exclusion Zone; Refers to the avoidance areas set aside at Mesa A where mining is prohibited under current Ministerial approval.

Survey – Refers to the two phases of sampling undertaken for the current scope of work.

3.4 Subterranean Fauna Overview

Until relatively recently, Australia was thought to lack habitat suitable for subterranean fauna. However, recent research (mostly with an emphasis on impact assessment) has revealed Australia to be highly diverse in subterranean fauna, with numerous areas of interest throughout the continent (Guzik et al. 2010). In Western Australia these zones of subterranean biodiversity can be found at Cape Range, Barrow Island, the Pilbara bioregion, the Yilgarn and the Nullarbor (Humphreys 2001, Page et al. 2008, Guzik et al. 2010).

Relatively recent surveys in the Pilbara have collected subterranean fauna from a range of geological units such as pisolitic iron formations, channel iron deposits, unconsolidated alluvium and sedimentary basalt (Marmonier et al. 1993, Biota 2004, 2006a, 2010, 2011b, 2013). This indicates that the suitability of a formation as habitat for subterranean fauna is mostly a function of the availability of habitable space (Marmonier et al. 1993, Humphreys 1999, Biota 2006a), rather than a specific geology unit.

Subterranean fauna habitats are characterised by shared physical parameters that include a lack of light, stable temperature, limited nutrient infiltration from surface environments and a constant humidity (Juberthie 2000, Romero 2009). These habitat characteristics have resulted in convergence in body morphology evolution amongst many subterranean fauna. Morphological characteristics common to most subterranean fauna include reduced or lack of pigmentation, reduced or lack of eyes, and elongate body morphology and appendages adapted for sensory movement (Culver and Pipan 2009, Romero 2009).

Subterranean fauna can be categorised into two distinct ecological groups based on habitat: troglofauna and stygofauna. Troglofauna are a suite of fauna that survive only in air-filled cavities and interstices between the surface and the water table. Stygofauna comprise aquatic taxa occurring in groundwater aquifers and subterranean water bodies. Troglobites and stygobites are obligatory subterranean habitat dwellers, and while they may occur close to surface environments, are strongly adapted to subterranean environments. This makes such fauna unable or highly unlikely to survive surface conditions. A range of similarly adapted fauna known as troglophiles, trogloxenes and edaphobites also occur; these fauna use subterranean habitats opportunistically but are able to survive outside these stable environments. Studies from the Pilbara bioregion have demonstrated that these suites of fauna are not similarly restricted in range and are therefore unlikely to be impacted by small-scale developments (Biota and Helix 2012, Helix 2012).

Troglofauna in semi-arid Australia are thought to be relictual rainforest fauna; fauna adapted to humid environments, which retreated underground to cave systems during the aridification of Australia (In the late Miocene; Humphreys 1993). This is inferred from affinities of the taxonomic groups represented amongst the troglofauna with other extant taxa in tropical climates. Some invertebrate groups with troglobitic representatives include the Arachnida (e.g. Schizomida, Pseudoscorpiones and Araneae), Chilopoda (e.g. Scolopendrida), Diplopoda (e.g. Polydesmida and Haplodesmida), and Insecta (e.g. Diplura, Thysanura, Coleoptera and Blattodea). A single troglobitic vertebrate species of blind snake (*Anilios longissimus*) is known from Australia, collected from Barrow Island (Aplin 1998, Humphreys et al. 2013).

Due to their dependence on constant humidity, the dispersal and distribution of troglobitic fauna species tends to remain limited to individual blocks of inter-connected habitat, leading to long periods of population isolation and speciation. As a result, troglobitic fauna are considered to be of conservation significance, given that species often display extreme short-range endemism and may therefore be affected by relatively small-scale developments such as mining and construction.

4.0 Methodology

4.1 Desktop Review and Database Searches

4.1.1 Review of Previous Relevant Studies

A literature review was completed to identify previous relevant surveys conducted within the survey area. This included searches of Biota's library database, GoogleScholar[1] and the EPA's website, in addition to the identification of previous surveys via database specimen records (Section 4.1.2). Reports and data supplied by Rio Tinto were also collated with the results of the literature search and reviewed.

4.1.2 Database Searches

The following databases were searched to assist with compilation of a list of potential species for the survey area:

1. NatureMap: a collaboration between the Department of Parks and Wildlife and the Western Australian Museum (WAM). This database represents the most comprehensive source of information on the distribution of Western Australia's fauna, comprising records from the Fauna Survey Returns database and WA Threatened Fauna Database (both maintained by the Department of Parks and Wildlife) and the WAM Specimen Database.
2. WAM's Arachnid, Myriapod and Crustacea database.
3. Biota Internal Database: This database includes all of the subterranean fauna data collected by Biota within Western Australia, which includes the majority of the historical records recorded from the Robe River valley.

Details of database searches conducted are summarised in Table 4.1.

Table 4.1: Summary and location of database searches completed

Database	Date	Search Target	Bounding Coordinates	
			Eastings (m E)	Northings (m N)
Biota, NatureMap	17/03/2017	Mesa A	384970	7603500
		Mesa K	423685	7598092
WAM	14/03/2017	Arachnida, Myriapoda and Crustacea	405138	7607948
			435642	7582695

4.2 Sampling Methodology

Troglobitic fauna sampling was completed under "Licence to Take Fauna for Scientific Purposes" No. 08-000238-1 issued to Penny Brooshooft (Appendix 1). Methodology and approach were consistent with those outlined in Technical Guidance; Subterranean Fauna Survey (EPA 2016c) and Technical Guidance; Sampling Methods for Subterranean Fauna (EPA 2016d). Similar methodologies have been used in previous Robe Valley subterranean fauna assessments (Biota 2006a, 2009a, 2011a). Troglobitic fauna were sampled using two methods; baited colonisation traps and drillhole scraping.

4.2.1 Colonisation Trapping

Custom-built litter colonisation traps were suspended at intervals within drillholes located within the study area. Traps were constructed from 60 mm internal diameter PVC irrigation pipe cut to a length of 180 mm. Each trap had a series of 20 mm holes drilled into the side, and traps remained open at the upper end. Up to three traps were installed such that they were in contact with the interior of the sampled drillhole, facilitating fauna entry into the trap.

[1] https://scholar.google.co.uk

Leaf litter was gathered locally from the ground surface in the study area, particularly from the bases of *Acacia* shrubs. The collected litter was soaked in water and irradiated in a microwave oven for two minutes on maximum power setting. The microwave acted to kill any surface invertebrates present and assisted in the breakdown of organic matter. Wet leaf litter was added to the traps, which were kept in sealed containers until immediately prior to insertion into the drillholes to avoid desiccation of the litter. After the installation of traps, the opening of each drillhole was sealed to maintain humidity and to avoid entry of surface fauna.

Traps were recovered from each drillhole after a minimum of six weeks, as per EPA guidance, and stored in labelled zip-lock bags in order to maintain humidity and prevent desiccation of potential troglofauna specimens during transportation to Perth.

Fauna specimens were recovered from the traps using specially designed Tullgren funnel units. The leaf litter from each trap was placed in a sieve under an aluminium lamp containing a 25-watt globe. This created a temperature of approximately 30°C at the surface of the leaf litter. A funnel situated below the leaf litter collected the fauna as they fell, directing them into an attached vial of 100% ethanol. Leaf litter was left in the Tullgren funnels for a period of 24 hours, or until dry, after which time the bulked invertebrate sample was removed.

4.2.2 Haul Net Scraping

Troglofauna were also sampled using reinforced haul nets. These nets were constructed from 70 µm plankton mesh and had 100 mm apertures attached to a weighted catch jar. Sampling took place by lowering the net to the bottom of the site before being hauled slowly to the surface whilst scraping the edge of the drillhole. This dislodged any fauna on the vertical surface of the drillhole interior. Each site was scraped a minimum of four times, scraping each side of the drillhole. On completion, fauna specimens were preserved in-situ in 100% ethanol and individually labelled. The contents of the net, which included dry soil and root matter, were emptied into a uniquely labelled container. The container was then filled with 100% ethanol to preserve any specimens that may have been in the soil and root matter for later sorting in the field laboratory.

4.2.3 Data Management

Preliminary identification of subterranean fauna involved identification of specimens to order level, where possible, or separation of specimens into distinct morphotypes. Sorting was completed in Perth using dissecting microscopes (Olympus SZ40 and SZ61, magnification up to 40x). Morphotypes were then assigned a unique number based on drill hole name, date and method of collection. Specimens were preserved in 100% ethanol once separated out into morphotypes, which allows for both morphological and molecular analyses.

4.3 Molecular Analysis

Molecular analysis of collected schizomida was completed to inform determinations of the number of species present, and compare the results with those obtained during previous surveys in the Robe Valley and wider Pilbara region. Yvette Hitchen of Helix Molecular Solutions (Helix) completed the molecular sequencing. Specimens were sequenced for variation at the mitochondrial cytochrome oxidase subunit I gene (CO1; Appendix 2).

Dr Terrie Finston (of Helix) provided analysis and interpretation of the molecular data (Appendix 2). The molecular analysis used was a preliminary neighbour-joining approach using representative sequences from regional context data sets, followed by a phylogenetic analysis using the sequence data from this study (Appendix 2). This resulted in specimens from the current survey being placed into genetic lineages, which also included specimens from collections elsewhere in the region. Determination of putative species was then inferred from these genetic lineages based on the level of divergence between lineages of the same group (such as order or family), giving consideration to the variation within each lineage.

It should be noted that detailed morphological analysis was not completed for most specimens and the phylogenetic analysis was based on sequence data from a single gene. Therefore, all species arrived at by this approach should be considered putative unless previously described and fully determined by taxonomic specialists. Lineages with a divergence of less than 4.0% were considered a single species, whereas lineages with a divergence greater than 6.0% were considered separate distinct species for the purpose of this report, unless advised otherwise by Helix based on other data for the relevant taxonomic group. Lineages with intermediate divergences ranging from 4.0–6.0% were resolved to a preliminary level for the purposes of this report, with further input from Helix, and consideration to collection proximity, habitat characteristics and geology.

4.4 Categories of Conservation Significance

For the purpose of this report, the conservation significance of the fauna collected during this study, or records collated during the desktop review, was categorised as per Table 4.2.

Table 4.2: Conservation classification used within this report.

Category	Description
Conservation Significant species	Species listed as Priority, Schedule or Vulnerable at State or Federal levels.
Confirmed Short-range endemic (SRE) species *	Species where sufficient taxonomic expertise is available, and with adequate representation in WAM collections or genetic databases, that are known to be limited in distribution based on geological characteristics.
Potential SRE species *	Species where there is insufficient taxonomic knowledge or too limited a number of collections to determine SRE status. Habitat, morphology, molecular or taxonomic data deficient, but belonging to groups that may display short-range endemism.
Widespread (not an SRE) species *	Well-collected species that are typically taxonomically well resolved. Species are not confined by geological barriers.

* Category based on WAM SRE guidelines (WAM 2014).

4.5 Survey Design

4.5.1 Survey Timing and Personnel

Two phases of troglofauna sampling involving three field mobilisations were conducted at Mesa A and K between December 2016 and March 2017 (Table 4.3).

Table 4.3: Summary of field mobilisations completed for the Mesa A and K troglofauna survey.

Mobilisation	Dates	Phase	Purpose	Personnel
1	6th – 11th December, 2016	1	Troglofauna scraping Installation of troglofauna traps	Nicola Watson, Jacinta King
2	30th January – 2nd February, 2017	1	Troglofauna trap recovery	Jason Alexander
		2	Installation of troglofauna traps	
3	21st – 23rd March, 2017	2	Troglofauna trap recovery	Jason Alexander

Jason Alexander managed the study, with directional input from Garth Humphreys. Preliminary sorting of collected subterranean fauna was completed by Nicola Watson, Penny Brooshooft and Jacinta King. All personnel involved in the project were from Biota and collectively hold several decades of experience in subterranean fauna surveys.

4.5.2 Weather

Temperature and rainfall data were obtained from Mesa J mining operations approximately 38.6 km east-southeast of Mesa A, and 4 km southwest of Mesa K. Long-term climatological reference data (rainfall from 1971 – 2014, temperature data from 1971 – 2005) were obtained from the Bureau of Meteorological (BOM) weather station in Pannawonica (station number 5069, approximately 44.1 km east of Mesa A.

Sampling occurred during the 2016-17 wet season. No major rainfall events occurred in the three months prior to sampling (Figure 4.1). During the sampling period, however, conditions varied between Mesas A and K: A total of 110 mm of rain fell at Mesa A between January and March 2017 (December data not available), while Mesa K received 408 mm of rain between December 2016 and the end of the sampling period in March 2017, with over double the long-term average rainfall amount received in February (Figure 4.1).

The findings from previous surveys in the Robe valley and elsewhere suggest that dry conditions preceding installation of troglofauna traps may create less than ideal conditions for capturing troglofauna (Biota 2006a). There is also evidence that significant rain events during sampling (while traps remain in the ground) may result in a reduced colonisation of traps due to surface soil being washed into the traps and leaf litter being washed out of the traps.

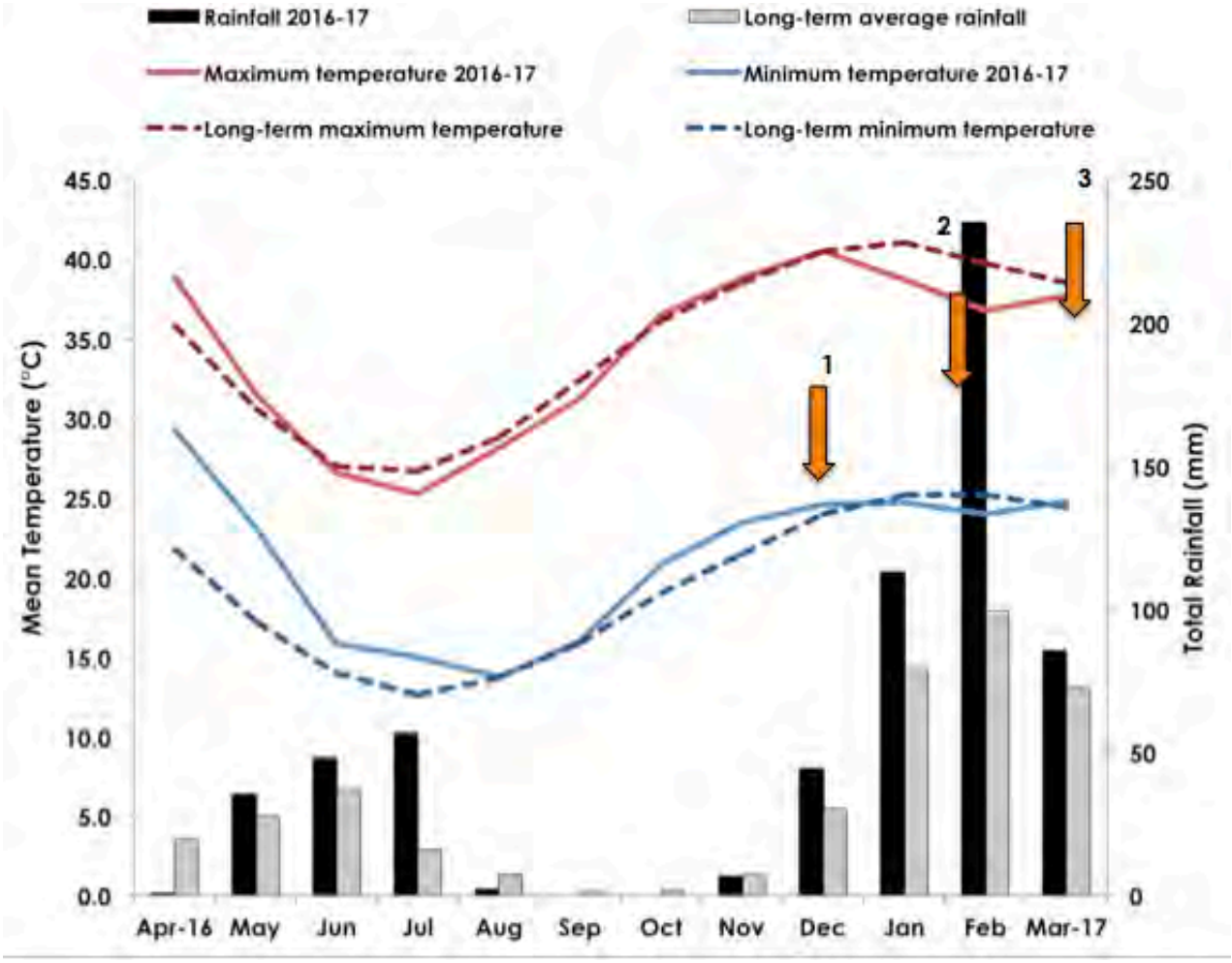

Figure 4.1: Climate and weather graph depicting long-term and monthly averages for the year preceding the final field mobilisation.

Long-term temperature data 1971-2005, rainfall data 1971-2014; arrows indicate field mobilisation timing as per Table 4.3.

4.5.3 Sampling Effort

A total of 19 drill holes were sampled within the Mesa A and Mesa K survey areas (14 and 5 sites respectively) (Table 4.4). On both phases two sites were unable to be accessed for installation or recovery of traps. As such a total of 17 sites were successfully sampled during Phase 1 and Phase 2, with 15 sites being sampled twice and four sites sampled once (Table 4.4). A total of 79 troglofauna traps were recovered from across both phases.

Haul net scraping was completed for 16 of the 19 sites prior to the installation of troglofauna traps. No haul net scraping was conducted during Phase 2 (Table 4.4).

Table 4.4: Troglofauna sampling sites within the Mesa A and Mesa K survey area.

Drill Hole Name	Location Description	Troglofauna Scrape	Traps		Notes
			Phase 1	Phase 2	
Mesa A					
MOB01A	Pit floor	Yes	2	2	
MOB01B	Pit floor	Yes	2	2	
MOB02A	Pit floor	-	0	2	No access for Phase 1.
MOB02B	Pit floor	-	0	2	No access for Phase 1.
MOB03A	Pit floor	Yes	2	1	1 trap* from Phase 2 under water, not processed.
MOB03B	Pit floor	Yes	2	2	
RC16MEA001	Pit floor	Yes	2	0	No access on recovery of Phase 2. Traps not retrieved*.
RC16MEA002	Pit floor	Yes	2	0	No access on recovery of Phase 2. Traps not retrieved*.
RC16MEA003	Pit floor	Yes	2	2	
RC16MEA004	Low grade waste dump	Yes	2	2	
RC16MEA005	Pit floor	Yes	3	2	1 trap* from Phase 2 under water, not processed.
RC16MEA006	Pit floor	Yes	3	2	1 trap* from Phase 2 under water, not processed.
RC16MEA007	Pit floor	-	3	3	
RC16MEA008	Portal breach	Yes	3	3	
Mesa K					
RC16MEK0001	Waste dump	Yes	1	1	
RC16MEK0002	In Pit - Higher RL than pit floor	Yes	3	3	
RC16MEK0003	Pit floor	Yes	3	3	
RC16MEK0004	Pit floor	Yes	3	3	
RC16MEK0005	Pit floor	Yes	3	3	
		Total number of traps installed	41	45	
		Total number of traps retrieved	41	38	
		Number of drill holes successfully sampled	17	17	

* - Not included in trap tally

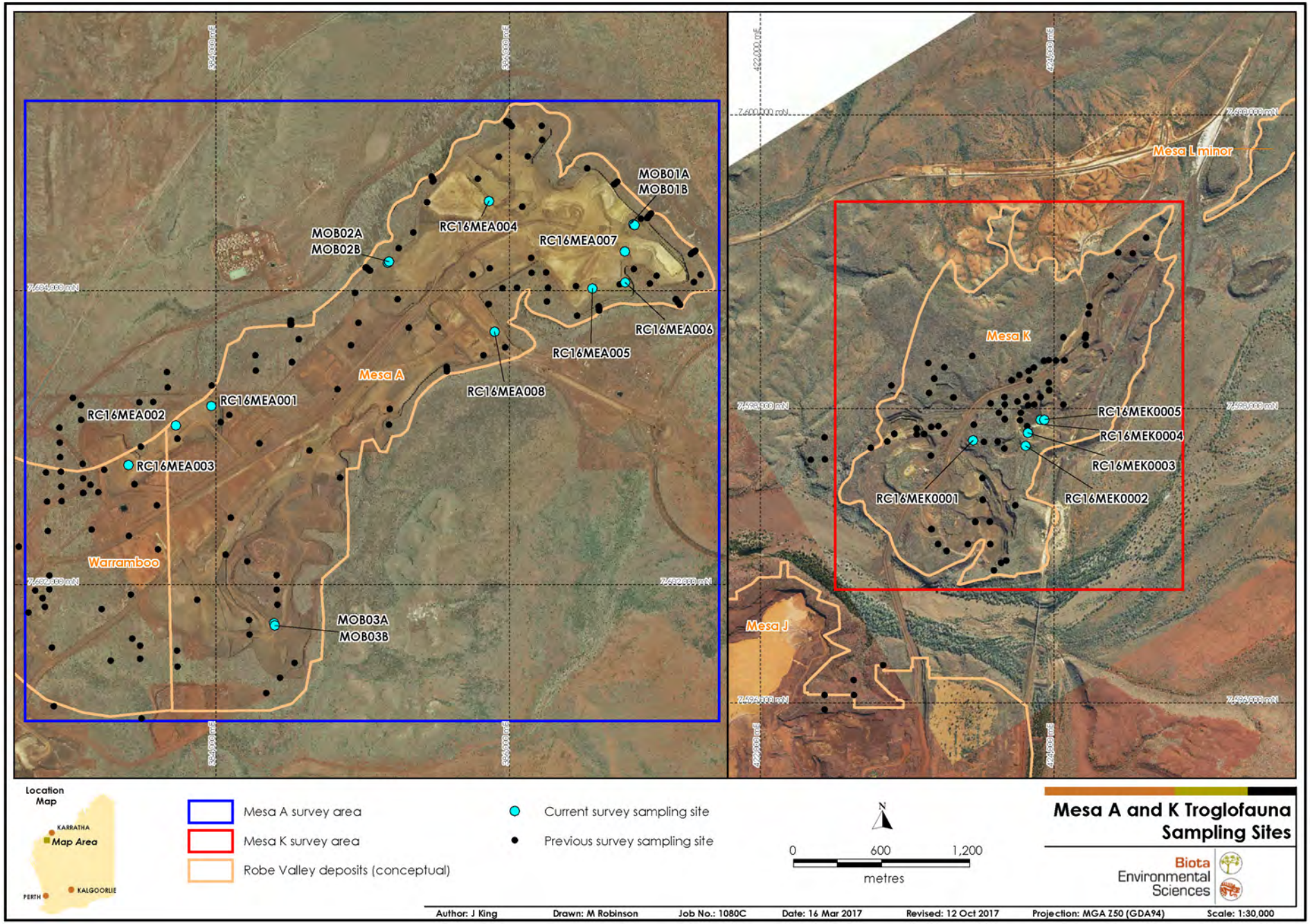

Figure 4.2: Location of current and previously sampled drill holes within and adjacent to the Mesa A and K survey area.

4.6 Limitations

Several limitations apply to this study, some of which are common functions of working on subterranean fauna, rather than functions of this specific study. These limitations include:

1. Sampling for troglofauna in the Robe Valley and wider Pilbara region relies on the use of drill holes, which are almost always installed as part of exploration drilling and thus focus on geological units of economical importance. This creates a bias in availability of drill holes for troglofauna sampling, as sampling tends to not extend far beyond the footprint of the target ore body and is focussed on particular rock types. This places limitations on determining wider species distributions and whether there are potential barriers to dispersal.
2. For most taxa, only adult specimens have diagnostic morphological characteristics necessary to be identified to species level. As juvenile specimens are often collected, this limited the level to which many specimens could be identified. These specimens, as well as those too damaged to identify have been classified as indeterminate species (sp. 'indet'). Indeterminate species (e.g. *Paradraculoides* sp. 'indet' and Thysanura sp. 'indet'), while reported on for transparency within the results, were removed from the discussion analysis. These specimens may represent multiple species or may equate to a species already known elsewhere.
3. A relatively small number of sampling locations were available to investigate the subterranean fauna habitat questions considered by this study (only a single site in the case of the low grade waste dump at Mesa A). With the high degree of ecological sampling effects and intra-site variation inherent in troglofauna data sets, this limits the power of the sampling design and thereby the conclusiveness with which this study can resolve habitat utilisation.

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5.0 Results

5.1 Desktop Review

5.1.1 Priority and Threatened Ecological Communities

Threatened Ecological Communities (TECs) are described by the Department of Parks and Wildlife as biological assemblages occurring in a particular habitat, which are under threat of modification or destruction from various processes (DEC 2013). Priority Ecological Communities (PECs) are biological (flora or fauna) communities that are recognised to be of significance, but do not meet the criteria for a TEC.

Two Priority Ecological Communities of relevance to the current study overlap both Mesas A and K (Table 5.1 and Figure 5.1). Both PECs are categorised as Priority One; Poorly-known ecological community. This category is defined as:

"*Ecological communities that are known from very few occurrences with a very restricted distribution (generally ≤5 occurrences or a total area of ≤ 100ha). Occurrences are believed to be under threat either due to limited extent, or being on lands under immediate threat (e.g. within agricultural or pastoral lands, urban areas, active mineral leases) or for which current threats exist. May include communities with occurrences on protected lands. Communities may be included if they are comparatively well-known from one or more localities but do not meet adequacy of survey requirements, and/or are not well defined, and appear to be under immediate threat from known threatening processes across their range*"(DEC 2013).

Table 5.1: Description of relevant PECs overlapping the survey area.

Community	Proximity to Survey Area
Subterranean invertebrate community of pisolitic hills in the Pilbara "Subterranean invertebrate communities of a series of isolated pisolitic mesas in the Robe Valley near Pannawonica in the Shire of Ashburton in the State's Pilbara Region. Includes Mesa A, B, C, G and K and mesas not yet surveyed. The mesas are remnants of old valley infill deposits of the palaeo Robe River. Mesas are flat topped hills with a hard laterised goethite cap (Biota 2006a). The cap is underlain by pisolite, which is made up of spherical accretions of iron minerals called pisoliths (the iron ore source), which often have small caverns and spaces between them. These interstices can be large enough to accommodate troglobitic fauna (Biota 2009b). It is assumed that the other ironstone hills also provide a similar habitat for troglobitic fauna that were located in these hills by Biota (Biota 2006a)."	Overlaps Mesa A < 5 kms south-east of Mesa K
Subterranean invertebrate communities of mesas in the Robe Valley region "Troglobitic faunal communities occur in extremely specialised habitats and appear to require the particular structure and hydrogeology associated with mesas (but also apparently with other ironstone hills in the Robe Valley Region; Biota 2006a) to provide a suitable humid habitat (EPA 2007). Specifically, the habitat is the humidified pisolitic strata (small round accretionary masses of rock). These troglobitic communities are believed to be relics of the late Miocene (23 to 5.3 million years BP), having arisen from tropical faunal lineages that descended into subterranean environments during the aridification of Australia (Biota 2006a). Short range endemism is common in these fauna (Biota 2006a). Eleven fauna taxa located in Mesa A, for example, was not located in any other mesa sampled. This high level of endemicity was the general pattern of distribution noted by Biota (Biota 2006a) for mesas and other hills in the Robe Valley that were thought to be likely habitat for troglofauna."	Overlaps Mesa A and Mesa K

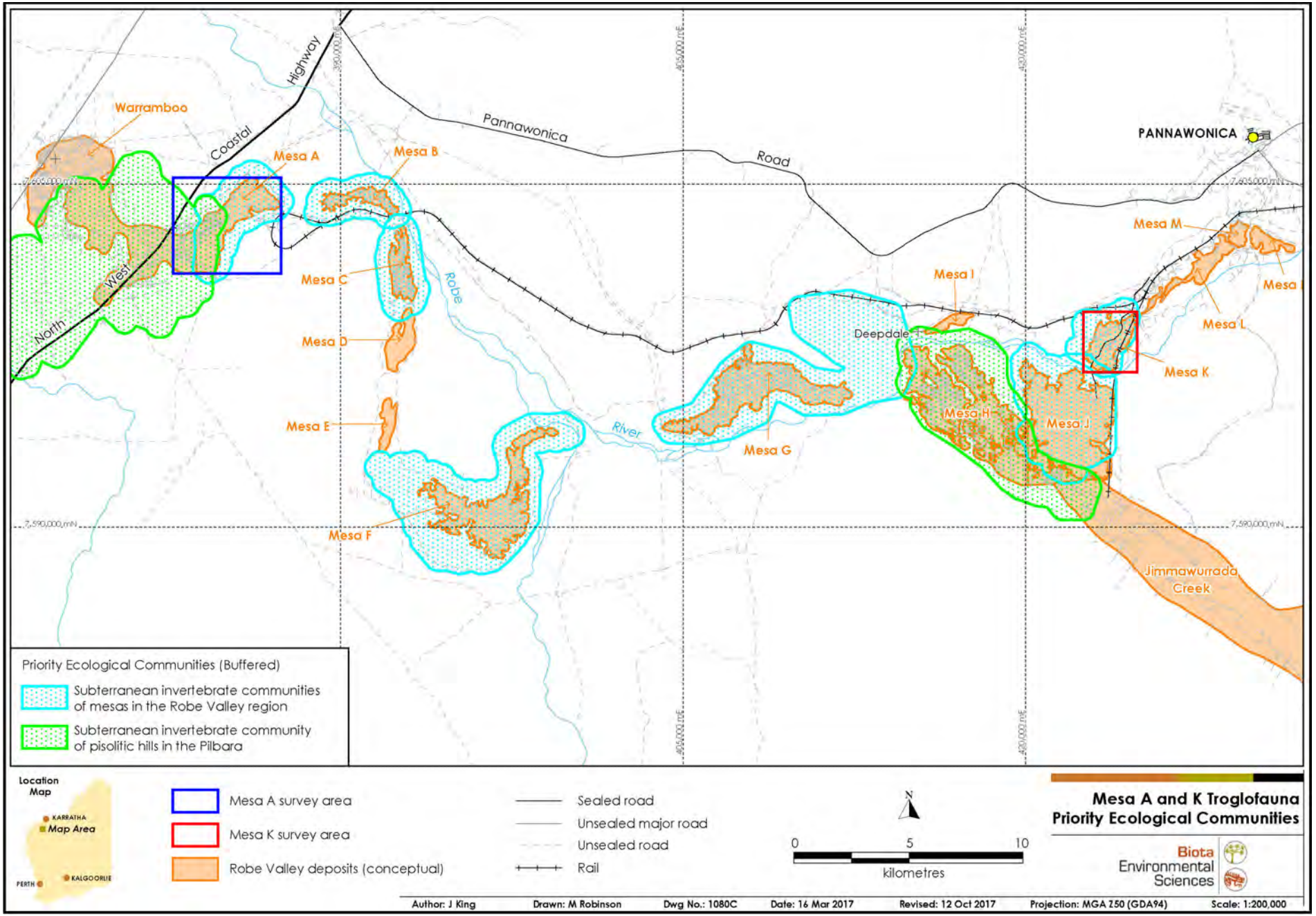

Figure 5.1: Relevant Priority Ecological Communities in the vicinity of the survey area.

5.1.2 Previous Relevant Surveys

Extensive subterranean fauna sampling has been conducted within the Robe Valley, including within the survey area. The focus of these surveys has included baseline studies, assessments and more recently, compliance monitoring. Five reports as listed below summarise the troglofauna sampling conducted at Mesa A. Eight reports as listed below summarise the sampling conducted at Mesa K:

5.1.2.1 Mesa A

- Mesa A Troglofauna Survey; Compilation of Sampling Results (Biota 2006b);
- Mesa A Troglobitic Fauna Compliance Monitoring 2012 (Biota 2012b);
- Mesa A Troglofauna Biennial Compliance Monitoring 2014 (MWH 2014a);
- Mesa A and Mesa B Annual Compliance Troglofauna Survey 2016 (Bennelongia 2017a); and
- Mesa A In-pit sampling July 2016 (Bennelongia 2017b).

5.1.2.2 Mesa K

- Mesa K Remnant Mining Project Troglobitic Fauna Survey (Biota 2007);
- Mesa K Troglobitic Fauna Compliance Monitoring 2010 (Biota 2011c);
- Mesa K Troglobitic Fauna Compliance Monitoring 2011 (Biota 2012a);
- Mesa K Troglobitic Fauna Compliance Monitoring 2012 (Biota 2012c);
- Mesa K Troglofauna Annual Compliance Monitoring 2013 (Outback Ecology 2014);
- Mesa K Troglofauna Annual Compliance Monitoring 2014 (MWH 2014b);
- Mesa K Remnant Mining Project: Troglofauna Compliance Report 2015 (Bennelongia 2015); and
- Mesa K Remnant Mining Project: Troglofauna Compliance Report 2016 (Bennelongia 2017c).

Collectively these sampling programmes represent 10 phases of sampling at Mesa A and 12 phases at Mesa K. These surveys have been reviewed and a summary of relevant information is presented in Table 5.2 and Table 5.3 for Mesa A and K, respectively. The location of previous surveys conducted within Mesas A and K is presented in Figure 5.2 and Figure 5.3.

A summary of the findings from these previous studies and a comparison with the current study is provided in Appendix 3.

Table 5.2: Summary of previous surveys completed within the current Mesa A survey area.

	Biota (2006b): Mesa A Troglofauna Survey; Compilation of Sampling Results	Biota (2012b): Mesa A Troglobitic Fauna Compliance Monitoring 2012	MWH (2014a): Mesa A Troglofauna Biennial Compliance Monitoring: 2014	Bennelongia (2017a): Mesa A and Mesa B Annual Compliance Troglofauna Survey 2016	Bennelongia (2017b): Mesa A In-pit sampling July 2016
Phases	6	1	1	1	1
Area Surveyed	Mesa A, B, C, F, G, H, 2402e, Todd Bore, Warramboo	Mesa A and B	Mesa A and B	Mesa A, B	Mesa A
Survey Timing	21 Nov' 2004 – 11 Apr' 2007	23 May - 20 Jul' 2012	25 Jun' - 5 Sep' 2014	20 Jul' - 18 Sep' 2016	20 Jul' - 18 Sep' 2016
Rain data (mm)					
Rain during sampling	44	51.6	0	5	5
Rain 3 months preceding	627.4	47.4	110	149	149
Sites sampled					
Trapped (Number of traps)	254 (776)	46 (135)	51 (158)	53 (84)	8 (32)
Scraped	0	0	50	42	0
Sites overlapping current survey area					
Trapped (Number of traps)	172 (523)	36 (105)	42 (136)	39 (44)	8 (32)
Scraped	0	0	41	37	0
Number of orders from study overlapping current survey area *	7	5	5	6	1

• Breakdown and comparison per phase in Appendix 3

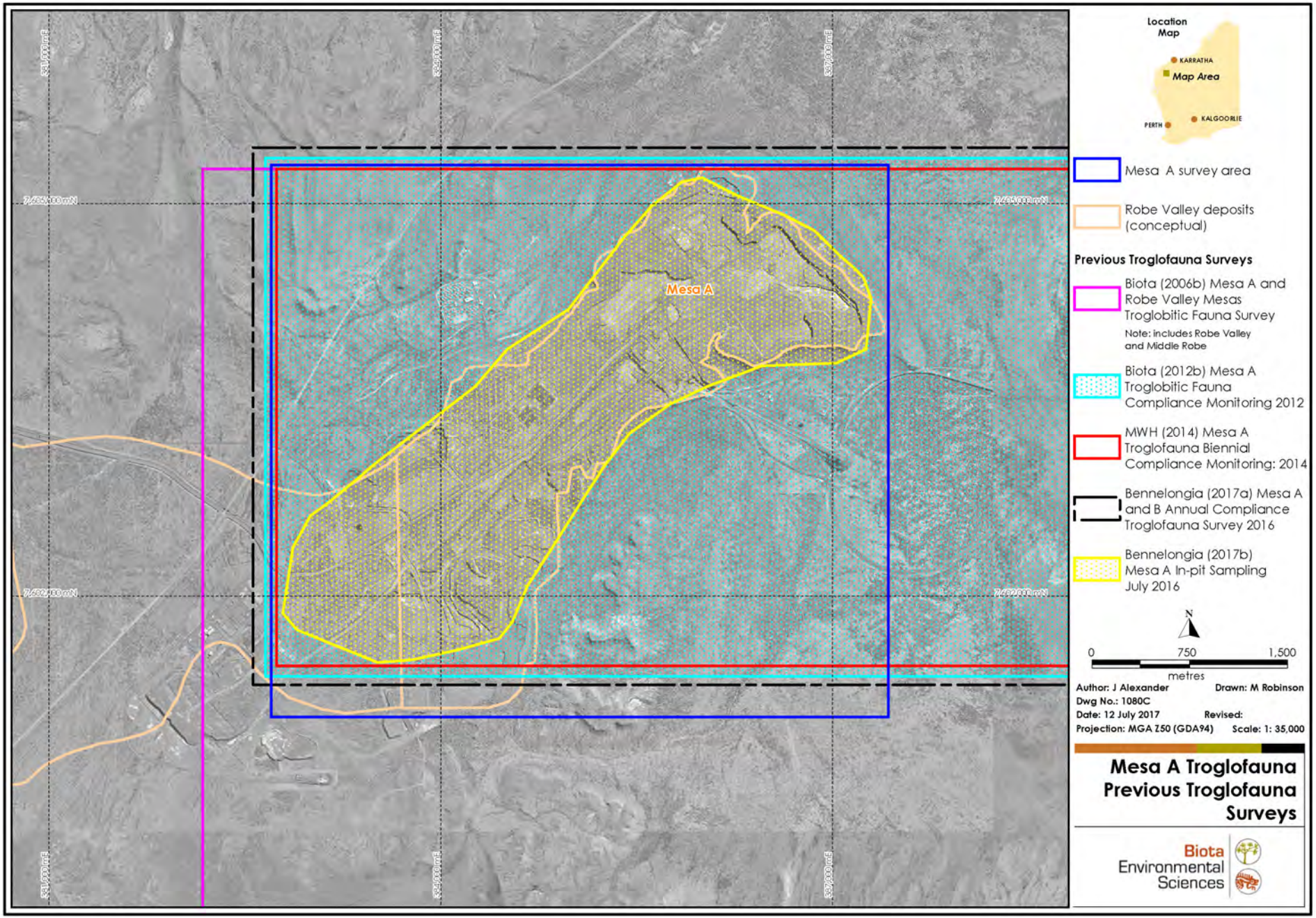

Figure 5.2: Summary of previous study locations in relation to the current survey – Mesa A.

Table 5.3: Summary of previous surveys completed within the current Mesa K survey area.

	Biota (2007): Mesa K Remnant Mining Project Troglobitic Fauna Survey	Biota (2011c): Mesa K Troglobitic Fauna Compliance Monitoring 2010	Biota (2012a): Mesa K Troglobitic Fauna Compliance Monitoring 2011	Biota (2012c): Mesa K Troglobitic Fauna Compliance Monitoring 2012	Outback Ecology (2014) Mesa K Troglofauna Annual Compliance Monitoring 2013	MWH (2014b): Mesa K Troglofauna Annual Compliance Monitoring 2014	Bennelongia (2015): Mesa K Remnant Mining Project: Troglofauna Compliance Report 2015	Bennelongia (2017c): Mesa K Remnant Mining Project: Troglofauna Compliance Report 2016
Phases	5	1	1	1	1	1	1	1
Area Surveyed	Mesa K	Mesa K	Mesa K	Mesa K	Mesa K	Mesa K	Mesa K	Mesa K
Survey Timing	2 May 2005 – 23 May 2007	4 Oct' - 30 Nov' 2010	18 Oct' - 30 Nov 2011	22 May - 18 Jul' 2012	16 Sep' - 14 Nov' 2013	25 Jun' - 5 Sep' 2014	15 Jun' - 11 Aug' 2015	20 Jul' - 18 Sep' 2016
Rain data (mm)								
Rain during sampling	947.6	1.6	0.6	43.2	7.6	0	14.2	5
Rain 3 months preceding	131.1	18.2	18	47.4	1	101.4	184.2	149
Sites sampled								
Trapped (Number of traps)	148 (440)	26 (77)	33 (92)	32 (82)	31 (82)	32 (72)	31 (32)	32 (31)
Scraped	0	0	0	0	0	30	31	31
Sites overlapping current survey area								
Trapped (Number of traps)	148 (440)	26 (77)	33 (92)	32 (82)	31 (82)	32 (72)	31 (32)	32 (31)
Scraped	0	0	0	0	0	30	31	31
Number of orders from study overlapping current survey area *	7	3	5	6	4	4	6	5

• Breakdown and comparison per phase in Appendix 3

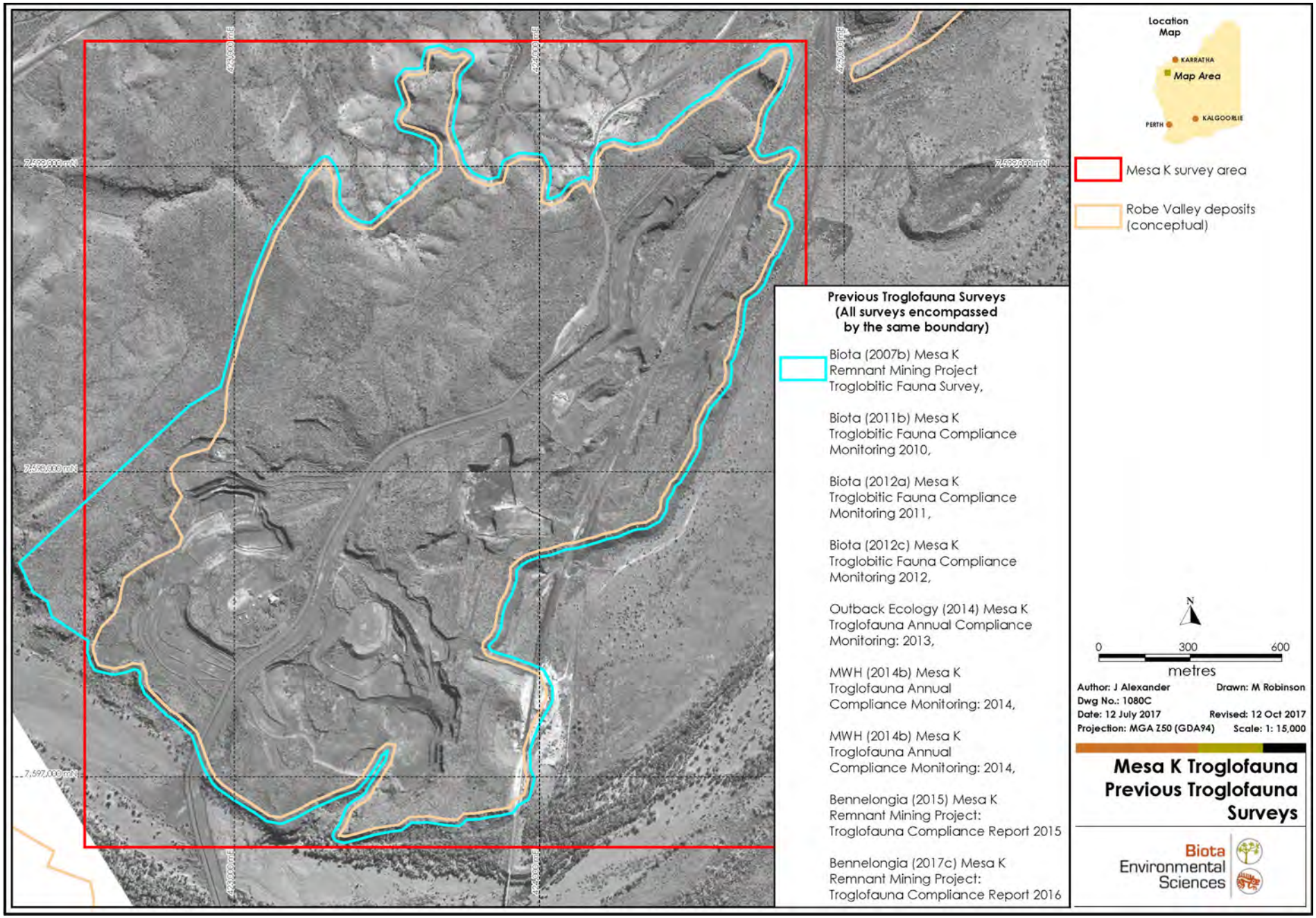

Figure 5.3: Summary of previous study locations in relation to the current survey – Mesa K.

5.1.3 Previously Recorded Fauna

5.1.3.1 Mesa A

A total of 383 specimens were documented from Mesa A from past surveys (Table 5.4 and Figure 5.4). Of these, 198 specimens could not be identified to species level, and are therefore not considered further. These indeterminate records are typically unable to be determined to species levels as they represent juvenile or damaged specimens, or a lack of taxonomic expertise exists for the respective groups. The remaining 185 specimens were identified as belonging to 24 species, of which six have been formally described. Eighteen species are undescribed. Complete details of all previous records are displayed in Appendix 3.

The most commonly collected species was the schizomid *Paradraculoides anachoretus*, representing 65.9% of identified records. This species, as well as four pseudoscorpion species, *Lagynochthonius asema*, *Tyrannochthonius* sp. 'Mesa A', *Ideoblothrus linnaei* and *Ideoblothrus* sp. 'Mesa A' are all listed as conservation significant. These are discussed further in Section 6.1.

Specimens belonging to the orders Polyxenida and Blattodea, and the pseudoscorpion species *Tyrannochthonius aridus* have been documented as having widespread spatial distributions throughout the Pilbara. These specimens are likely troglophilic or epigean and therefore not directly relevant to this troglofauna assessment.

5.1.3.2 Mesa K

The Mesa K desktop review yielded 363 specimens (Table 5.5 and Figure 5.5). Sixty-five specimens were unable to be identified to species level and are therefore not considered further. The remaining 298 specimens were identified as belonging to 22 species. Four species have previously been formally described, and the remaining 18 taxa are currently undescribed. Complete details of all previous records are displayed in Appendix 3.

The schizomid species *Paradraculoides kryptus* was most commonly recorded, representing 50.5% of identified Mesa K records. This species is the only listed conservation significant fauna identified from the desktop review for Mesa K.

The geophilid centipede *Ballophilus australiae*, which has been recorded from Mesa K, is widespread throughout Australia and is epigean. Specimens from the order Polyxenida (corresponding to the species *Lophoturus madecassus*) were also documented from Mesa K. As with the Mesa A results, these taxa are widespread and are likely troglophilic or edaphobitic.

Table 5.4: Previously recorded troglofauna from Mesa A.

Taxonomy			Number Collected	Drill holes
Order	Family	Species		
Araneae	Indeterminate	Araneae sp. 'indet'	3	MEADC2517A, MEARC4283, MEARC4305
	Oonopidae	*Prethopalpus scanloni*	1	MEARC4279
	Pholcidae	*Trichocyclus* sp. 'Mesa A'	1	MEADC2493
Blattodea	Indeterminate	Blattodea sp. 'indet'	3	MEARC4294, MEARC4304
	Nocticolidae	*Nocticola* sp. 'indet'	1	MEARC4018
		Nocticola sp. 'OES11'	2	MEARC4305
Coleoptera	Indeterminate	Coleoptera sp. 'indet'	1	MEARC4038
	Curculionidae	Curculionidae sp. 'B02'	2	MEARC4279, MEARC4297
		Curculionidae sp. 'OES10'	5	MEARC4294, MEARC4304
	Staphylinidae	Staphylinidae sp. 'indet'	9	MEA4155
		Staphylinidae sp. 'MesaKOES2'	1	MEARC4297
Diplura	Indeterminate	Diplura sp. 'Indet'	1	MEARC2702
	Campodeidae	Campodeidae sp. 'nov. gen.'	1	MEARC2656
		Campodeidae sp. 'OES3'	1	MEARC4279
	Japygidae	Japygidae sp. 'indet'	2	MEADC2496, MEADC2497
		Japyx sp. 'indet'	1	MEARC2740
	Projapygidae	Projapygidae nov. gen. sp. 'Mesa A'	2	MEA4318, MEARC4024
Isopoda	Indeterminate	Isopoda sp. 'indet'	5	MEADC2517A, MEARC4281, MEARC4295, MEARC4303
	Armadillidae	Armadillidae sp. 'MesaAOES19'	1	MEARC4293
	Oniscidae	*Hanoniscus* sp. 'MesaAOES22'	5	MEARC4290, MEARC4299, MEARC4304
Polydesmida	Haplodesmidae	Haplodesmidae sp. 'indet'	1	MEA4296
		Haplodesmidae nov. gen. sp. '1'	1	MEADC2497
Polyxenida	Indeterminate	Polyxenida sp. 'indet'	38	MEA2513, MEA4318, MEA2999
	Lophoproctidae	*Lophoturus madecassus*	2	MEARC4281, MEARC4304
		Lophoproctidae sp. 'indet'	66	MEARC4026, MEARC4282, MEARC4296, MEARC4298, MEARC4299, MEARC4301, MEARC4303
Pseudoscorpiones	Chthoniidae	Chthoniidae sp. 'indet'	1	MEARC4279
		*Lagynochthonius asema**	8	MEA4026, MEA4306, MEARC4278, MEARC4284, MEARC4287, MEARC4292, MEARC4296
		Tyrannochthonius aridus	1	MEARC4296
		Tyrannochthonius sp. 'indet'	1	MEARC4047

Taxonomy			Number Collected	Drill holes
Order	Family	Species		
		Tyrannochthonius sp. 'Mesa A'*	1	MEA4476
	Syarinidae	*Ideoblothrus* sp. 'indet'	5	MEARC2856, MEARC2927, MEARC4284, MEARC4290, MEARC4291
		*Ideoblothrus linnaei**	4	MEARC2927, MEARC4018, MEARC4281, MEARC4316
		Ideoblothrus sp. 'Mesa A'*	6	MEA2856, MEA2988, MEA4063, MEARC4301
		Ideoblothrus sp. 'Mesa A2'	1	MEARC4038
Scolopendromorpha	Indeterminate	Scolopendrida sp. 'indet'	3	MEARC2560, MEARC3073, MEARC4016
	Cryptopidae	*Cryptops* sp. 'indet'	6	MEADC2497, MEARC2858, MEARC4284, MEARC4285, MEARC4296, MEARC4307
		Cryptops sp. 'nov'	1	MEADC2500
Schizomida	Hubbardiidae	*Paradraculoides* sp. 'indet'	48	MEADC2517A, MEADC4151, MEARC2740, MEARC2927, MEARC3042, MEARC4038, MEARC4278, MEARC4279, MEARC4280, MEARC4281, MEARC4283, MEARC4284, MEARC4290, MEARC4292, MEARC4293, MEARC4294, MEARC4296, MEARC4298, MEARC4299, MEARC4301, MEARC4304, MOB3A, MOB3B,
		*Paradraculoides anachoretus**	122	A1149, MEA11, MEA2504, MEA2827, MEA2828, MEA2927, MEA2988, MEA3092, MEA4026, MEA4027, MEA4144, MEA4150, MEA4151, MEA4155, MEA4284, MEA4296, MEA4306, MEA4307, MEADC2492, MEADC2497, MEADC2500, MEADC2501, MEADC2517A, MEADC2582, MEADC3188, MEARC2497, MEARC2582, MEARC2611, MEARC2702, MEARC2740, MEARC2858, MEARC2934, MEARC3066, MEARC3073, MEARC4018, MEARC4026, MEARC4151, MEARC4280, MEARC4281, MEARC4283, MEARC4284, MEARC4290, MEARC4291, MEARC4292, MEARC4293, MEARC4294, MEARC4295, MEARC4296, MEARC4299, MEARC4304, MEARC4305, MEARC4306, MEARC4422
		Paradraculoides sp. 'SCH034'	3	MEADC4018, MEARC4151, RC16MEA004
Thysanura	Indeterminate	Thysanura sp. 'Indet'	1	MEA2513
	Nicoletiidae	Nicoletiidae sp. 'indet'	2	MEAD4151, MEARC4305
		Trinemura sp. 'Mesa A 1'	7	MEADC2496, MEADC2501, MEADC2517A, MEADC2523, MEADC2582, MEARC3098
		Trinemura sp. 'Mesa A 2'	5	MEARC4296, MEARC4305

* Conservation significant fauna.

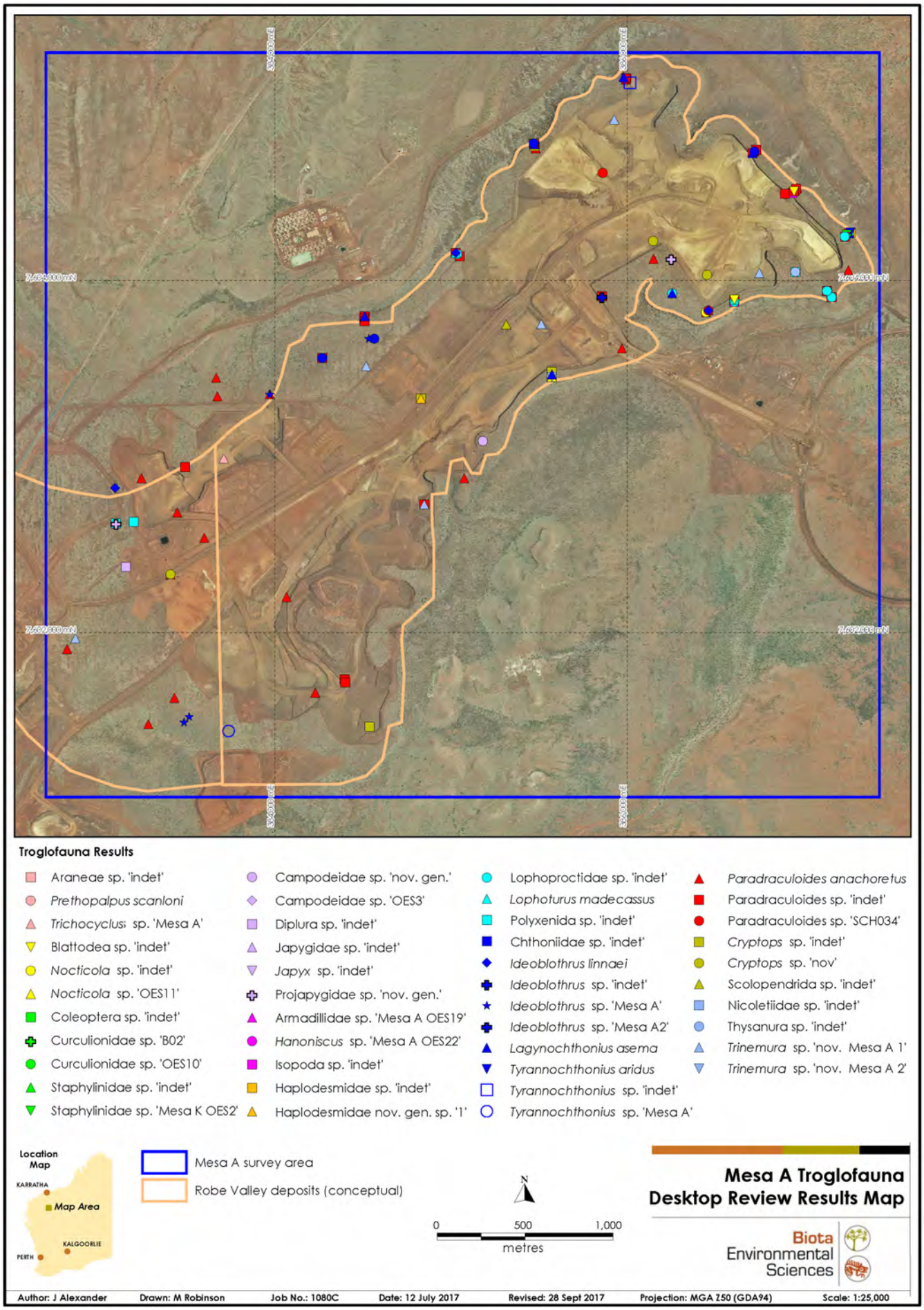

Figure 5.4: Previous sampling locations and recorded troglofauna for Mesa A.

Table 5.5: Previously recorded troglofauna from Mesa K.

Taxonomy			Number Collected	Drill holes
Order	Family	Species		
Araneae	Micropholcommatidae	Micropholcommatidae sp. 'WAMARA001'	1	MEKRC1703
Blattodea	Nocticolidae	*Nocticola* 'OES11'	7	K0740, K0989, K0996, MEK1718, MEK1731
Cephalostigmata	Indeterminate	Symphyla sp. 'Indet'	1	MEKRC1731
Coleoptera	Ptiliidae	*Ptinella* sp. 'B01'	13	MEK1718, MEK1735
	Curculionidae	Cryptorhynchinae sp. 'B04'	2	MEK1478, MEK1486
		Curculionidae sp. 'OES10'	1	MEK1486
		Curculionidae gen. nov. sp. 'B01'	1	MEK1486
Diplura	Japygidae	*Heterojapyx* sp. 'nov'	1	MEK1478
Geophilomorpha	Ballophilidae	*Ballophilus australiae*	1	MEK1731
Isopoda	Oniscidae	*Hanoniscus* sp. '1'	4	MEK1337, K1074, MEK1486
	Philosciidae	*Andricophiloscia* sp. 'B19'	2	K0739
Polyxenida	Lophoproctidae	*Lophoturus madecassus*	60	K0502, K0607, K0672, K0989, K0996, MEK1478, MEK1486, MEK1558, MEK1703, MEK1712, MEK1718, MEK1731
Polydesmida	Indeterminate	Polydesmida sp. "Indet'	1	MEK1712
Pseudoscorpiones	Atemnidae	*Paratemnoides* sp. 'Indet'	1	K0607
		Oratemnus sp. 'PSE081'	3	K0996, K1074, MEK1735
	Chthoniidae	*Lagynochthonius* sp. 'Mesa K'	4	MEK1685, MEK1689, MEK1731, MEK1735
	Hyidae	*Indohya* sp. 'Mesa K'	6	K0740, K0502, K0607, MEK1696, MEK1558
	Olpiidae	*Linnaeolpium linnaei*	1	K0502
	Syarinidae	*Ideoblothrus* sp. 'Mesa K'	2	K0996, MEK1685A
		Ideoblothrus sp. 'indet'	1	K0996
		Ideoblothrus sp. 'nov'	1	MEK1721
Schizomida	Hubbardiidae	*Paradraculoides kryptus**	150	K0502, K0607, K0672, K0739, K0740, K0948, K0968, K0989, K0996, K1074, K1328, MEK0672, MEK0739, MEK1337, MEK1478, MEK1486, MEK1558, MEK1570A, MEK1685, MEK1689A, MEK1696, MEK1697, MEK1702, MEK1703, MEK1712, MEK1718, MEK1724, MEK1728, MEK1731, MEK1732, MEK1735, MEK1735A
		Paradraculoides sp. 'Indet'	59	K0502, K0557, K0607, K0672, K0740, K0989, K0996, K1066, K1068, K1074, K1337, K1598, MEK1558, MEK1570, MEK1609, MEK1685, MEK1689A, MEK1697, MEK1703, MEK1712, MEK1718, MEK1721, MEK1724, MEK1731, MEK1732, MEK1735, MEK1735a, OPK01
Scolopendromorpha	Cryptoptidae	*Cryptops* sp. '1'	2	K0502, MEK1302, MEK1731

Taxonomy			Number Collected	Drill holes
Order	Family	Species		
		Cryptops sp. 'B47'	1	MEK1735
	Scolopendridae	Scolopendridae sp. 'B03'	1	K0502
	Dalodesmidae	Dalodesmidae sp. 'B08'	34	MEK1609, MEK1703
Spirobolida	Indeterminate	Spirobolida sp. 'Indet'	1	K0502
Thysanura	Indeterminate	Thysanura sp.'Indet'	1	MEK1731

* Conservation significant fauna.

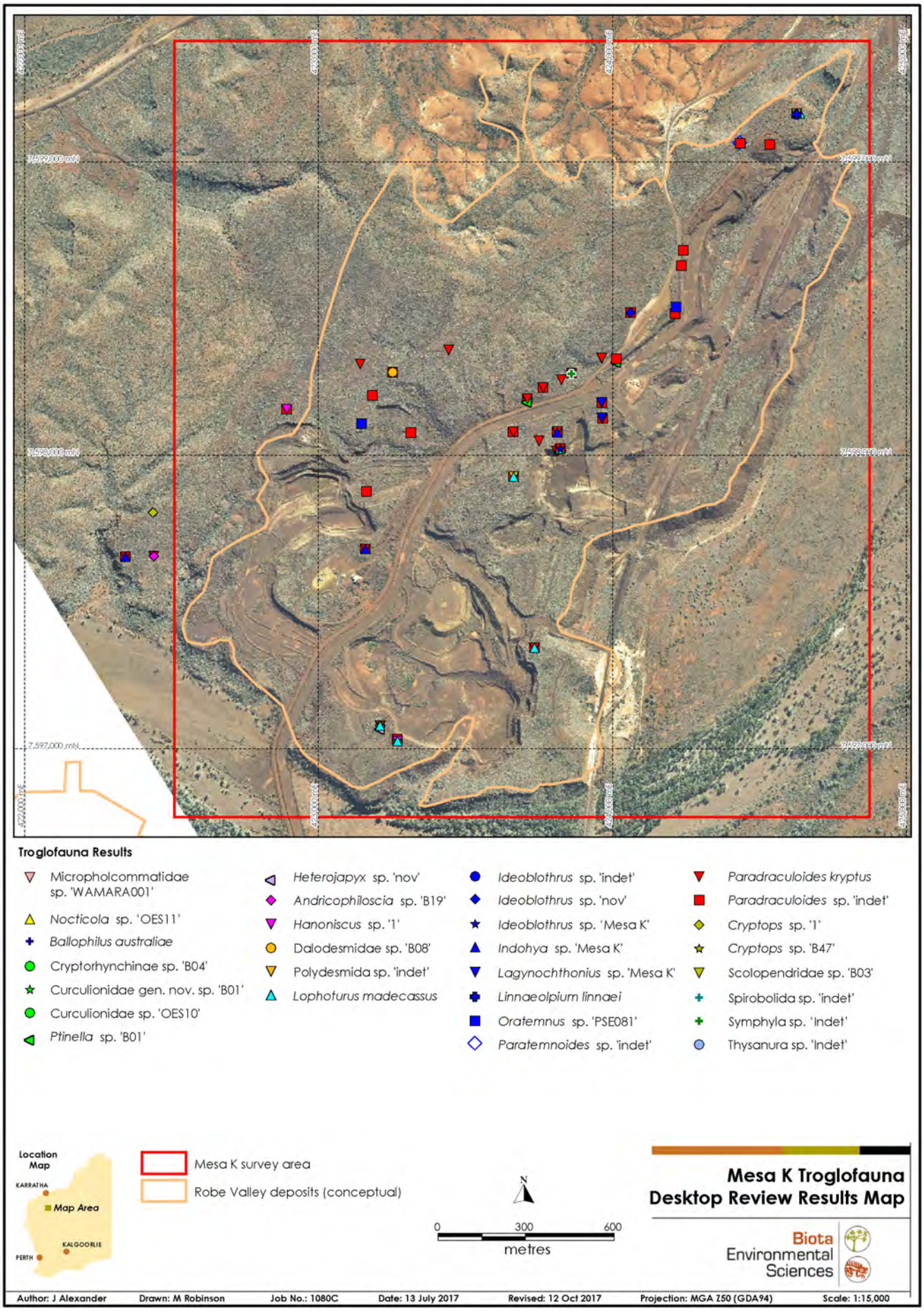

Figure 5.5: Previous sampling locations and recorded troglofauna for Mesa K.

5.2 Survey Results

5.2.1 Mesa A

A complete account of all specimens recorded, including surface and edaphobitic specimens, is presented in Appendix 4. Only troglomorphic fauna records from the survey area will be discussed further.

5.2.1.1 Schizomida

Four schizomid specimens were recorded from drillhole RC16MEA004 at Mesa A (Table 5.6), all of which were recorded during Phase 2. Genetic analysis of collected Schizomida determined the presence of two distinct lineages, with divergence levels indicating they represent distinct species (Table 5.6, Plate 5.1, Plate 5.2, Figure 5.7).

Table 5.6: Schizomida records from Mesa A.

Family	Genetic Lineage	Species Name	Number Recorded	Drillhole
Hubbardiidae	Schizomida SCH034	*Paradraculoides* sp. 'SCH034'	3	RC16MEA004
	Schizomida SCH063	*Paradraculoides anachoretus*	1	RC16MEA004

Plate 5.1: *Paradraculoides* sp. 'SCH034' .

Plate 5.2: *Paradraculoides anachoretus* .

Paradraculoides sp. 'SCH034' differs from *Paradraculoides anachoretus* by between 5.6% and 6.3% genetic divergence, and from their next closest related reference species, *Paradraculoides* sp. 'SCH003' (Warramboo) and *Paradraculoides bythius* (Mesa B), by 7.7% and 8.4% genetic divergence respectively.

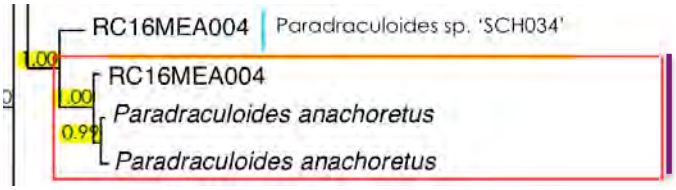

Figure 5.6: Excerpt of the Helix Bayesian analysis of CO1 haplotypes of the family Hubbardiidae collected from Mesa A.
(Numbers on major nodes correspond to posterior probabilities; values <50% are not shown. Coloured blocks indicate specimens belonging to a single species.)

Paradraculoides anachoretus has been widely recorded from Mesa A and is considered to be endemic to the mesa. *Paradraculoides* sp. 'SCH034' was recorded from RC16MEA004, which intercepts both the low grade waste dump and strata beneath the pit floor. This species is also known from two other sites within the MEZ. Sequencing of the schizomids recorded from Mesa A during the current study also included a juvenile specimen recorded from Mesa A by Bennelongia (2017b).

This specimen was originally only identified to genus level based on morphology, but genetic analysis undertaken in the current study has determined that it too belongs to *Paradraculoides* sp. 'SCH034', and was recorded from the same drillhole, RC16MEA004 (Appendix 2).

5.2.2 Mesa K

No troglomorphic specimens were collected from Mesa K.

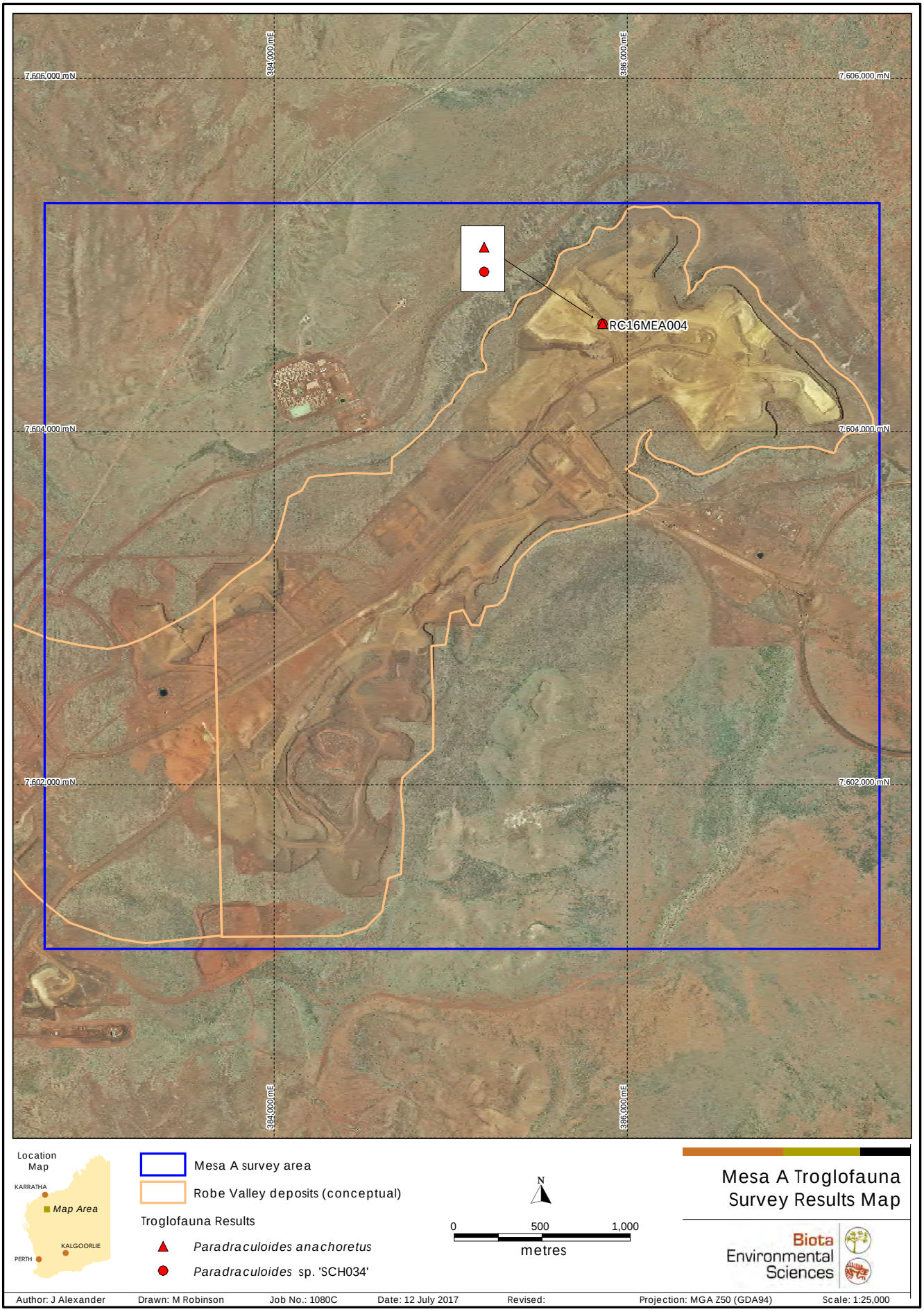

Figure 5.7: Location of schizomid records collected from Mesa A during current survey.

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6.0 Discussion

6.1 Conservation Significance and Distribution of In-pit Records

6.1.1 Mesa A

A total of 22 taxa identified to species level have been recorded from the Mesa A deposit. Five of these (one schizomid and four pseudoscorpion taxa) represent species that are of conservation significance:

1. *Paradraculoides anachoretus* (Schedule 3): Over 120 specimens known only from Mesa A.
2. *Ideoblothrus linnaei* (Priority 1): Four specimens known only from Mesa A.
3. *Ideoblothrus* sp. 'Mesa A' (Priority 1): Six specimens known only from Mesa A.
4. *Lagynochthonius asema* (Priority 1): Eight specimens known only from Mesa A.
5. *Tyrannochthonius* sp. 'Mesa A' (Priority 1): One specimen known only from Mesa A.

Of these five conservation significant species, one was recorded from in-pit sampling at Mesa A during the current survey, with a single *Paradraculoides anachoretus* specimen collected from RC16MEA004. This species is well represented and commonly recorded throughout Mesa A, with more than 120 records confirmed (Table 5.4). A separate species, *Paradraculoides* sp. 'SCH034', was collected from the same drillhole, RC16MEA004, during the current survey. The presence of two species of schizomid within the Mesa A landform is notable, as previous sampling has indicated the presence of only one species per mesa landform (Harvey et al. 2008). The collection of *Paradraculoides anachoretus* from the same drillhole indicates that the two species occur in sympatry, though the possibility exists that the habitats of the two species are vertically separated and thus effectively precluding sympatry. Six specimens from the specied *Paradraculoides* sp. 'SCH034' have been recorded, including the specimen collected by Rio Tinto during a previous survey at Mesa A (Bennelongia 2017b).

A summary of schizomid species recorded from Mesa A during the current survey, including their conservation status and known distribution is presented in Table 6.1. All Schizomida from the Robe Valley mesas are considered strongly obligate troglofauna, and as such *Paradraculoides* sp. 'SCH034' is unlikely to have a distribution greater than the Mesa A landform. *Paradraculoides* sp. 'SCH034' therefore currently represents a potential SRE species (Table 6.1). The distribution of previously recorded conservation significant and potential SRE troglofauna species recorded at Mesa A (including those from the current study) is presented in Figure 6.1.

Table 6.1: Summary of species recorded from Mesa A for the current Scope of Work, including their conservation status and distribution.

(Coordinates in GDA94, Zone 50; A summary of the WAM SRE categories is located in Appendix 4).

Species Name	Distribution (km^2)	Collection Representation*	New Species	Singleton Record ∞	SRE Sub-Categories ^	Notes
Conservation Significant Species						
Paradraculoides anachoretus	5.7	Good	-	-	-	Listed as Schedule 3. Over 120 specimens known from Mesa A distribution.
Potential SRE Species						
Paradraculoides sp. 'SCH034'	0.24	Fair	X	X	A. Data Deficient D. Molecular evidence	Multiple specimens from single location.

* Poor: <5 specimens, Fair: 5 – 15, Good: >15.

∞ includes multiple specimens collected from single site.

^ A. Data Deficient, B. Habitat Indicators, C. Morphology indicators, D. Molecular Evidence, E. Research and Expertise (more detail in Appendix 5).

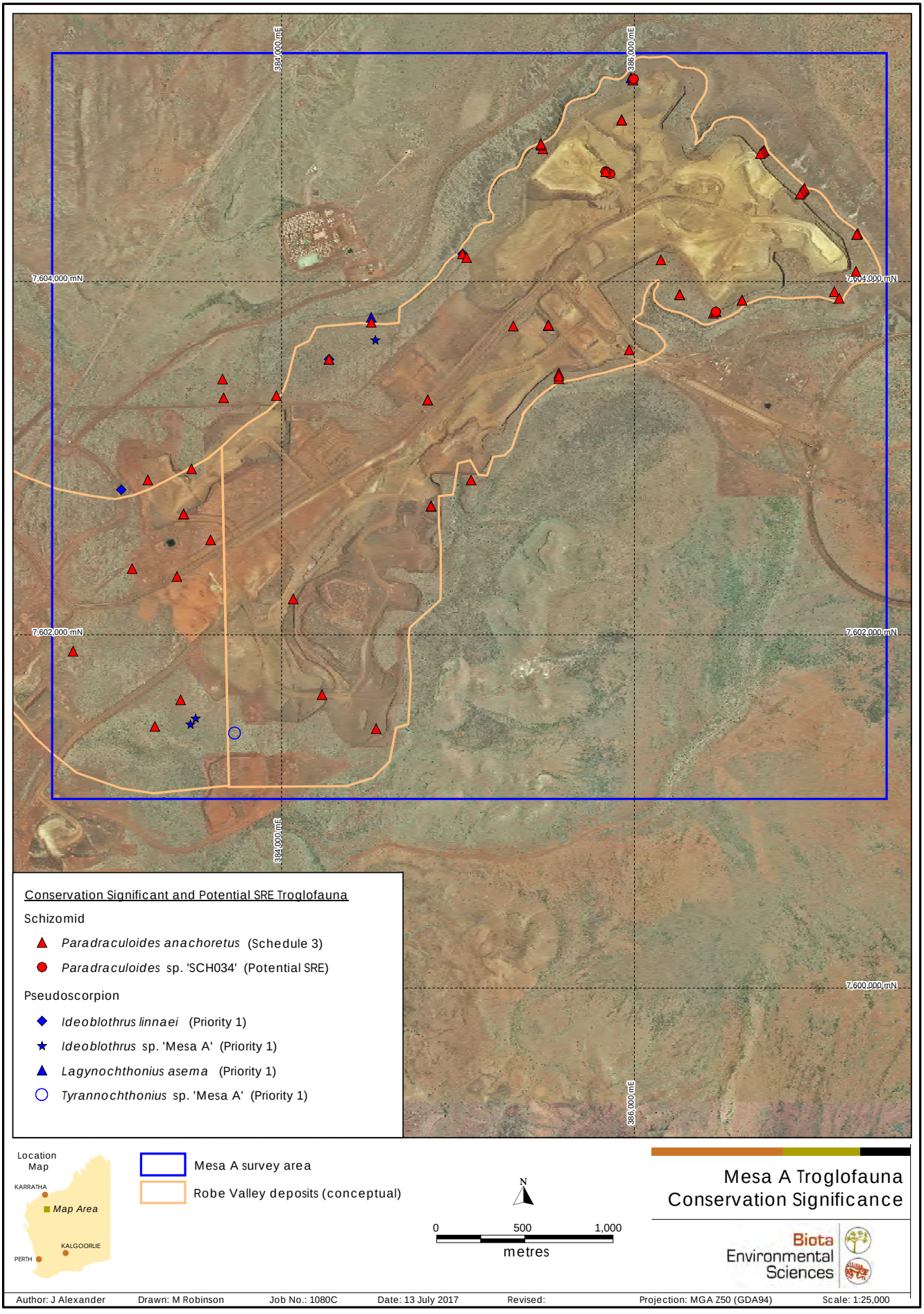

Figure 6.1: Distribution of conservation significant and potential SRE troglofauna species at Mesa A.

6.1.2 Mesa K

A total of 22 species have been recorded from the Mesa K deposit. The current survey did not add any further records to this total. Of the recorded taxa, only one species, the schizomid *Paradraculoides kryptus* is listed as being of conservation significance. This species is listed as Schedule 3 fauna, with 120 specimens recorded solely from Mesa K (Table 5.5). The distribution of this species at Mesa K is presented in Figure 6.2.

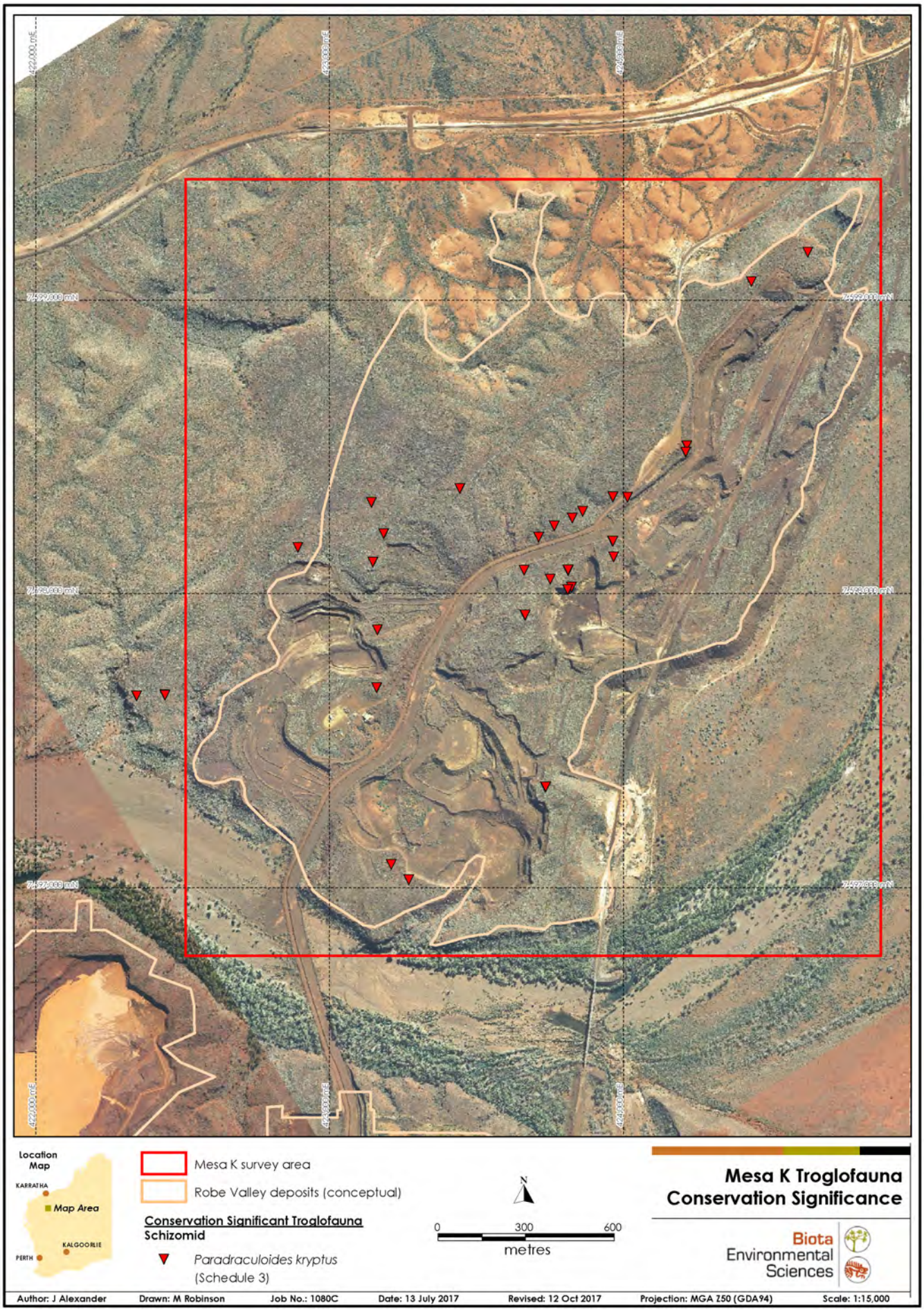

Figure 6.2: Distribution of conservation significant troglofauna species at Mesa K.

6.2 Troglofauna Communities of In-pit Habitats

Currently, insufficient data exist to allow for a robust analysis comparing the results of in-pit sampling at Mesa A with the results of sampling within the MEZ and prior to mining operations, but as a minimum, this study has confirmed that both schizomid species recorded in-pit also occur within the MEZ. Most sampling effort since operations commenced has focused on reference area sampling, creating a biased data set.

Some observations can be made from the results of the in-pit sampling. From the very limited data available, it is possible troglofauna may be utilising the low-grade waste dump at Mesa A as habitat. However, information provided by Rio Tinto indicates that the sampled drill hole was also drilled beyond the base of the waste dump and into intact troglofauna habitat below. This introduces the more likely possibility that the troglobites recorded from this site may have entered the drillhole from intact habitat at depth, rather than truly utilising the waste dump as habitat.

7.0 Glossary

Edaphobite	Deep soil inhabitant.
Endemic	Native to or confined to a certain region.
EPA	Environmental Protection Authority of Western Australia.
Epigean	Fauna from above the soil level.
Karst	Soluble-rock landscape; terrain with distinctive hydrology and landforms arising from a combination of high rock solubility and well-developed secondary porosity.
Mesocaverns	Underground voids in the size range 0.1 – 20cm, especially in karst and volcanic substrates.
Pisolite	Rock composed of pisoliths.
Short-Range Endemic (SRE)	A species that has a naturally small distribution and is often characterised by having poor dispersal capabilities, confinement to disjunct habitats and low fecundity. WAM guidelines for determining SRE status in Appendix 5.
Species Complex	A group of closely related species currently placed within a single species name.
Stygobite / Stygofauna	Fauna inhabiting the various types of groundwater.
Sympatry	The occurrence of populations in overlapping geographical areas, but without interbreeding.
Troglobite / Troglofauna	Species that do not exist outside caves. They may, however, occur in the superficial underground compartment or in the upper hypogean zone.
Troglophile / Troglophilic	Species that utilise, but are not restricted to, subterranean environments. Able to use surface environments for dispersal.

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Appendix 1

Licence to take Fauna for Scientific Purposes (Licence: 08-000238-1)

DEPARTMENT OF PARKS AND WILDLIFE

Department of Parks and Wildlife

Enquiries: 17 DICK PERRY AVE, KENSINGTON, WESTERN AUSTRALIA
Telephone: 08 9219 9000
Facsimile: 08 9219 8242
Web Site: https://wildlifelicensing.dpaw.wa.gov.au/
Correspondance: **Locked Bag 30**
Bentley Delivery Centre WA 6983

Wildlife Conservation Act 1950

REGULATION 17

Regulation 17 – Licence to take fauna for scientific purposes (Regulation 17 - Standard)

The undermentioned person may take fauna for research or other scientific purposes and where authorised, keep it in captivity, subject to the following and attached conditions, which may be added to, suspended or otherwise varied as considered fit.

Director General

Conditions

1 The licensee shall comply with the provisions of the Wildlife Conservation Act 1950, Wildlife Conservation Regulations 1970 and any Notices in force under this legislation.

2 The licensee shall take fauna only in the manner stated on the endorsed Regulation 17 licence application form and endorsed related correspondence.

3 Unless specifically authorised in the conditions of this Licence or otherwise in writing by the Director General, species of fauna declared as likely to become extinct, rare or otherwise in need of special protection shall not be taken.

4 Any by-catch of fauna, which is declared to be rare, likely to become extinct, or otherwise in need of special protection shall be released immediately at the point of capture. Where such fauna taken under this licence is injured or deceased, the licensee shall contact the Department's Wildlife Licensing Section for advice on disposal. Records must be kept of any such fauna so captured and details are to be included in the report required under further condition below.

5 Any interaction involving Gazetted Threatened Fauna that may be harmful to the fauna and/or invasive may require approval from the Commonwealth Department of the Environment ph 02 6274 1111. Interaction with such species is controlled by the Commonwealth Environment Protection and Biodiversity Conservation Act 1999 and Environment Protection and Biodiversity Conservation Regulations 2000 as well as the Wildlife Conservation Act 1950 and Wildlife Conservation Regulations 1970.

6 No fauna shall be taken in areas where it would impinge on pre-existing scientific research programs.

7 Except in the case of approved lethal traps, the licensee shall ensure that measures are taken in the capture and handling of fauna to prevent injury or mortality resulting from that capture or handling. Where traps or other mechanical means or devices are used to capture fauna these shall be deployed so as to prevent exposure of trapped animals to ants and debilitating weather conditions and inspected at regular intervals throughout each day of their use. At the conclusion of research all markers used, and signs and structures erected by the licensee shall be removed and the environment returned to its original condition.

8 Not more than ten specimens of any one protected species of fauna shall be taken and removed from any location less than 20km apart. Where exceptional circumstances make it necessary to take a larger number of specimens from a particular location in order to obtain adequate statistical data, the collector must proceed with circumspection and justify their actions to the Director General in advance.

9 The licensee shall not release any fauna or their progeny in any area where it does not naturally occur, nor hand such fauna over to any other person or authority unless approved by the Director General, nor dispose of the remains of such fauna in any manner likely to confuse the natural or present day distribution of the species.

10 Bioprospecting involving the removal of sample aquatic and terrestrial organisms for chemical extraction and bioactivity screening shall not be conducted without specific written approval by the Director General.

11 No fauna shall be taken from any CALM land, as defined in the Conservation and Land Management Regulations 2002, without prior written approval of the Director General. No fauna shall be taken from any public land without the prior written approval of the Government Authority managing that land.

12 The licensee shall not enter upon any private property or pastoral lease for the purposes of this licence, nor take any fauna from any private land or pastoral lease without the prior consent in writing of the owner or occupier. Similarly, in the case of Aboriginal lands, the licensee must not enter upon or take fauna from such lands without the written approval of the Department of Aboriginal Affairs and/or the relevant native title holders or applicants.

13 Copies of this licence and any written approval or consent required by conditions of this licence must be carried by the licensee and any person/s authorised under the licence at all times when conducting activities relevant to the licence

Department of Parks and Wildlife

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Bentley Delivery Centre WA 6983

and must be presented to an authorised officer of the Department upon request.

14 All holotypes and syntypes and a half share of paratypes of species or subspecies permitted to be permanently taken under this licence shall be donated to the Western Australian Museum. Duplicates (one pair in each case) of any species collected, which represents a significant extension of geographic range shall upon request be donated to the Western Australian Museum.

15 To prevent any unnecessary collecting in this State, all specimens and material taken and retained under the authority of this license shall, upon request, be loaned to the Western Australian Museum. Any unused portion or portions of any specimen collected under the authority of this license shall be offered to the Western Australian Museum for inclusion in its collection or made available to other scientific workers if so required.

16 Within one month of the expiration of this licence, the holder shall submit an electronic return into the department's Wildlife Licensing System, detailing the locality, site, geocode, date and number of each species of fauna captured, sighted or vouchered during the currency of the licence. A copy of any paper, report or thesis resulting from the research shall upon completion be lodged with the Director General.

Purpose

Troglofauna and Stygofauna survey for environmental impact assessment via plankton net hauls, PVC leaf-litter traps and net haul scrapings in accordance with EPA guidance statement 54a

Locations

Warramboo, Mesa A, Mesa C, Mesa K

Authorised Person

Surname	Given name(s)
Alexander	Jason
Watson	Nicola
King	Jacinta
Teale	Roy
Kamien	Daniel
Schmidt	Sylvie
Humphreys	Garth
Werner	Scott
Keirle	David
Ford	Stewart
Greenham	Michael
Adam	Cassie

DEPARTMENT OF PARKS AND WILDLIFE

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Date of Issue 21/02/2017
Valid From 21/02/2017
Date of Expiry 20/02/2018

Licensee: Ms Penny Brooshooft
Address Biota Environmental Sciences
PO Box 155
Leederville WA 6903
Australia

Issued by a Wildlife Licensing Officer of the Department of Parks and Wildlife under delegation from the Minister for Environment pursuant to section 133(1) of the Conservation and Land Management Act 1984.

Appendix 2

Molecular Analysis Report

Summary of Helix Sequences

Tracking Number	Mesa	Taxon	Helix ID	WAM ID	lineage	Notes
RC16MEC0177-20170309-01	C	Araneae	LI29	T144228	AG001	
MEAWO4088-20170307-01	C	Diplura	LI30		DJA011	No WAM number. Specimen used in sequence
RC16MEC0177-20170309-02	C	Pseudoscorpiones	LI31	T144224	PC058	
RC16MEC0102-170308-2	C	Schizomida	LI32	T144242	SCH001	*Paradraculoides bythius*
MEAWO4086-20170308-04	C	Thysanura	LI33	E34017	TN010	
RC16MEK002-20170321-T2-1	K	Pseudoscorpion	LI34	T144225	PC059	
RC16MEK002-20170321-T3-1	K	Pseudoscorpion	LI35	T144226	PC059	
RC16MEA004-20170322-T1-1	A	Schizomida	LI36	T144230	SCH034	
RC16MEA004-20170322-T1-2	A	Schizomida	LI37	T144232	SCH034	
RC16MEA004-20170322-T1-3	A	Schizomida	LI38	T144231	SCH034	
RC16MEA004-20170322-T1-4	A	Schizomida	LI39	T144233	SCH036	*Paradraculides anachoretus*
142611	A	Schizomida	LI40	T142611	SCH036	*Paradraculides anachoretus*
142610	A	Schizomida	LI41	T142610	SCH036	*Paradraculides anachoretus*
142613	A	Schizomida	LI42	T142613	SCH036	*Paradraculides anachoretus*
142612	A	Schizomida	LI43	T142612	SCH034	
MEBRC0008	B	Coleoptera	LI44		CCU012	
MEBRC0016	B	Coleoptera	LI45		CCU012	

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6 July, 2017

Jason Alexander
Biota Environmental Sciences
Level 1, 228 Carr Place
Leederville, WA 6007

Via email

Re. Report on the molecular systematics of troglofauna from Warramboo, and Mesas A, C and K (Biota 1080c)

Dear Jason,

Following is a summary of the results of the troglofauna study we have completed for six taxonomic groups (Araneae, Coleoptera, Diplura, Pseudoscorpiones, Schizomida, Thysanura) from Mesas A, C, K and Warramboo. Nine distinct genetic lineages were detected in the collections, five of which have been detected previously in the Pilbara.

Thanks once again for collaborating on this project with Helix. We hope we can continue to provide you with useful information, and feel free to contact us if you have any questions or would like to discuss the results in detail.

Sincerely,

Dr. Terrie Finston, Yvette Hitchen and Dr. Oliver Berry
Helix Molecular Solutions

Background and Objective

Seventeen specimens of troglofauna from six taxonomic groups (Araneae, Coleoptera, Diplura, Pseudoscorpiones, Schizomida, Thysanura) were collected from Mesas A, C, K and Warramboo and sequenced for variation at the mitochondrial COI gene, with the exception of the Thysanura, which was sequenced for 12s. The molecular data were assessed in order to determine the number of species present and compare the results to those obtained during previous surveys in the Pilbara.

Executive summary

- Seventeen specimens of troglofauna from Mesas A, C, K and Warramboo were sequenced for variation at the COI or 12s gene.
- Nine distinct genetic lineages from were detected among the 17 specimens.
- Five of the lineages have been detected previously in the Pilbara, during previous surveys at Mesa B and C.
- Four of the lineages appear to be new, based on the material available for comparison.

Methods

Seventeen specimens of troglofauna from six taxonomic groups (Araneae, Coleoptera, Diplura, Pseudoscorpiones, Schizomida, Thysanura) were sequenced for variation at the mitochondrial cytochrome oxidase subunit I gene (COI) using primers LCOI/HCO2, with one exception. The Thysanura was sequenced for the 12s gene, using primers 12sai/12sbi (Simon et al., 1994).

Sequences were edited using GENEIOUS software (Drummond *et al.* 2011). Alignment was performed with CLUSTAL W (Thompson *et al*. 1994) using default parameters. Genetic distances between unique genetic sequences (haplotypes) were measured using uncorrected p-distances (total percentage of nucleotide differences between sequences).

MODELTEST software (Posada and Crandall, 1998) was used to determine the model of sequence evolution that best fitted the data for each taxonomic group. Bayesian analysis was used to construct the phylogenetic trees, incorporating the model as identified in MODELTEST for each taxonomic group. The phylogeny, branch lengths and posterior probabilities were obtained by running two trees simultaneously, each running four simultaneous MCMC chains. The number of cycles needed was determined by the standard deviation of the split frequencies of the two trees. The analysis was paused after every 1 x 10^6 generations and when the standard deviation fell below 0.01, the analysis was stopped. A majority rule consensus tree was constructed after discarding the "burn-in" trees in both analyses. The burn-in value was determined by plotting the posterior probabilities obtained after every generation and identifying the point at which the values reach stationarity (= the asymptote). Trees produced prior to stationarity were discarded.

For the purposes of this report, lineages were defined as haplotypes or groups of haplotypes differing from other such groups by >3% sequence divergence. This cut-off was selected based on bar-coding data, which indicates that intra-specific variation rarely exceeds 2-3% (Hebert et al., 2003b).

Results

Araneae

A single specimen of Araneae from Mesa C was sequenced for COI (Table 6). The sequence was compared to sequences of Araneae in the Helix and GenBank databases. The specimen was most similar to specimens of Gnaphosidae (85% similarity to a Genbank specimen of *Zelanda*), however a subset of reference specimens that differed by ≤15% from the Mesa B and C specimens from all phases were selected to include in the phylogenetic analysis, including 33 specimens of Araneae from the Pilbara, eight of which were collected during previous surveys at Mesas B and C, as well as eight GenBank reference specimens as follows: Gnaphosidae: *Zeland* sp. (Genbank accession # KY017738) Aranidae: *Arachnura scorpiooides*, (GenBank accession #KJ957946 and *Gea theridoides* (Genbank accession #KJ959766), Oonopidae: *Ischnothyreus auritus* (Genbank accession# KR864743) Theridiidae: *Theridion ohlerti* (Genbank accession #GU684645), *Robertus neglectus* (GenBank accession #AY231053), *Theridion boesonbergi* (Genbank accession #KX537094) and *Coleosoma acutiventer* (Genbank

accession # EF050286). Two specimens of Mygalomorphae, *Missulena* sp. WAM T97637 (Genbank accession # KC708097) and *Missulena* sp. WAM T113626 (Genbank accession # KC708079) were used as outgroups.

Phylogenetic analysis
The phylogenetic analysis, which included the new specimen from Mesa C, in addition to 41 reference specimens, placed the Mesa C specimen in a single genetically distinct lineage (Figure 4). The lineage was placed in a clade containing a Genbank reference specimen of Gnaphosidae and four specimens from Jirrpalpur, Opthalmia and Wheelarra Hill, and thus was assigned to the new lineage AG003 (Figure 4). The specimens of Araneae from previous sampling phases at Mesas B and C were placed in clades containing Theridae/Symphytognathidae, Aranidae and Oonopidae (Figure 4).

Differentiation within and between lineages
The new specimen from Mesa C (lineage AG003) differed from the reference specimens by between 15.0 and 27.7% sequence divergence (Table 7).

Coleoptera
Reference specimens and outgroups
Two specimens of Coleoptera from Mesa B were sequenced for COI (Table 6). In order to reduce analysis time and to simplify the presentation of results, a preliminary neighbour-joining (NJ) analysis was conducted on the Mesa B specimens and analysed with 123 reference sequences of Coleoptera, including 23 provided by the WAM, to identify a manageable and relevant reference data set. The specimens were most closely related to reference specimens of Curculionidae, so the final dataset consisted of a Genbank voucher sequence (Curculionidae sp. 8, Genbank accession #KU519717) and 29 reference specimens of Curculionidae from the Pilbara, including 15 sequences provided by the WAM, representing eight species and ten from previous surveys at Mesas B and C. Two specimens of Coleoptera from the family Dermestidae, *Dermestes maculatus* (Genbank accession # HM909035) and *Dermestes frischii* (Genbank accession # KM578824) were used as outgroups.

Phylogenetic analysis
The phylogenetic analysis, which included the two specimens from Mesa B, in addition to 30 reference specimens, placed the Mesa B specimens in a single lineage, which also contained five reference specimens of Curculionidae from previous surveys at Mesas B and C in the Robe Valley (Figure 5). Thus the new Mesa B specimens were assigned to the existing lineage CCU012 (Figure 5). The lineage was placed in a well-supported clade containing two WAM reference specimens of Curculionidae sp. 8 (Figure 5). The specimens of Coleoptera from previous sampling phases at Mesas B and C were all placed in the Curculionidae (Figure 5).

Differentiation within and between lineages
The two specimens of Curculionidae from Mesa B differed from one another by 0.9% sequence divergence (Table 8).

The Mesa B specimens differed from the reference specimens by between 0 and 23.0% sequence divergence (Table 8). In particular, the Mesa B specimens differed from five reference specimens from previous surveys at Mesas B and C by between 0 and 0.9% sequence divergence and from the reference specimens in clade Curculionidae sp. 8 by between 2.7 and 3.4% sequence divergence (Table 8).

Diplura
Reference specimens and outgroups
One specimen of Diplura from Mesa C was sequenced for COI (Table 6). Comparisons to Genbank and Helix databases showed that the specimen was most closely related to the family Japygidae, however, the specimen was analysed with 36 specimens of Diplura from the Pilbara belonging to three families, in order to include specimens from previous surveys at Mesas B and C: Campodeidae, Japygidae, and Parajapygidae, as well as five Genbank voucher specimens, Diplura sp., which is most similar to Genbank specimens of Campodeidae (Genbank accession #HQ943342), *Campodea tillyardi* (Genbank accession # AF370844) and *Lepiodocampa weberi* (Genbank accession #HQ882832) from the family Campodeidae,

Parajapyx pauliani (Genbank accession #JQ692327) from the family Parajapygidae and *Japyx solifugus* (Genbank accession #AY771989) from the family Japygidae. The planthopper *Lycorma delicatula* (Genbank accession # FJ456942) and a specimen of Fulgoridae (Hemiptera sp.; Genbank accession #GU671563) were used as outgroups.

Phylogenetic analysis
The phylogenetic analysis, which included the new specimen of Diplura from Mesa C, in addition to 36 reference specimens, placed the Mesa C specimen in a distinct genetic lineage that did not contain any reference specimens (Figure 6). The specimen was placed in a clade containing lineages of Japygidae, and was assigned to the new lineage DJA011 (Figure 6). The specimens of Diplura from previous sampling phases at Mesas B and C were placed in the Parajapygidae and Campodeidae (Figure 6).

Differentiation within and between lineages
The specimen of Japygidae from Mesa C differed from the nearest reference specimen (JU01) by 15.0% sequence divergence (Table 9).

Thysanura
Reference specimens and outgroups
One specimen of Thysanura from Mesa C was sequenced for 12s (Table 6). A search of similar sequences on Genbank and in the Helix database indicated that the specimen most closely matched database specimens of the subfamily Nicoletiinae. Based on those results, GenBank voucher sequences were included as reference sequences of Nicoletiinae (two specimens) as follows: *Trinemura callawa* and *T. cundalin* (GenBank accession #JQ282164 and JQ282165). In addition, as local references, 33 specimens of Nicoletiinae, including five from previous surveys at Mesa B/C, were included in the analysis. A specimen of Atelurinae was used as an outgroup: *Atelura formicaria* (Genbank accession # EU084035).

Phylogenetic analyses
The phylogenetic analysis, which included the new specimen from Mesa C, in addition to 35 reference specimens, placed the Mesa C specimen in a single distinct genetic lineage, which also contained two reference specimens from a previous survey at Mesa B/C, thus was assigned to the existing lineage TN010 (Figure 7). The specimens of Thysanura from previous sampling phases at Mesas B and C were all placed in the subfamily Nicoletiinae (Figure 7).

Differentiation within and between lineages
The lineage of Nicoletiinae differed from nearest reference specimens IV333 and IV227 by 0.5 and 2.8% sequence divergence, respectively and from the remaining reference specimens by >9% (Table 10).

Pseudoscorpions

Reference sequences and outgroups
Three pseudoscorpions were sequenced from Mesa C and K (Table 6). A search of similar sequences on Genbank and in the Helix database indicated that all of the specimens most closely matched the family Chthoniidae. Based on those results, a reference dataset of 81 Genbank and Pilbara specimens was reduced to a more manageable and relevant dataset by selecting only the 41 reference specimens that occurred in the same clades as the Mesa C and K specimens, based on a preliminary neighbour joining analysis. Two Genbank voucher sequences of Chthoniidae were included in the analysis as follows: *Paraliochthonius* sp JM 2008 (Genbank accession #EU5595505) and *Tyrannochthonius aridus* (GenBank accession # KJ659959 from Western Australia). In addition, as local references, 39 specimens of Chthoniidae from previous surveys in the Pilbara, were included in the analysis, including 16 from previous surveys at Mesas B and C. Sequences of the scorpion *Pandinus imperator* (Genbank accession # AY1565821) and harvestman spider *Siro rubens* (Genbank accession # DQ5131111) were used as outgroups.

Phylogenetic analysis
The phylogenetic analysis of the Chthoniidae, which included the three Chthoniidae specimens from Mesa C and K, in addition to 41 reference specimens, placed the Mesa C and K specimens in two distinct genetic lineages (Figure 8). Neither lineage contained reference

specimens and the two were therefore assigned to the new lineages PC058 and PC059 (Figure 8). However the lineages showed significant although distant relationships with some reference specimens (Figure 8). Specifically, specimen LI31/lineage PC058 formed a well-supported clade with specimens of lineage PC047 (IV261, KD66, KD67 and KD69) from Mesas B and C (Figure 10). Similarly, specimens LI34 and LI35/lineage PC059 formed well-supported clades with specimens IV212/IV226 and IV269, respectively, from previous surveys in the Robe Valley (Figure 8). The specimens of Pseudoscorpiones from previous sampling phases at Mesas B and C were placed in the Chthoniidae (Figure 8) and the Hyiidae (not shown).

Differentiation within and between lineages

The three specimens of Chthoniidae from Mesa C and K differed from one another by between 0.0 and 20.2% sequence divergence and from the reference lineages by > 6.0% sequence divergence (Table 11). Specifically, specimen LI31 (lineage PC058) differed from the nearest reference specimens, IV261, KD66, KD67 and KD69 (lineage PC057) by between 6.1 and 6.3% sequence divergence (Table 11). Specimens LI34 and LI35 (lineage PC059) differed from the nearest reference specimens, IV212, IV226 and KD24 (lineages PC009, PC010 and PC053, respectively) by between 7.6 and 10.2% sequence divergence (Table 11).

Schizomids

Preliminary analysis - Reference sequences and outgroups

Eleven schizomids were sequenced from Mesas A and C (Table 6). In order to assemble a relevant reference data set, a preliminary neighbour-joining (NJ) analysis was conducted on the 11 Mesa A and C specimens, to identify the number of genetic lineages present. A representative from each was compared to Helix and Genbank sequence databases, representing >500 reference sequences of schizomids from previous surveys in the Pilbara. The reference sequences were selected based on the criteria that they showed ≤ 15% sequence divergence from at least one of Mesa A and C lineages.

Three distinct genetic lineages were detected and the number of individuals within each lineage ranged from one to four (Figure 9). All three showed the highest genetic similarity to reference specimens of *Paradraculoides*. A representative from each was analysed in a model-based phylogenetic analysis with 27 reference specimens of *Paradraculoides*, including five Genbank voucher specimens of *Paradraculoides*: *P. anachoretus* (GenBank accession # EU272701), *P. bythius* (GenBank accession # EU272715), *P. gnophicola* (GenBank accession # EU272716) *P. kryptus* (GenBank accession # EU272723), and *Paradraculoides* sp (GenBank accession # EU272697). As local references, 22 specimens from previous surveys in the Pilbara were included in the analysis, including 11 from previous surveys at Mesas B and C. Two specimens of *Draculoides*, *D. julianeae* (GenBank accession # EU272696) and *D. vinei* (GenBank accession # EU272690) were used as outgroups.

Phylogenetic analysis

The phylogenetic analysis, which included the three Mesa A and C specimens, in addition to 27 reference specimens of *Paradraculoides*, placed the Mesa A and C specimens in three distinct lineages, all three of which (SCH001 (*P. bythius)*, SCH034 and SCH036 (*P. anachoretus*) also contained reference specimens from previous surveys at Mesa B and C (Figure 10). Lineages SCH034 and SCH036 formed a well-supported clade, with the lineages separated by relatively short branch lengths (Figure 10). The specimens of Schizomida from previous sampling phases at Mesas B and C were placed in the genus *Paradraculoides* (Figure 10) and a new genus, perhaps closely related to *Bamazomus* (not shown).

Differentiation within and between lineages

The three lineages of *Paradraculoides* detected at Mesa A and C differed from one another by between 5.6 and 9.4% mean sequence divergence (Table 12). Individuals within each of the three lineages differed from one another by 0.1% mean sequence divergence (Table 13).

The three lineages (SCH001, SCH034 and SCH036) differed from the closest reference lineages by ≤1% sequence divergence (Table 14).

Conclusions

COI is widely considered to show suitable variation to distinguish species (Hebert et al., 2003a). In a comparison of COI sequences for over 13,000 pairs of taxa, Hebert et al (2003b) found a mean of 11.1% sequence divergence between distinct species. Nearly 80% of the comparisons showed that species pairs differed from one another by greater than 8% sequence divergence. However, a taxon by taxon approach, examining the amount of phylogenetic variation within and between species is the most widely accepted method of defining species.

Araneae

A single genetically distinct lineage of Araneae was detected at Mesa C (AG003), representing a single distinct species, owing to the high level of sequence divergence between it and the reference lineages. The lineage differed from the reference lineages by >15%, indicating that it is likely to be a new species, based on the material available for comparison. The species is likely to belong to the family Gnaphosidae (ground spiders), based on its phylogenetic placement and similarity to a reference specimen of *Zelanda* from New Zealand. The family is widespread in Australia, and two troglobitic species are known from Barrow Island (Humphreys et al., 2013). Previous specimens of Araneae collected at Mesa B/C were putatively assigned to the families Theridae/Symphytognathidae, Aranidae and Oonopidae.

Gnaphosidae (putative)
AG001 = new lineage and species

Coleoptera

A single genetic lineage of Coleoptera was detected at Mesa B. The lineage differed from specimens of the nearest reference lineage CCU012 by < 1%, indicating that the specimen represents a lineage and species of Curculionidae that has been detected previously.
The Mesa B specimen was placed in a clade containing reference specimens from the WAM, assigned to the species Curculionidae sp. 8. Differentiation within the clade ranged from 2.7-3.3% sequence divergence, suggesting that the species from Mesa C belongs to Curculionidae sp. 8. For comparison, differentiation within the four WAM species for which there are multiple sequences (species 1, 3, 4, 8) ranges from a mean of 0.1% (species 1) to 5.2% (species 4). Previous specimens of Coleoptera collected at Mesa B/C were also assigned to the family Curculionidae.

Curculionidae
CCU012 = lineage and species detected previously at Mesas B and C in the Robe Valley

Diplura

A single distinct genetic lineage of Diplura was detected at Mesa C. The lineage was placed with the Japygidae (lineage DJA011). The lineage differed from the reference lineages by >15% sequence divergence, indicating that it is likely to represent a new species, which has so far not been detected in the Pilbara, based on the material available for comparison. Previous specimens of Diplura collected at Mesa B/C were putatively assigned to the families Parajapygidae and Campodeidae.

Japygidae
DJA011 = new lineage and species

Thysanura

The mitochondrial gene 12S is widely used in insect systematics (Simon et al., 1996; Caterino et al., 2000), although in contrast to the mitochondrial gene COI, fewer broadscale comparative studies are available to provide a basis for species discrimination. Nonetheless, 12S has proven useful for establishing phylogenetic relationships in many insect groups (Caterino et al., 2000). The 12S gene evolves approximately 1.5 times (Mueller, 2006) more slowly than COI. Hence we would expect that the threshold for species discrimination using 12S would be, by inference, lower than COI.

A single distinct lineage of Thysanura was detected at Mesa C, Nicoletiinae TN010. It differed from the nearest reference specimens by between 0.5 and 2.8% sequence divergence.

Using a conversion factor of 1.5 x to account for the slower 12s rate of evolution, this value might correspond to approximately 0.8 to 4.2% of COI divergence. For comparison, the six specimens of *Trimenura callawa* differ by a mean of 0.4% sequence divergence (range = 0 to -0.9% at 12s may correspond to up to approximately 1.4% at COI). Given the relatively low value between specimens of TN010, but keeping in mind that these are estimates based on current understanding of 12s and COI evolution rates, it is likely that lineage TN010 represents a single species, showing some genetic divergence among drillholes. Previous specimens of Thysanura collected at Mesa B/C were also assigned to the sub-family Nicoletiinae.

Nicoletiinae
TN010 = lineage and species that has been detected previously at Mesa B/C.

Pseudoscorpiones

Two distinct genetic lineages of pseudoscorpions were detected at Mesa C and K, both likely belonging to the family Chthoniidae. The two lineages of Chthoniidae differed from one another by approximately 20% sequence divergence, thus each is likely to represent a distinct species. Further, both Chthoniidae lineages from Mesa C and K differed from the nearest reference specimens by ≥6%, indicating that the two are likely to be new species that have so far not been detected in the Pilbara, based on the material available for comparison. Previous specimens of Pseudoscorpiones collected at Mesa B/C were assigned to the families Chthoniidae and Hyiidae.

Chthoniidae
PC058 = new lineage, new species
PC059 = new lineage, new species

Schizomida
Previous analyses of genetic variation between morphologically distinct species of Schizomida can be used as a genetic 'yardstick' to interpret the current data set. The five described species of *Paradraculoides* (Harvey et al, 2008) differ from one another by between 8.4 to 12.1% sequence divergence (uncorrected p-distances; calculated by us from the Harvey et al., 2008 data). Similarly, the four described species of *Draculoides* differ from one another by between 4.5 to 13.7% sequence divergence (uncorrected p-distances calculated by us from Harvey et al., 2008).

Three genetically distinct lineages of schizomids were detected at Mesa A and C. The three lineages correspond to three species, all of which were assigned to existing lineages and species. Specifically, one specimen was assigned to *Paradraculoides bythius* (lineage SCH001) and four specimens were assigned to *Paradraculoides anachoretus* (lineage SCH036), differing from these reference lineages by <3%. Finally, x specimens were assigned to the existing lineage SCH034, as it differed from the reference specimens of that lineage by >1%. Lineages SCH034 and SCH036 formed a well-supported clade and differed by a moderately low level of sequence divergence (5.6 to 6.3% sequence divergence). This variation is greater than would be expected within a single species, and given that both lineages were detected in the same drillhole (RC16MEA004), indicates that that the two lineages are reproductively isolated. Previous specimens of Schizomida collected at Mesa B/C were assigned to the genus *Paradraculoides* and a new genus, putatively related to *Bamzomus*.

Paradracucloides
SCH001 = previously detected lineage and species (*Paradraculoides bythius*)
SCH034 = previously detected lineage and species
SCH036 = previously detected lineage and species (*Paradraculoides anachoretus*)

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Table 6. Specimens of Troglofauna used in the present study and the lineage to which they were assigned, based on variation at the COI or 12s genes. *=new lineage this study.

Tracking Number	Mesa	Taxonomy	Cap #	Helix ID	Lineage
RC16MEC0177-20170309-01	C	Araneae	21	LI29	AG001*
MEAWO4088-20170307-01	C	Diplura	1	LI30	DJA011*
RC16MEC0177-20170309-02	C	Pseudoscorpiones	22	LI31	PC058*
RC16MEC0102-170308-2	C	Schizomida	11	LI32	SCH001 (P. bythius)
MEAWO4086-20170308-04	C	Thysanura	14	LI33	TN010
RC16MEK0002-20170321-T2-1	K	Pseudoscorpiones	1	LI34	PC059*
RC16MEK0002-20170321-T3-1	K	Pseudoscorpiones	2	LI35	PC059*
RC16MEA004-20170322-T1-1	A	Schizomida	4	LI36	SCH034
RC16MEA004-20170322-T1-2	A	Schizomida	5	LI37	SCH034
RC16MEA004-20170322-T1-3	A	Schizomida	6	LI38	SCH034
RC16MEA004-20170322-T1-4	A	Schizomida	7	LI39	SCH036 (P. anachoretus)
MOB3a	A	Schizomida		LI40	SCH036 (P. anachoretus)
MOB3b	A	Schizomida		LI41	SCH036 (P. anachoretus)
MOB3b	A	Schizomida		LI42	SCH036 (P. anachoretus)
RC16MEA004	A	Schizomida		LI43	SCH034
MEBRC0008	B	Coleoptera		LI44	CCU012
MEBRC0016	B	Coleoptera		LI45	CCU012

Table 7 (attached). COI genetic distances (below diagonal) and standard error (above diagonal, in blue) between specimens of Araneae detected at Mesa C and the reference lineages as shown in Figure 4. Distances between the Mesa C specimen and the reference specimens are highlighted in yellow.

Table 8 (attached). COI genetic distances (below diagonal) and standard error (above diagonal, in blue) between specimens of Coleoptera detected at Mesa B and the reference lineages as shown in Figure 5. Distances between the Mesa C specimens and the reference specimens are highlighted in yellow.

Table 9 (attached). COI genetic distances (below diagonal) and standard error (above diagonal, in blue) between specimens of Diplura detected at Mesa C and the reference lineages as shown in Figure 6. Distances between the Mesa C specimen and the reference specimens are highlighted in yellow.

Table 10 (attached). 12s genetic distances (below diagonal) and standard error (above diagonal, in blue) between specimens of Thysanura detected at Mesa C and the reference lineages as shown in Figure 7. Distances between the Mesa C specimen and the reference specimens are highlighted in yellow.

Table 11 (attached). COI genetic distances (below diagonal) and standard error (above diagonal, in blue) between specimens of Pseudoscorpiones detected at Mesa C and K and the reference lineages as shown in Figure 8. Distances between the Mesa C specimen and the reference specimens are highlighted in yellow.

Table 12. Mean genetic distance (p-distances, below diagonal) and standard error (blue, above diagonal) between lineages of Schizomida at COI as shown in Figure 9.

Lineage	**1**	**2**	**3**
1		0.009	0.012
2	0.058		0.011
3	0.085	0.094	

Table 13. Mean genetic distance (p-distances) and standard errors within lineages of Schizomida at COI as shown in Figure 9. N= number of specimens in the lineage and rep= specimen selected to represent the lineage in the model-based phylogenetic analysis.

Lineage	**D**	**s.e.**	**N**	**rep**
1	0.001	0.001	4	LI38
2	0.001	0.001	4	LI39
3	n/c	n/c	1	LI32

Table 14 (attached). COI genetic distances (below diagonal) and standard error (above diagonal, in blue) between specimens of Schizomida detected at Mesa A and C and the reference lineages as shown in Figure 10. Distances between the Mesa A and C specimens and the reference specimens are highlighted in yellow.

Figure 4. Bayesian analysis of COI haplotypes of Araneae from the present study and reference specimens from Genbank and previous surveys in the Pilbara. Numbers on major nodes correspond to posterior probabilities; values <50% are not shown. Specimens from the present study are highlighted in yellow; specimens from previous phases at Mesa B/C are highlighted in green; GenBank voucher specimens highlighted in turquoise. Scale bar= number of substitutions per site.

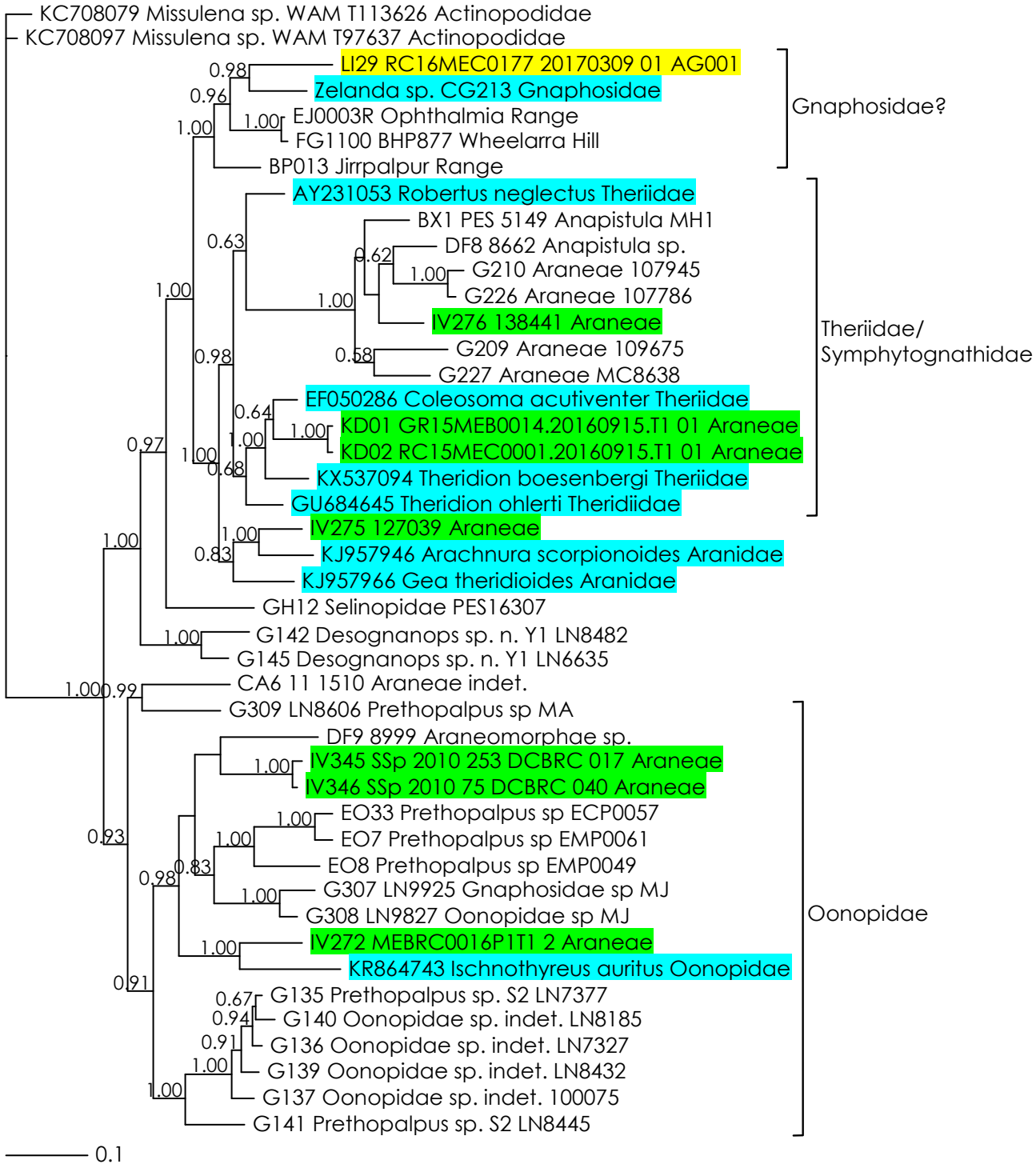

Figure 5. Bayesian analysis of COI haplotypes of Coleoptera from the present study and reference specimens from Genbank and previous surveys in the Pilbara. Numbers on major nodes correspond to posterior probabilities; values <50% are not shown. Specimens from the present study are highlighted in yellow; specimens from previous phases at Mesa B/C are highlighted in green; GenBank voucher specimens highlighted in turquoise. Scale bar= number of substitutions per site. Red boxes enclose species defined with high confidence.

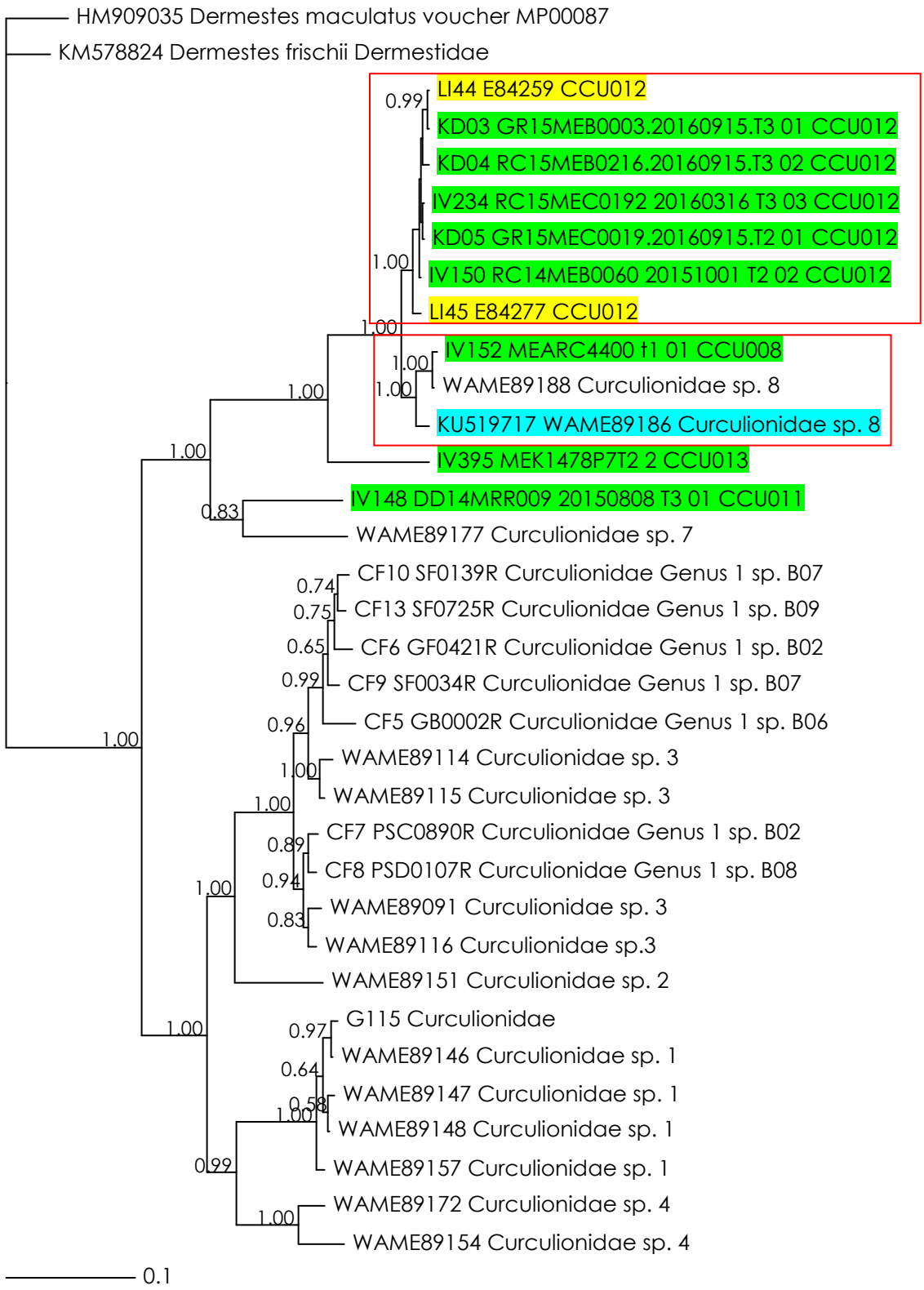

Figure 6. Bayesian analysis of COI haplotypes of Diplura from the present study. Numbers on major nodes correspond to posterior probabilities; values <50% are not shown. Specimens from the present study are highlighted in yellow; specimens from previous phases at Mesa B/C are highlighted in green; GenBank voucher specimens highlighted in turquoise. Scale bar= number of substitutions per site.

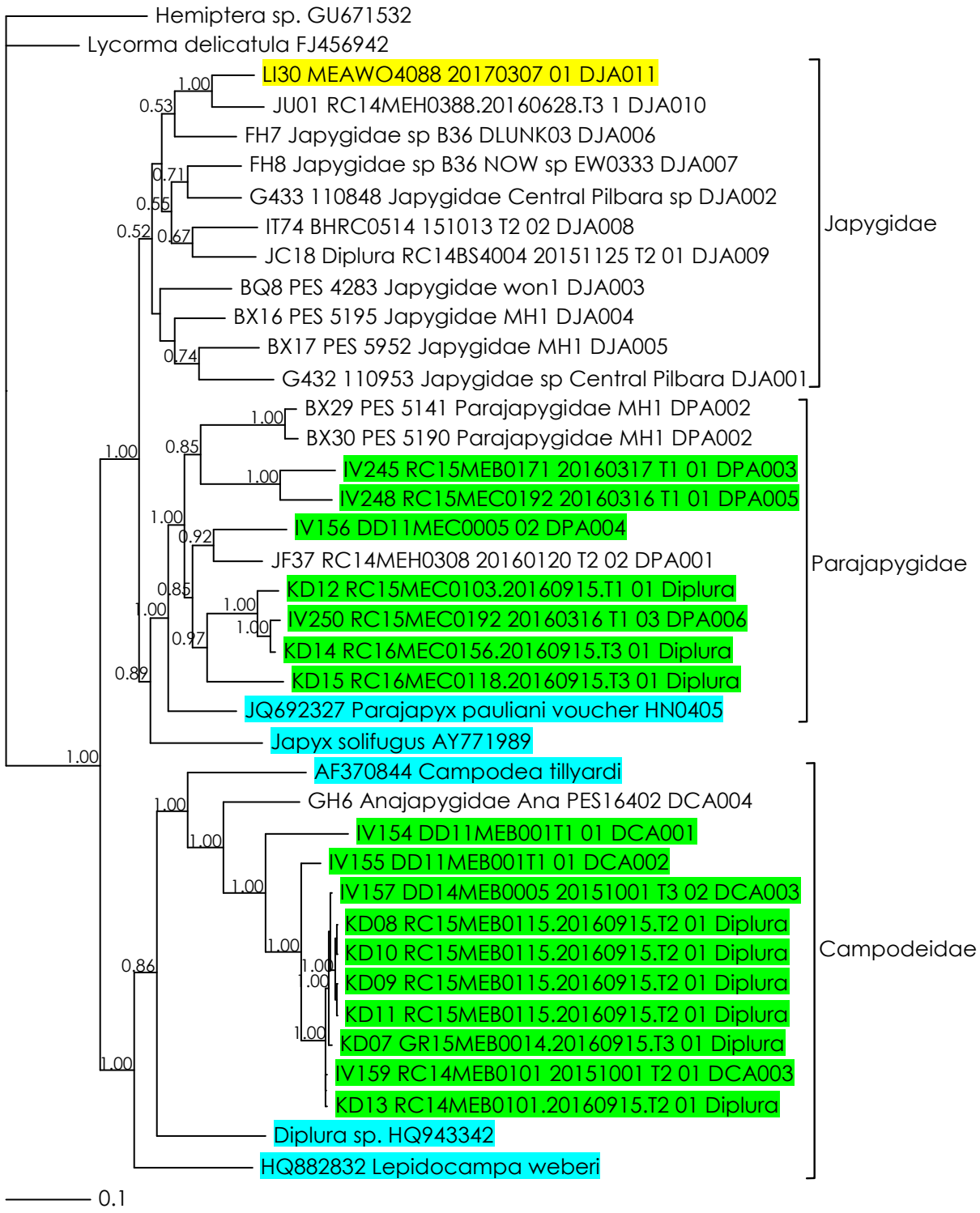

Figure 7. Bayesian analysis of 12s haplotypes of Thysanura from the present study and reference specimens from Genbank and previous surveys in the Pilbara. Numbers on major nodes correspond to posterior probabilities; values <50% are not shown. Specimens from the present study are highlighted in yellow; specimens from previous phases at Mesa B/C are highlighted in green; GenBank voucher specimens highlighted in turquoise. Scale bar= number of substitutions per site. Red boxes enclose species defined with high confidence.

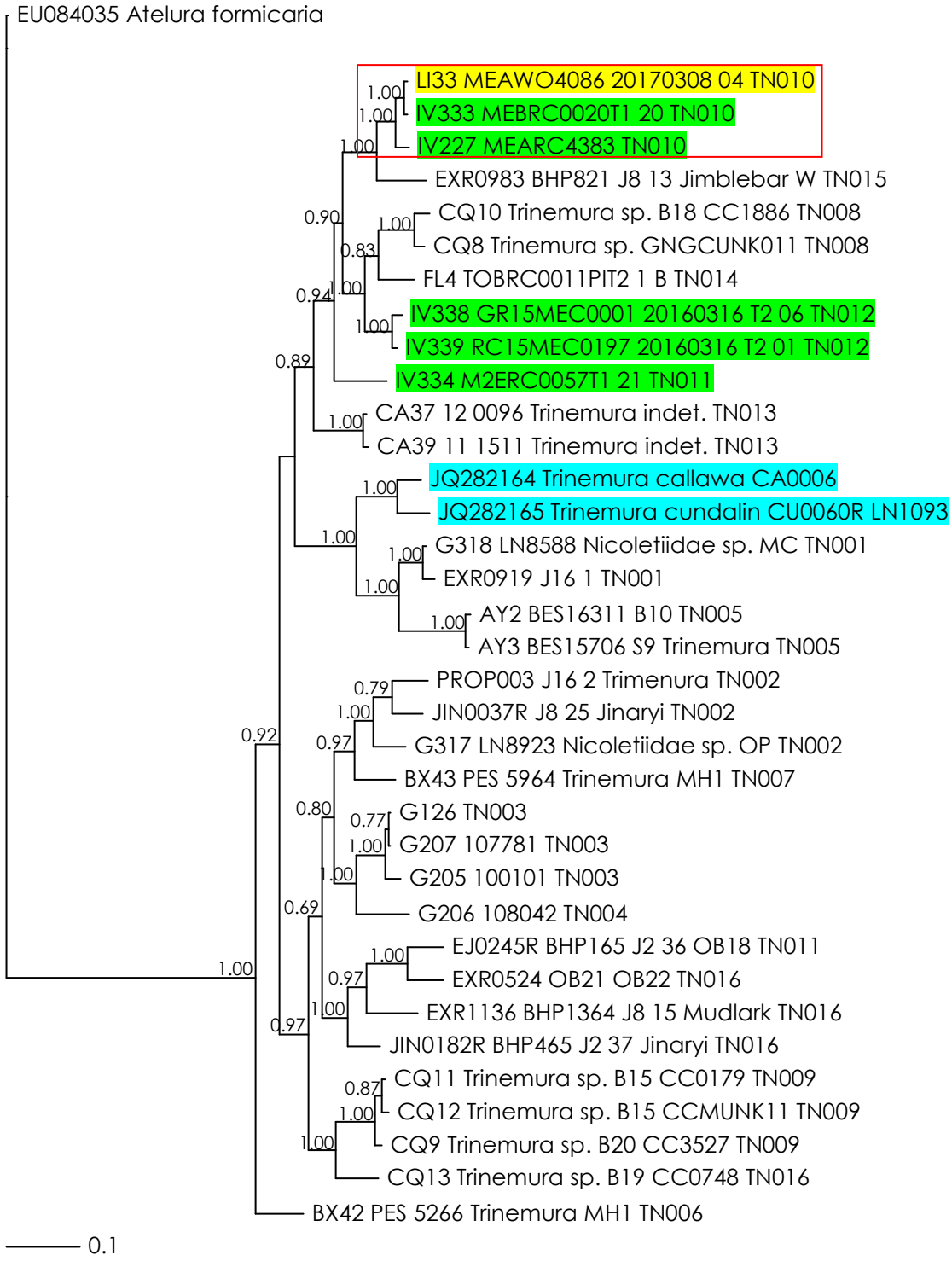

Figure 8. Bayesian analysis of COI haplotypes of Pseudoscorpiones from the present study and reference specimens from Genbank and previous surveys in the Pilbara. Numbers on major nodes correspond to posterior probabilities; values <50% are not shown. Specimens from the present study are highlighted in yellow; specimens from previous phases at Mesa B/C are highlighted in green; GenBank voucher specimens highlighted in turquoise. Scale bar= number of substitutions per site.

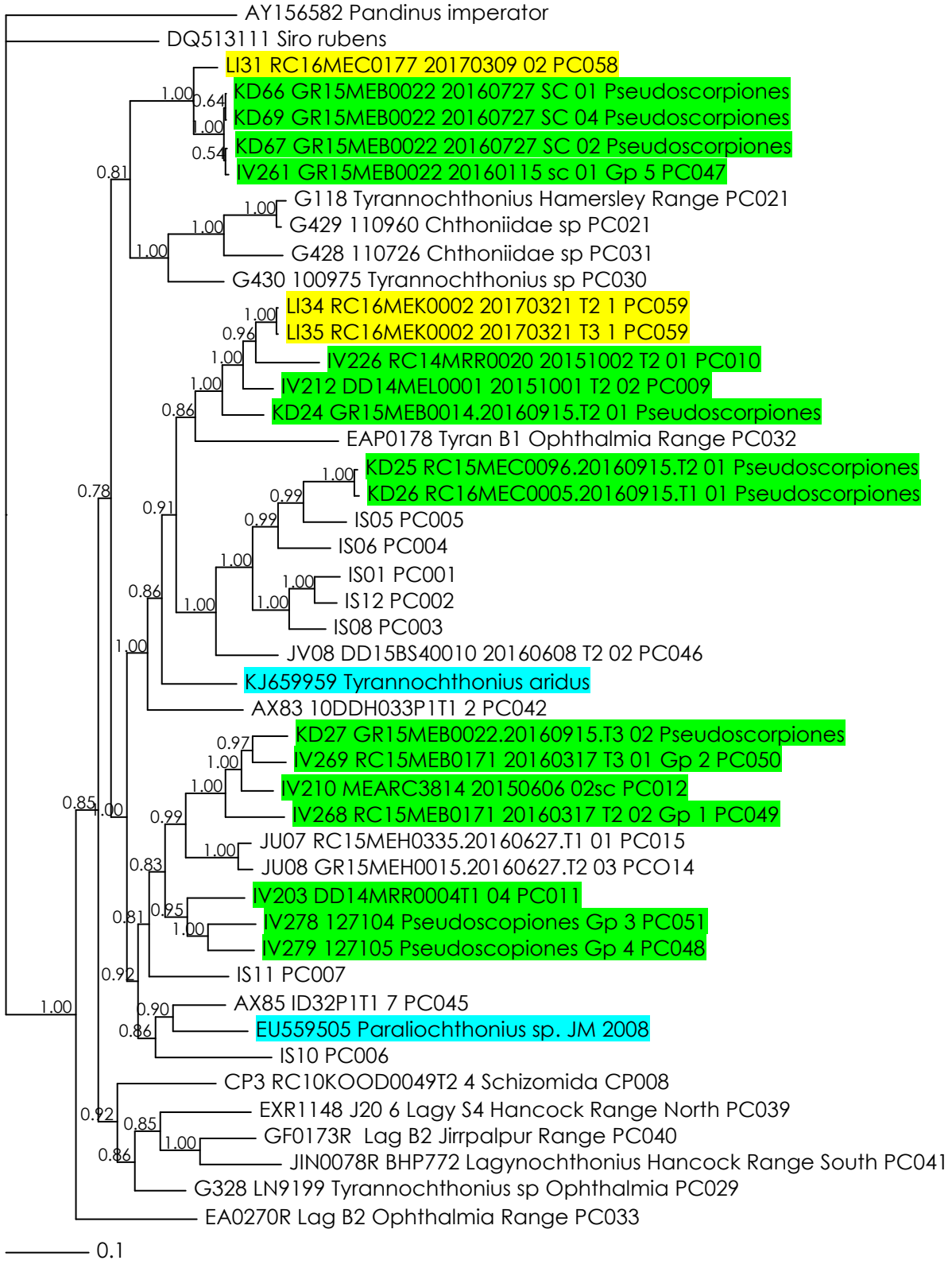

Figure 9. Neighbour-joining analysis of COI haplotypes of Schizomida from the present study. Numbers on major nodes correspond to bootstrap support over 100 iterations; values <50% are not shown. Scale bar= genetic distance. The specimens used to represent each lineage in the model-based phylogenetic analysis are highlighted in yellow.

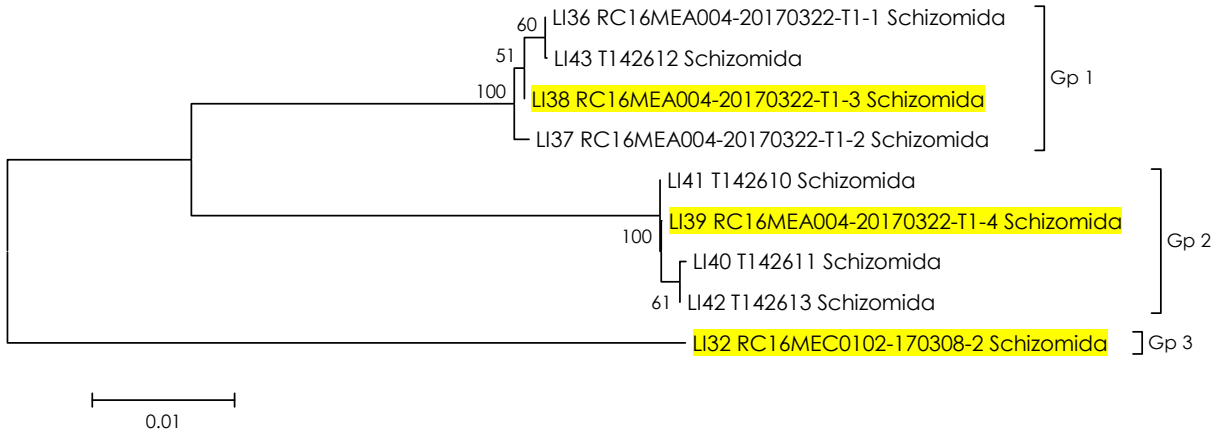

Figure 10. Bayesian analysis of COI haplotypes of Schizomida from the present study and reference specimens from Genbank and previous surveys in the Pilbara. Numbers on major nodes correspond to posterior probabilities; values <50% are not shown. Specimens from the present study are highlighted in yellow; specimens from previous phases at Mesa B/C are highlighted in green; GenBank voucher specimens highlighted in turquoise. Scale bar= number of substitutions per site. Red boxes enclose species defined with high confidence.

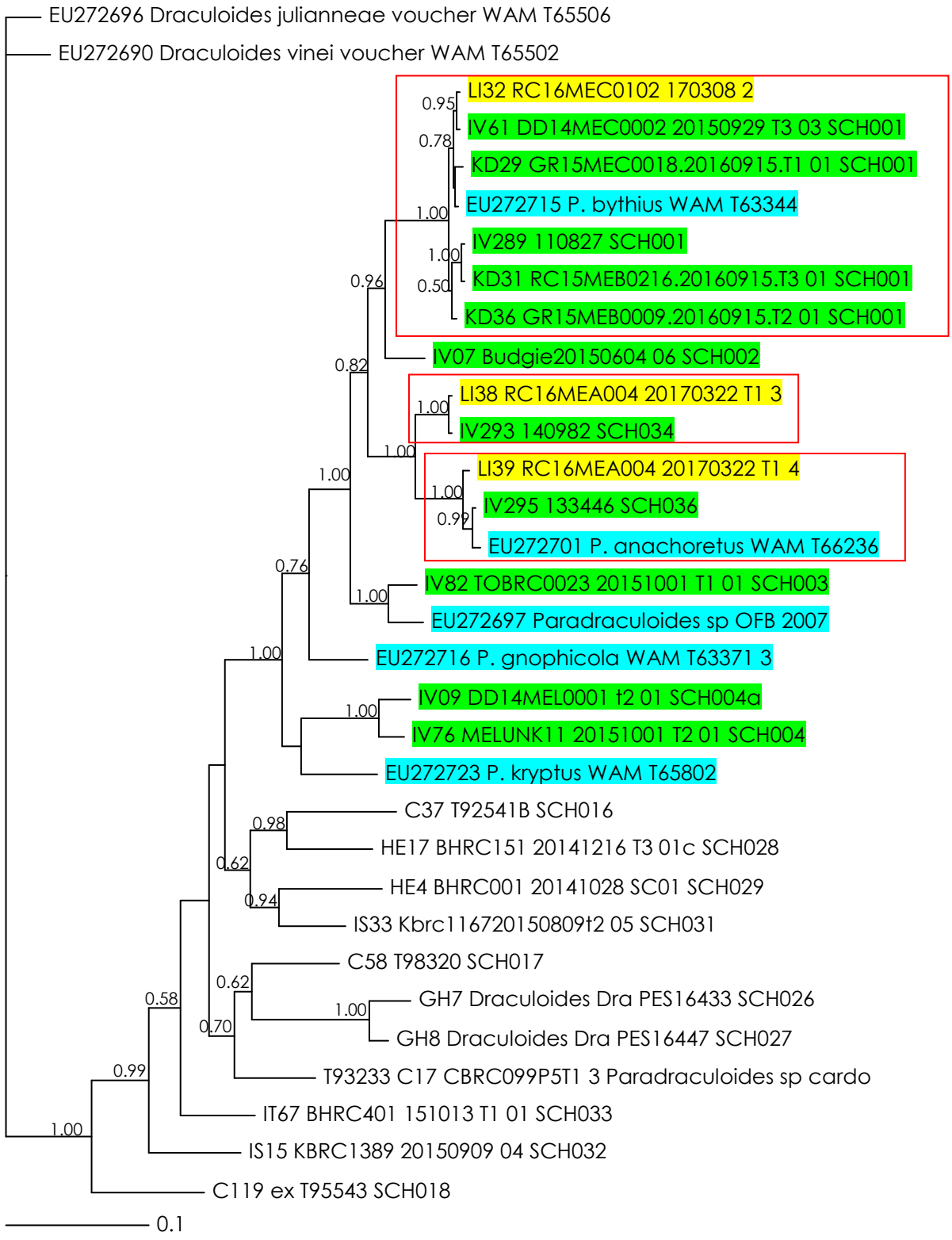

Table 7. Estimates of Evolutionary Divergence between Sequences

Specimen ID	LI29 RC16MEC0177-20170309-01	AY231053 Robertus neglectus Theriidae	BP013 Deposit B	BX1 PES-5149 Anapistula MH1	CA6 11:1510 indet.	DF8 8662 Anapistula sp.	DF9 8999 Araneomorphae sp.	EF050286 Coleosoma acutiventer Theriidae	EJ0003R OB18	EO33 Prethopalpus sp ECP0057	EO7 Prethopalpus sp EMP0061	EO8 Prethopalpus sp EMP0049	FG1100 BHP877 Jimblebar	G135 Prethopalpus sp. S2 LN7377	G136 Oonopidae sp. indet. LN7327	G137 Oonopidae sp. indet. 100075	G139 Oonopidae sp. indet. LN8432	G140 Oonopidae sp. indet. LN8185	G141 Prethopalpus sp. S2 LN8445	G142 Desognanops sp. n. Y1 LN8482	G145 Desognanops sp. n. Y1 LN6635	G209 109675	G210 107945	G226 107786	G227 MC8638	G307 LN9925 Gnaphosidae sp MJ	G308 LN9827 Oonopidae sp MJ	G309 LN8606 Prethopalpus sp MA	GH12 Selinopidae PES16307	GU684645 Theridion ohlerti Theridiidae	IV272 MEBRC0016P1T1-2	IV275 127039	IV276 138441	IV345 SSp-2010-253 DCBRC 017	IV346 SSp-2010-75 DCBRC 040	KD01 GR15MEB0014.20160915.T1-01	KD02 RC15MEC0001.20160915.T1-01	KJ957946 Arachnura scorpionoides Aranidae	KJ957966 Gea theridioides Aranidae	KR864743 Ischnothyreus auritus Oonopidae	KX537094 Theridion boesenbergi Theriidae	Zelanda sp. CG213 isolate ARACG000213
LI29 RC16MEC0177-20170309-01		0.018	0.017	0.019	0.019	0.021	0.020	0.019	0.018	0.024	0.025	0.022	0.018	0.021	0.021	0.019	0.021	0.021	0.019	0.019	0.020	0.020	0.021	0.021	0.019	0.019	0.021	0.018	0.021	0.020	0.021	0.019	0.021	0.020	0.020	0.019	0.019	0.020	0.019	0.021	0.020	0.017
AY231053 Robertus neglectus Theriidae	0.185		0.016	0.019	0.018	0.022	0.019	0.015	0.017	0.026	0.026	0.022	0.017	0.021	0.021	0.020	0.021	0.021	0.020	0.017	0.018	0.023	0.022	0.021	0.020	0.022	0.021	0.021	0.018	0.015	0.019	0.015	0.021	0.020	0.021	0.018	0.017	0.014	0.014	0.020	0.016	0.019
BP013 Deposit B	0.150	0.152		0.020	0.017	0.021	0.020	0.015	0.015	0.024	0.024	0.023	0.016	0.020	0.020	0.020	0.021	0.020	0.019	0.018	0.017	0.021	0.020	0.021	0.020	0.021	0.021	0.017	0.018	0.017	0.021	0.018	0.023	0.021	0.020	0.018	0.018	0.018	0.017	0.020	0.017	0.016
BX1 PES-5149 Anapistula MH1	0.246	0.190	0.224		0.022	0.014	0.023	0.019	0.020	0.025	0.027	0.021	0.020	0.022	0.022	0.022	0.022	0.022	0.022	0.019	0.019	0.015	0.015	0.015	0.015	0.022	0.022	0.024	0.020	0.018	0.022	0.019	0.014	0.021	0.021	0.019	0.018	0.020	0.021	0.020	0.019	0.022
CA6 11:1510 indet.	0.222	0.199	0.207	0.246		0.021	0.019	0.018	0.019	0.021	0.022	0.020	0.019	0.020	0.019	0.018	0.019	0.020	0.017	0.017	0.016	0.022	0.019	0.020	0.021	0.019	0.019	0.018	0.019	0.018	0.020	0.019	0.022	0.018	0.020	0.019	0.018	0.019	0.018	0.018	0.018	0.018
DF8 8662 Anapistula sp.	0.231	0.210	0.230	0.112	0.235		0.022	0.020	0.021	0.023	0.025	0.021	0.021	0.022	0.021	0.022	0.021	0.022	0.022	0.021	0.021	0.014	0.015	0.014	0.014	0.021	0.022	0.023	0.021	0.020	0.022	0.021	0.016	0.021	0.021	0.019	0.019	0.021	0.022	0.019	0.021	0.022
DF9 8999 Araneomorphae sp.	0.239	0.213	0.236	0.279	0.220	0.273		0.021	0.019	0.023	0.024	0.022	0.019	0.019	0.019	0.019	0.019	0.019	0.018	0.019	0.020	0.021	0.023	0.023	0.022	0.020	0.019	0.018	0.018	0.021	0.018	0.021	0.024	0.016	0.016	0.019	0.020	0.021	0.019	0.018	0.019	0.019
EF050286 Coleosoma acutiventer Theriidae	0.193	0.104	0.160	0.203	0.179	0.198	0.241		0.018	0.026	0.026	0.023	0.018	0.020	0.020	0.019	0.020	0.021	0.019	0.017	0.016	0.019	0.019	0.019	0.019	0.019	0.018	0.020	0.017	0.014	0.021	0.015	0.021	0.020	0.020	0.013	0.018	0.015	0.019	0.014	0.017
EJ0003R OB18	0.159	0.173	0.119	0.227	0.224	0.215	0.228	0.166		0.023	0.024	0.019	0.005	0.019	0.019	0.019	0.020	0.019	0.019	0.018	0.016	0.021	0.020	0.021	0.020	0.020	0.019	0.020	0.019	0.017	0.019	0.018	0.023	0.019	0.018	0.018	0.019	0.019	0.018	0.018	0.020	0.015
EO33 Prethopalpus sp ECP0057	0.276	0.284	0.284	0.270	0.222	0.250	0.207	0.276	0.259		0.010	0.019	0.023	0.020	0.020	0.020	0.020	0.020	0.020	0.022	0.021	0.023	0.021	0.021	0.024	0.021	0.020	0.021	0.025	0.026	0.023	0.025	0.023	0.019	0.019	0.025	0.024	0.026	0.025	0.020	0.025	0.023
EO7 Prethopalpus sp EMP0061	0.282	0.285	0.300	0.272	0.214	0.263	0.198	0.279	0.257	0.038		0.022	0.024	0.023	0.024	0.021	0.022	0.022	0.023	0.024	0.023	0.025	0.023	0.024	0.025	0.020	0.019	0.024	0.027	0.026	0.024	0.025	0.025	0.021	0.022	0.026	0.025	0.026	0.026	0.021	0.026	0.024
EO8 Prethopalpus sp EMP0049	0.260	0.258	0.260	0.247	0.217	0.245	0.187	0.263	0.245	0.145	0.149		0.019	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.021	0.020	0.020	0.021	0.021	0.020	0.021	0.022	0.022	0.019	0.022	0.021	0.018	0.018	0.022	0.023	0.024	0.022	0.021	0.022	0.021
FG1100 BHP877 Jimblebar	0.165	0.177	0.130	0.233	0.230	0.223	0.227	0.169	0.008	0.259	0.257	0.245		0.019	0.018	0.020	0.020	0.019	0.019	0.017	0.016	0.021	0.020	0.021	0.020	0.019	0.019	0.020	0.019	0.018	0.019	0.019	0.022	0.018	0.018	0.018	0.019	0.019	0.019	0.018	0.021	0.015
G135 Prethopalpus sp. S2 LN7377	0.244	0.221	0.226	0.245	0.183	0.252	0.186	0.213	0.221	0.185	0.201	0.189	0.219		0.005	0.010	0.009	0.008	0.017	0.018	0.017	0.020	0.021	0.022	0.020	0.018	0.019	0.020	0.019	0.021	0.017	0.022	0.023	0.019	0.019	0.021	0.021	0.019	0.019	0.017	0.022	0.019
G136 Oonopidae sp. indet. LN7327	0.253	0.226	0.235	0.252	0.185	0.254	0.186	0.215	0.221	0.179	0.201	0.194	0.219	0.019		0.010	0.010	0.008	0.016	0.017	0.017	0.020	0.021	0.021	0.020	0.019	0.018	0.020	0.019	0.021	0.017	0.021	0.022	0.019	0.018	0.021	0.021	0.019	0.019	0.018	0.022	0.019
G137 Oonopidae sp. indet. 100075	0.244	0.226	0.235	0.254	0.180	0.257	0.191	0.206	0.215	0.182	0.201	0.207	0.212	0.055	0.057		0.010	0.010	0.015	0.017	0.017	0.021	0.021	0.021	0.020	0.018	0.018	0.019	0.019	0.021	0.016	0.020	0.022	0.018	0.017	0.019	0.019	0.020	0.018	0.017	0.021	0.018
G139 Oonopidae sp. indet. LN8432	0.253	0.223	0.241	0.263	0.178	0.254	0.195	0.213	0.226	0.190	0.211	0.199	0.223	0.040	0.043	0.053		0.009	0.016	0.017	0.019	0.020	0.022	0.022	0.021	0.017	0.018	0.020	0.021	0.022	0.019	0.021	0.024	0.021	0.020	0.021	0.021	0.021	0.019	0.020	0.023	0.019
G140 Oonopidae sp. indet. LN8185	0.236	0.223	0.230	0.249	0.169	0.252	0.175	0.215	0.210	0.188	0.192	0.189	0.208	0.030	0.036	0.060	0.049		0.016	0.017	0.018	0.019	0.021	0.021	0.020	0.018	0.018	0.020	0.020	0.020	0.017	0.021	0.023	0.020	0.020	0.021	0.021	0.019	0.019	0.018	0.022	0.019
G141 Prethopalpus sp. S2 LN8445	0.218	0.226	0.224	0.263	0.165	0.252	0.184	0.213	0.230	0.188	0.189	0.192	0.227	0.132	0.130	0.130	0.130	0.123		0.018	0.018	0.021	0.021	0.020	0.019	0.017	0.018	0.018	0.020	0.022	0.018	0.021	0.022	0.018	0.017	0.020	0.020	0.020	0.017	0.020	0.021	0.020
G142 Desognanops sp. n. Y1 LN8482	0.216	0.181	0.198	0.243	0.216	0.235	0.231	0.181	0.202	0.276	0.282	0.215	0.199	0.215	0.209	0.209	0.211	0.204	0.202		0.011	0.021	0.021	0.021	0.019	0.019	0.018	0.019	0.019	0.018	0.017	0.017	0.022	0.019	0.019	0.018	0.018	0.018	0.018	0.019	0.018	0.017
G145 Desognanops sp. n. Y1 LN6635	0.209	0.190	0.183	0.243	0.214	0.235	0.246	0.172	0.182	0.267	0.282	0.237	0.180	0.187	0.191	0.191	0.204	0.209	0.202	0.085		0.019	0.020	0.020	0.018	0.018	0.016	0.018	0.018	0.018	0.018	0.019	0.021	0.019	0.019	0.018	0.017	0.020	0.018	0.019	0.020	0.015
G209 109675	0.262	0.228	0.233	0.134	0.254	0.130	0.266	0.215	0.219	0.267	0.285	0.260	0.214	0.245	0.253	0.249	0.249	0.236	0.255	0.240	0.240		0.014	0.014	0.015	0.018	0.021	0.023	0.021	0.020	0.022	0.023	0.016	0.021	0.021	0.020	0.020	0.021	0.023	0.021	0.020	0.021
G210 107945	0.264	0.220	0.241	0.135	0.264	0.117	0.287	0.220	0.227	0.247	0.260	0.235	0.225	0.276	0.276	0.278	0.283	0.278	0.278	0.246	0.230	0.136		0.007	0.016	0.021	0.020	0.025	0.022	0.019	0.022	0.021	0.016	0.021	0.022	0.020	0.019	0.021	0.022	0.020	0.021	0.021
G226 107786	0.255	0.210	0.233	0.121	0.253	0.105	0.292	0.219	0.226	0.264	0.272	0.240	0.228	0.285	0.288	0.281	0.295	0.283	0.269	0.235	0.231	0.144	0.025		0.016	0.021	0.021	0.024	0.021	0.019	0.022	0.021	0.015	0.022	0.021	0.020	0.019	0.021	0.021	0.020	0.021	0.022
G227 MC8638	0.257	0.196	0.223	0.124	0.247	0.130	0.261	0.198	0.216	0.253	0.260	0.240	0.212	0.232	0.232	0.235	0.254	0.230	0.247	0.203	0.213	0.133	0.135	0.134		0.019	0.020	0.024	0.019	0.019	0.020	0.018	0.017	0.020	0.020	0.020	0.019	0.019	0.019	0.020	0.020	0.020
G307 LN9925 Gnaphosidae sp MJ	0.253	0.240	0.249	0.240	0.194	0.223	0.200	0.228	0.249	0.199	0.211	0.192	0.246	0.182	0.180	0.178	0.182	0.182	0.182	0.208	0.213	0.222	0.250	0.248	0.226		0.011	0.016	0.019	0.022	0.017	0.020	0.022	0.018	0.018	0.020	0.020	0.020	0.018	0.018	0.021	0.019
G308 LN9827 Oonopidae sp MJ	0.248	0.229	0.238	0.240	0.189	0.214	0.186	0.206	0.231	0.170	0.167	0.187	0.224	0.184	0.178	0.169	0.178	0.182	0.173	0.191	0.206	0.218	0.252	0.244	0.226	0.059		0.018	0.018	0.021	0.017	0.020	0.022	0.019	0.019	0.020	0.019	0.020	0.019	0.017	0.021	0.020
G309 LN8606 Prethopalpus sp MA	0.239	0.215	0.205	0.228	0.176	0.229	0.198	0.195	0.209	0.210	0.220	0.189	0.206	0.173	0.182	0.184	0.169	0.184	0.173	0.215	0.195	0.246	0.264	0.255	0.237	0.171	0.173		0.018	0.021	0.019	0.021	0.027	0.018	0.019	0.020	0.021	0.021	0.019	0.019	0.021	0.019
GH12 Selinopidae PES16307	0.200	0.155	0.170	0.233	0.222	0.241	0.194	0.166	0.172	0.278	0.276	0.242	0.180	0.210	0.212	0.223	0.223	0.221	0.232	0.189	0.182	0.268	0.250	0.244	0.242	0.218	0.220	0.218		0.021	0.019	0.021	0.022	0.018	0.018	0.019	0.019	0.020	0.019	0.019	0.020	0.019
GU684645 Theridion ohlerti Theridiidae	0.214	0.116	0.158	0.212	0.223	0.196	0.259	0.101	0.169	0.290	0.297	0.253	0.173	0.235	0.242	0.233	0.240	0.240	0.249	0.194	0.189	0.210	0.221	0.214	0.209	0.246	0.227	0.220	0.192		0.020	0.018	0.019	0.020	0.020	0.017	0.018	0.017	0.014	0.021	0.017	0.019
IV272 MEBRC0016P1T1-2	0.237	0.223	0.251	0.255	0.222	0.232	0.211	0.234	0.221	0.207	0.211	0.210	0.224	0.194	0.191	0.191	0.202	0.189	0.200	0.202	0.213	0.245	0.236	0.230	0.234	0.206	0.202	0.211	0.242	0.248		0.020	0.023	0.016	0.016	0.019	0.018	0.019	0.019	0.016	0.021	0.019
IV275 127039	0.198	0.133	0.163	0.235	0.227	0.228	0.252	0.141	0.174	0.293	0.303	0.260	0.175	0.232	0.230	0.232	0.238	0.234	0.226	0.183	0.198	0.232	0.239	0.239	0.200	0.230	0.224	0.246	0.198	0.147	0.240		0.021	0.019	0.019	0.019	0.019	0.014	0.014	0.021	0.014	0.018
IV276 138441	0.262	0.201	0.243	0.115	0.250	0.108	0.314	0.210	0.238	0.261	0.279	0.265	0.237	0.272	0.274	0.264	0.289	0.274	0.269	0.256	0.241	0.140	0.122	0.124	0.132	0.269	0.261	0.266	0.282	0.186	0.250	0.230		0.025	0.024	0.020	0.020	0.021	0.021	0.022	0.021	0.023
IV345 SSp-2010-253 DCBRC 017	0.235	0.237	0.229	0.244	0.194	0.237	0.169	0.221	0.217	0.190	0.189	0.154	0.219	0.199	0.199	0.192	0.217	0.189	0.187	0.192	0.203	0.249	0.245	0.253	0.235	0.171	0.176	0.174	0.221	0.236	0.178	0.242	0.269		0.006	0.019	0.019	0.020	0.020	0.018	0.019	0.018
IV346 SSp-2010-75 DCBRC 040	0.226	0.235	0.231	0.240	0.189	0.237	0.169	0.219	0.219	0.179	0.176	0.144	0.221	0.194	0.194	0.192	0.212	0.187	0.178	0.192	0.203	0.251	0.241	0.248	0.235	0.169	0.176	0.169	0.219	0.241	0.171	0.242	0.266	0.014		0.019	0.019	0.020	0.020	0.017	0.020	0.017
KD01 GR15MEB0014.20160915.T1-01	0.195	0.139	0.166	0.206	0.215	0.210	0.228	0.096	0.168	0.273	0.285	0.230	0.172	0.226	0.230	0.215	0.226	0.228	0.226	0.177	0.181	0.210	0.220	0.216	0.212	0.218	0.202	0.211	0.178	0.123	0.221	0.174	0.225	0.216	0.218		0.004	0.019	0.016	0.017	0.016	0.017
KD02 RC15MEC0001.20160915.T1-01	0.189	0.136	0.165	0.205	0.207	0.205	0.231	0.093	0.174	0.264	0.282	0.232	0.180	0.222	0.227	0.211	0.222	0.224	0.227	0.176	0.180	0.216	0.216	0.212	0.204	0.212	0.203	0.216	0.177	0.123	0.218	0.175	0.221	0.217	0.219	0.009		0.019	0.016	0.018	0.016	0.017
KJ957946 Arachnura scorpionoides Aranidae	0.205	0.127	0.168	0.238	0.235	0.230	0.234	0.155	0.170	0.287	0.294	0.240	0.171	0.223	0.223	0.226	0.230	0.217	0.251	0.191	0.200	0.223	0.232	0.232	0.202	0.213	0.204	0.213	0.200	0.147	0.220	0.114	0.230	0.228	0.224	0.174	0.172		0.015	0.019	0.017	0.019
KJ957966 Gea theridioides Aranidae	0.205	0.129	0.172	0.235	0.231	0.226	0.245	0.137	0.166	0.287	0.297	0.245	0.167	0.251	0.257	0.247	0.251	0.253	0.240	0.204	0.221	0.232	0.245	0.241	0.217	0.224	0.232	0.226	0.188	0.136	0.240	0.124	0.235	0.226	0.226	0.163	0.164	0.140		0.020	0.018	0.018
KR864743 Ischnothyreus auritus Oonopidae	0.236	0.234	0.247	0.269	0.208	0.254	0.217	0.245	0.230	0.256	0.257	0.230	0.231	0.199	0.199	0.210	0.221	0.205	0.226	0.246	0.230	0.253	0.252	0.253	0.255	0.218	0.225	0.227	0.223	0.254	0.164	0.236	0.279	0.220	0.218	0.199	0.204	0.241	0.245		0.023	0.019
KX537094 Theridion boesenbergi Theriidae	0.203	0.118	0.169	0.221	0.234	0.225	0.239	0.088	0.189	0.281	0.294	0.258	0.193	0.233	0.233	0.221	0.230	0.233	0.247	0.189	0.203	0.230	0.232	0.228	0.214	0.227	0.217	0.225	0.161	0.125	0.257	0.136	0.245	0.236	0.239	0.114	0.111	0.156	0.150	0.246		0.019
Zelanda sp. CG213 isolate ARACG000213	0.153	0.187	0.136	0.244	0.218	0.247	0.230	0.172	0.132	0.273	0.282	0.273	0.129	0.213	0.217	0.226	0.230	0.219	0.226	0.202	0.194	0.247	0.250	0.244	0.223	0.239	0.235	0.224	0.188	0.194	0.238	0.173	0.252	0.231	0.235	0.173	0.172	0.179	0.185	0.236	0.180	

1. Tamura K., Stecher G., Peterson D., Filipski A., and Kumar S. (2013). MEGA6: Molecular Evolutionary Genetics Analysis version 6.0. Molecular Biology and Evolution30: 2725-2729.

The number of base differences per site from between sequences are shown. Standard error estimate(s) are shown above the diagonal. The analysis involved 42 nucleotide sequences. Codon positions included were 1st+2nd+3rd+Noncoding. All ambiguous positions were removed for each sequence pair. There were a total of 495 positions in the final dataset. Evolutionary analyses were conducted in MEGA6 [1].

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Table 8. Estimates of Evolutionary Divergence between Sequences

Specimen ID	LI44 E84259	LI45 E84277	CF10 SF0139R Curculionidae Genus 1 sp. B07	CF13 SF0725R Curculionidae Genus 1 sp. B09	CF5 GB0002R Curculionidae Genus 1 sp. B06	CF6 GF0421R Curculionidae Genus 1 sp. B02	CF7 PSC0890R Curculionidae Genus 1 sp. B02	CF8 PSD0107R Curculionidae Genus 1 sp. B08	CF9 SF0034R Curculionidae Genus 1 sp. B07	G115 Curculionidae	IV148 DD14MRR009-20150808-T3-01	IV150 RC14MEB0060-20151001-T2-02	IV152 MEARC4400-t1-01	IV234 RC15MEC0192-20160316-T3-03	IV395 MEK1478P7T2-2	KD03 GR15MEB0003.20160915.T3-01	KD04 RC15MEB0216.20160915.T3-02	KD05 GR15MEC0019.20160915.T2-01	KU519717 WAME89186 Curculionidae sp. 8	WAME89091 Curculionidae sp. 3	WAME89114 Curculionidae sp. 3	WAME89115 Curculionidae sp. 3	WAME89116 Curculionidae sp.3	WAME89146 Curculionidae sp. 1	WAME89147 Curculionidae sp. 1	WAME89148 Curculionidae sp. 1	WAME89151 Curculionidae sp. 2	WAME89157 Curculionidae sp. 1	WAME89172 Curculionidae sp. 4	WAME89177 Curculionidae sp. 7	WAME89188 Curculionidae sp. 8	WAME89154 Curculionidae sp. 4
LI44 E84259		0.003	0.016	0.016	0.017	0.016	0.017	0.017	0.016	0.021	0.016	0.002	0.007	0.002	0.014	0.000	0.002	0.002	0.006	0.018	0.017	0.016	0.018	0.017	0.017	0.017	0.017	0.017	0.015	0.007	0.017
LI45 E84277	0.009		0.017	0.017	0.017	0.016	0.017	0.017	0.016	0.020	0.016	0.003	0.008	0.002	0.013	0.003	0.004	0.003	0.006	0.017	0.017	0.016	0.017	0.017	0.017	0.017	0.017	0.017	0.016	0.007	0.017
CF10 SF0139R Curculionidae Genus 1 sp. B07	0.216	0.226		0.004	0.007	0.005	0.008	0.007	0.004	0.016	0.015	0.017	0.016	0.017	0.017	0.016	0.017	0.017	0.017	0.007	0.007	0.007	0.008	0.012	0.012	0.012	0.014	0.012	0.015	0.017	0.014
CF13 SF0725R Curculionidae Genus 1 sp. B09	0.216	0.226	0.014		0.007	0.005	0.008	0.006	0.004	0.017	0.014	0.017	0.016	0.017	0.017	0.016	0.017	0.017	0.017	0.008	0.006	0.007	0.008	0.013	0.013	0.013	0.014	0.012	0.014	0.017	0.014
CF5 GB0002R Curculionidae Genus 1 sp. B06	0.221	0.230	0.038	0.035		0.007	0.008	0.007	0.006	0.015	0.015	0.017	0.017	0.017	0.018	0.017	0.017	0.017	0.018	0.008	0.008	0.007	0.008	0.013	0.013	0.013	0.012	0.014	0.015	0.017	0.015
CF6 GF0421R Curculionidae Genus 1 sp. B02	0.213	0.223	0.024	0.021	0.036		0.007	0.007	0.005	0.016	0.015	0.016	0.016	0.016	0.017	0.016	0.016	0.016	0.017	0.008	0.007	0.007	0.008	0.012	0.012	0.012	0.013	0.013	0.014	0.016	0.014
CF7 PSC0890R Curculionidae Genus 1 sp. B02	0.215	0.221	0.039	0.038	0.046	0.045		0.004	0.007	0.016	0.016	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.005	0.008	0.006	0.004	0.013	0.013	0.013	0.013	0.014	0.014	0.017	0.013
CF8 PSD0107R Curculionidae Genus 1 sp. B08	0.216	0.226	0.035	0.033	0.042	0.038	0.013		0.007	0.017	0.016	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.018	0.006	0.007	0.007	0.005	0.014	0.014	0.014	0.013	0.014	0.014	0.017	0.013
CF9 SF0034R Curculionidae Genus 1 sp. B07	0.206	0.215	0.014	0.014	0.029	0.024	0.041	0.039		0.016	0.014	0.016	0.016	0.016	0.017	0.016	0.016	0.016	0.016	0.007	0.006	0.006	0.007	0.012	0.012	0.012	0.013	0.013	0.014	0.016	0.014
G115 Curculionidae	0.223	0.217	0.124	0.130	0.126	0.124	0.132	0.137	0.124		0.020	0.021	0.020	0.021	0.021	0.021	0.021	0.021	0.021	0.017	0.018	0.017	0.017	0.002	0.006	0.006	0.016	0.007	0.017	0.021	0.019
IV148 DD14MRR009-20150808-T3-01	0.189	0.198	0.176	0.171	0.173	0.180	0.177	0.177	0.167	0.211		0.016	0.015	0.016	0.015	0.016	0.016	0.016	0.016	0.016	0.015	0.015	0.016	0.016	0.016	0.016	0.017	0.016	0.015	0.014	0.016	0.016
IV150 RC14MEB0060-20151001-T2-02	0.001	0.006	0.220	0.220	0.224	0.217	0.215	0.217	0.209	0.222	0.190		0.007	0.000	0.014	0.002	0.002	0.000	0.006	0.017	0.017	0.016	0.017	0.017	0.016	0.016	0.016	0.017	0.016	0.016	0.007	0.017
IV152 MEARC4400-t1-01	0.034	0.034	0.221	0.218	0.228	0.218	0.223	0.224	0.214	0.227	0.190	0.032		0.007	0.013	0.007	0.007	0.007	0.006	0.017	0.017	0.016	0.017	0.016	0.017	0.017	0.016	0.017	0.016	0.015	0.002	0.017
IV234 RC15MEC0192-20160316-T3-03	0.001	0.005	0.222	0.222	0.226	0.219	0.217	0.219	0.212	0.221	0.192	0.000	0.033		0.014	0.002	0.002	0.000	0.006	0.017	0.017	0.016	0.017	0.017	0.016	0.016	0.016	0.017	0.016	0.016	0.007	0.017
IV395 MEK1478P7T2-2	0.130	0.129	0.217	0.220	0.226	0.219	0.213	0.217	0.216	0.242	0.179	0.129	0.135	0.129		0.014	0.014	0.014	0.014	0.018	0.017	0.017	0.017	0.015	0.016	0.016	0.017	0.016	0.016	0.017	0.014	0.016
KD03 GR15MEB0003.20160915.T3-01	0.000	0.009	0.217	0.217	0.221	0.214	0.215	0.217	0.206	0.223	0.189	0.001	0.034	0.001	0.130		0.002	0.002	0.006	0.018	0.017	0.016	0.018	0.017	0.017	0.017	0.017	0.017	0.015	0.007	0.017
KD04 RC15MEB0216.20160915.T3-02	0.004	0.011	0.218	0.218	0.220	0.213	0.217	0.215	0.208	0.221	0.190	0.003	0.035	0.003	0.132	0.004		0.002	0.007	0.017	0.017	0.016	0.017	0.016	0.016	0.016	0.016	0.017	0.016	0.007	0.017
KD05 GR15MEC0019.20160915.T2-01	0.001	0.006	0.219	0.219	0.223	0.216	0.215	0.216	0.209	0.222	0.190	0.000	0.032	0.000	0.129	0.001	0.003		0.006	0.017	0.017	0.016	0.017	0.017	0.016	0.016	0.016	0.017	0.016	0.016	0.007	0.017
KU519717 WAME89186 Curculionidae sp. 8	0.030	0.027	0.228	0.228	0.236	0.225	0.229	0.231	0.220	0.226	0.198	0.029	0.021	0.029	0.140	0.030	0.032	0.029		0.017	0.017	0.016	0.017	0.017	0.017	0.017	0.016	0.017	0.016	0.015	0.006	0.017
WAME89091 Curculionidae sp. 3	0.228	0.228	0.036	0.040	0.049	0.041	0.017	0.018	0.040	0.129	0.184	0.226	0.234	0.226	0.223	0.228	0.226	0.226	0.233		0.007	0.007	0.005	0.013	0.013	0.013	0.013	0.014	0.014	0.017	0.017	0.014
WAME89114 Curculionidae sp. 3	0.228	0.228	0.038	0.035	0.044	0.043	0.041	0.033	0.035	0.136	0.184	0.229	0.234	0.229	0.217	0.228	0.233	0.229	0.233	0.036		0.004	0.008	0.014	0.014	0.014	0.014	0.013	0.015	0.017	0.017	0.013
WAME89115 Curculionidae sp. 3	0.223	0.223	0.035	0.032	0.041	0.040	0.035	0.033	0.029	0.129	0.175	0.225	0.229	0.225	0.216	0.223	0.228	0.225	0.228	0.033	0.012		0.007	0.013	0.013	0.013	0.013	0.014	0.014	0.016	0.016	0.014
WAME89116 Curculionidae sp.3	0.217	0.217	0.036	0.040	0.052	0.047	0.014	0.015	0.040	0.134	0.182	0.216	0.223	0.216	0.222	0.217	0.219	0.216	0.222	0.015	0.040	0.033		0.013	0.013	0.013	0.013	0.014	0.014	0.017	0.017	0.013
WAME89146 Curculionidae sp. 1	0.213	0.209	0.116	0.120	0.122	0.117	0.126	0.128	0.114	0.002	0.193	0.211	0.216	0.211	0.225	0.213	0.208	0.211	0.213	0.122	0.131	0.122	0.125		0.004	0.004	0.013	0.004	0.013	0.017	0.016	0.014
WAME89147 Curculionidae sp. 1	0.210	0.206	0.114	0.119	0.123	0.119	0.125	0.129	0.112	0.014	0.191	0.208	0.216	0.208	0.225	0.210	0.208	0.208	0.210	0.120	0.129	0.120	0.123	0.009		0.003	0.014	0.005	0.013	0.017	0.017	0.014
WAME89148 Curculionidae sp. 1	0.210	0.206	0.117	0.122	0.123	0.119	0.128	0.129	0.116	0.014	0.193	0.208	0.216	0.208	0.226	0.210	0.205	0.208	0.210	0.123	0.132	0.123	0.126	0.008	0.005		0.014	0.003	0.013	0.017	0.017	0.014
WAME89151 Curculionidae sp. 2	0.211	0.211	0.119	0.119	0.116	0.122	0.103	0.106	0.114	0.132	0.199	0.210	0.207	0.210	0.217	0.211	0.213	0.210	0.210	0.109	0.122	0.117	0.105	0.129	0.131	0.132		0.014	0.012	0.016	0.016	0.013
WAME89157 Curculionidae sp. 1	0.214	0.211	0.117	0.116	0.123	0.119	0.125	0.123	0.116	0.018	0.193	0.213	0.220	0.213	0.231	0.214	0.210	0.213	0.214	0.126	0.129	0.123	0.126	0.012	0.012	0.008	0.131		0.013	0.017	0.017	0.013
WAME89172 Curculionidae sp. 4	0.217	0.217	0.128	0.126	0.132	0.132	0.126	0.129	0.123	0.127	0.167	0.216	0.220	0.216	0.216	0.217	0.216	0.216	0.222	0.129	0.134	0.126	0.122	0.114	0.119	0.120	0.132	0.117		0.015	0.016	0.009
WAME89177 Curculionidae sp. 7	0.190	0.194	0.204	0.198	0.199	0.199	0.198	0.195	0.195	0.224	0.138	0.191	0.191	0.191	0.195	0.190	0.191	0.191	0.191	0.202	0.204	0.195	0.196	0.193	0.193	0.191	0.205	0.191	0.188		0.015	0.016
WAME89188 Curculionidae sp. 8	0.033	0.030	0.229	0.226	0.237	0.226	0.231	0.233	0.222	0.229	0.198	0.032	0.002	0.032	0.137	0.033	0.035	0.032	0.021	0.234	0.234	0.229	0.223	0.214	0.214	0.214	0.208	0.219	0.220	0.191		0.017
WAME89154 Curculionidae sp. 4	0.214	0.214	0.138	0.141	0.140	0.144	0.137	0.135	0.137	0.139	0.201	0.213	0.217	0.213	0.213	0.214	0.213	0.213	0.216	0.144	0.137	0.135	0.132	0.125	0.129	0.128	0.141	0.123	0.052	0.201	0.217	

1. Tamura K., Stecher G., Peterson D., Filipski A., and Kumar S. (2013). MEGA6: Molecular Evolutionary Genetics Analysis version 6.0. Molecular Biology and Evolution30: 2725-2729.

The number of base differences per site from between sequences are shown. Standard error estimate(s) are shown above the diagonal. The analysis involved 42 nucleotide sequences. Codon positions included were 1st+2nd+3rd+Noncoding. All ambiguous positions were removed for each sequence pair. There were a total of 495 positions in the final dataset. Evolutionary analyses were conducted in MEGA6 [1].

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Table 9. Estimates of Evolutionary Divergence between Sequences

Specimen ID	LI30 MEAWO4088-20170307-01	AF370844 Campodea tillyardi	BQ8 PES 4283 Japygidae won1 DJA003	BX16 PES-5195 Japygidae MH1 DJA004	BX17 PES-5952 Japygidae MH1 DJA005	BX29 PES-5141 Parajapygidae MH1 DPA002	BX30 PES-5190 Parajapygidae MH1 DPA002	Diplura sp. HQ943342	FH7 Japygidae sp B36 DLUNK03 DJA006	FH8 Japygidae sp B36 NOW sp EW0333 DJA007	G432 110953 Japygidae sp Central Pilbara DJA001	G433 110848 Japygidae Central Pilbara sp DJA002	GH6 Anajapygidae Ana-PES16402 DCA004	HQ882832 Lepidocampa weberi	IT74 BHRC0514-151013-T2-02 DJA008	IV154 DD11MEB001T1-01 DCA001	IV155 DD11MEB001T1-01 DCA002	IV156 DD11MEC0005-02 DPA004	IV157 DD14MEB0005-20151001-T3-02 DCA003	IV159 RC14MEB0101-20151001-T2-01 DCA003	IV245 RC15MEB0171-20160317-T1-01 DPA003	IV248 RC15MEC0192-20160316-T1-01 DPA005	Japyx solifugus AY771989	JC18 RC14BS4004-20151125-T2-01 DJA009	JF37 RC14MEH0308-20160120-T2-02 DPA001	JQ692327 Parajapyx pauliani voucher HN0405	JU01 RC14MEH0388.20160628.T3-1 DJA010	KD07 GR15MEB0014.20160915.T3-01	KD08 RC15MEB0115.20160915.T2-01	KD09 RC15MEB0115.20160915.T2-01	KD10 RC15MEB0115.20160915.T2-01	KD11 RC15MEB0115.20160915.T2-01	KD12 RC15MEC0103.20160915.T1-01	IV250 RC15MEC0192-20160316-T1-03 DPA006	KD13 RC14MEB0101.20160915.T2-01	KD14 RC16MEC0156.20160915.T3-01	KD15 RC16MEC0118.20160915.T3-01
LI30 MEAWO4088-20170307-01		0.017	0.015	0.013	0.013	0.015	0.014	0.013	0.013	0.013	0.012	0.014	0.016	0.015	0.017	0.016	0.016	0.013	0.015	0.015	0.015	0.015	0.014	0.014	0.014	0.015	0.013	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
AF370844 Campodea tillyardi	0.278		0.017	0.016	0.016	0.016	0.016	0.015	0.017	0.016	0.015	0.018	0.015	0.017	0.017	0.015	0.015	0.017	0.014	0.013	0.017	0.016	0.017	0.018	0.018	0.015	0.017	0.014	0.014	0.014	0.014	0.018	0.016	0.013	0.016	0.019
BQ8 PES 4283 Japygidae won1 DJA003	0.172	0.251		0.013	0.014	0.016	0.017	0.016	0.012	0.013	0.014	0.013	0.016	0.017	0.013	0.015	0.017	0.015	0.015	0.015	0.015	0.016	0.016	0.016	0.013	0.016	0.014	0.013	0.016	0.016	0.016	0.016	0.016	0.015	0.015	0.017
BX16 PES-5195 Japygidae MH1 DJA004	0.164	0.249	0.138		0.011	0.016	0.016	0.015	0.013	0.012	0.012	0.014	0.014	0.015	0.014	0.015	0.015	0.015	0.014	0.014	0.015	0.015	0.015	0.011	0.014	0.014	0.012	0.014	0.014	0.014	0.014	0.013	0.014	0.014	0.013	0.016
BX17 PES-5952 Japygidae MH1 DJA005	0.166	0.267	0.147	0.130		0.015	0.015	0.015	0.013	0.013	0.012	0.013	0.013	0.015	0.013	0.015	0.015	0.015	0.013	0.014	0.015	0.013	0.011	0.012	0.014	0.012	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.014
BX29 PES-5141 Parajapygidae MH1 DPA002	0.216	0.278	0.210	0.213	0.204		0.006	0.016	0.014	0.014	0.015	0.018	0.015	0.015	0.017	0.016	0.017	0.015	0.016	0.016	0.014	0.015	0.014	0.014	0.014	0.014	0.016	0.016	0.017	0.017	0.017	0.017	0.013	0.013	0.016	0.014	0.015
BX30 PES-5190 Parajapygidae MH1 DPA002	0.209	0.274	0.217	0.219	0.208	0.028		0.016	0.015	0.015	0.016	0.019	0.015	0.016	0.017	0.016	0.017	0.016	0.017	0.016	0.014	0.015	0.015	0.015	0.014	0.015	0.016	0.016	0.017	0.017	0.017	0.017	0.014	0.013	0.016	0.015	0.015
Diplura sp. HQ943342	0.245	0.214	0.216	0.220	0.248	0.263	0.267		0.017	0.016	0.015	0.016	0.017	0.016	0.017	0.015	0.015	0.017	0.014	0.014	0.016	0.016	0.018	0.016	0.017	0.014	0.015	0.014	0.014	0.014	0.014	0.014	0.018	0.017	0.014	0.017	0.019
FH7 Japygidae sp B36 DLUNK03 DJA006	0.150	0.263	0.152	0.138	0.156	0.200	0.204	0.246		0.012	0.013	0.013	0.014	0.017	0.015	0.015	0.016	0.014	0.014	0.014	0.014	0.015	0.014	0.012	0.014	0.015	0.012	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014
FH8 Japygidae sp B36 NOW sp EW0333 DJA007	0.156	0.267	0.150	0.143	0.163	0.204	0.206	0.237	0.141		0.013	0.011	0.013	0.017	0.013	0.015	0.016	0.014	0.015	0.015	0.014	0.015	0.014	0.013	0.015	0.015	0.013	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
G432 110953 Japygidae sp Central Pilbara DJA001	0.144	0.270	0.172	0.157	0.149	0.202	0.212	0.247	0.165	0.171		0.014	0.015	0.015	0.014	0.014	0.016	0.014	0.015	0.014	0.017	0.016	0.015	0.014	0.015	0.014	0.014	0.014	0.015	0.015	0.015	0.015	0.014	0.014	0.014	0.014
G433 110848 Japygidae Central Pilbara sp DJA002	0.163	0.259	0.142	0.128	0.153	0.208	0.208	0.244	0.139	0.124	0.174		0.015	0.017	0.014	0.017	0.016	0.016	0.014	0.014	0.015	0.015	0.016	0.013	0.014	0.015	0.014	0.014	0.014	0.014	0.014	0.014	0.015	0.015	0.014	0.015	0.015
GH6 Anajapygidae Ana-PES16402 DCA004	0.245	0.214	0.229	0.203	0.230	0.264	0.261	0.228	0.226	0.233	0.241	0.231		0.015	0.017	0.014	0.014	0.016	0.014	0.014	0.014	0.015	0.015	0.014	0.015	0.016	0.016	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.015	0.016
HQ882832 Lepidocampa weberi	0.237	0.233	0.230	0.204	0.213	0.247	0.244	0.233	0.234	0.231	0.252	0.227	0.227		0.017	0.017	0.017	0.018	0.016	0.016	0.017	0.017	0.016	0.016	0.016	0.015	0.015	0.016	0.016	0.015	0.015	0.015	0.015	0.015	0.017	0.016	0.016	0.017
IT74 BHRC0514-151013-T2-02 DJA008	0.155	0.277	0.163	0.161	0.152	0.223	0.232	0.242	0.150	0.147	0.158	0.155	0.257	0.258		0.015	0.016	0.015	0.016	0.016	0.016	0.016	0.015	0.013	0.015	0.015	0.017	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.017	0.016
IV154 DD11MEB001T1-01 DCA001	0.266	0.219	0.248	0.229	0.252	0.273	0.276	0.249	0.243	0.251	0.255	0.261	0.188	0.253	0.257		0.014	0.017	0.013	0.013	0.015	0.015	0.015	0.016	0.016	0.016	0.015	0.013	0.013	0.013	0.013	0.013	0.016	0.016	0.013	0.016	0.015
IV155 DD11MEB001T1-01 DCA002	0.270	0.222	0.233	0.215	0.237	0.270	0.268	0.227	0.249	0.246	0.263	0.247	0.167	0.211	0.257	0.144		0.015	0.009	0.008	0.016	0.015	0.018	0.018	0.017	0.015	0.016	0.009	0.009	0.009	0.009	0.009	0.017	0.015	0.008	0.016	0.016
IV156 DD11MEC0005-02 DPA004	0.193	0.281	0.185	0.203	0.204	0.175	0.178	0.263	0.190	0.203	0.205	0.191	0.257	0.263	0.197	0.261	0.256		0.015	0.014	0.014	0.015	0.015	0.013	0.014	0.015	0.016	0.015	0.015	0.015	0.015	0.015	0.014	0.014	0.015	0.014	0.013
IV157 DD14MEB0005-20151001-T3-02 DCA003	0.258	0.216	0.226	0.210	0.223	0.258	0.255	0.223	0.245	0.245	0.246	0.227	0.166	0.213	0.252	0.153	0.054	0.243		0.003	0.014	0.014	0.017	0.017	0.015	0.014	0.016	0.002	0.003	0.003	0.003	0.003	0.016	0.015	0.003	0.015	0.015
IV159 RC14MEB0101-20151001-T2-01 DCA003	0.260	0.214	0.224	0.210	0.224	0.258	0.255	0.222	0.242	0.243	0.245	0.226	0.165	0.215	0.254	0.153	0.047	0.241	0.006		0.014	0.015	0.017	0.017	0.015	0.014	0.016	0.003	0.004	0.004	0.004	0.004	0.016	0.015	0.000	0.015	0.015
IV245 RC15MEB0171-20160317-T1-01 DPA003	0.215	0.263	0.222	0.199	0.221	0.221	0.215	0.236	0.219	0.224	0.233	0.220	0.249	0.263	0.223	0.274	0.267	0.207	0.256	0.256		0.011	0.013	0.014	0.013	0.013	0.017	0.014	0.014	0.014	0.014	0.014	0.014	0.015	0.014	0.014	0.014
IV248 RC15MEC0192-20160316-T1-01 DPA005	0.221	0.263	0.200	0.215	0.224	0.218	0.215	0.245	0.218	0.209	0.232	0.197	0.234	0.242	0.212	0.268	0.261	0.194	0.244	0.246	0.121		0.014	0.015	0.015	0.014	0.015	0.014	0.014	0.014	0.014	0.014	0.014	0.015	0.014	0.014	0.016
Japyx solifugus AY771989	0.201	0.260	0.185	0.179	0.200	0.223	0.224	0.243	0.203	0.192	0.196	0.185	0.241	0.250	0.172	0.257	0.254	0.207	0.239	0.242	0.203	0.215		0.015	0.014	0.015	0.014	0.017	0.017	0.017	0.017	0.017	0.015	0.015	0.017	0.015	0.015
JC18 RC14BS4004-20151125-T2-01 DJA009	0.158	0.271	0.165	0.150	0.175	0.194	0.207	0.243	0.137	0.130	0.174	0.159	0.248	0.247	0.141	0.255	0.252	0.204	0.251	0.252	0.221	0.229	0.195		0.013	0.013	0.015	0.017	0.017	0.017	0.017	0.017	0.013	0.013	0.018	0.013	0.014
JF37 RC14MEH0308-20160120-T2-02 DPA001	0.177	0.289	0.195	0.187	0.191	0.166	0.181	0.252	0.181	0.175	0.197	0.180	0.251	0.251	0.193	0.258	0.252	0.134	0.243	0.242	0.181	0.191	0.216	0.179		0.013	0.016	0.016	0.015	0.015	0.015	0.015	0.013	0.013	0.016	0.013	0.013
JQ692327 Parajapyx pauliani voucher HN0405	0.188	0.271	0.173	0.167	0.184	0.187	0.182	0.248	0.191	0.170	0.191	0.173	0.248	0.218	0.184	0.272	0.250	0.181	0.243	0.242	0.198	0.213	0.195	0.185	0.163		0.014	0.014	0.015	0.015	0.015	0.015	0.014	0.013	0.014	0.013	0.014
JU01 RC14MEH0388.20160628.T3-1 DJA010	0.108	0.272	0.156	0.171	0.168	0.225	0.229	0.248	0.153	0.164	0.174	0.160	0.251	0.244	0.166	0.261	0.254	0.203	0.242	0.242	0.218	0.218	0.196	0.178	0.185	0.199		0.016	0.016	0.016	0.016	0.016	0.015	0.015	0.016	0.016	0.016
KD07 GR15MEB0014.20160915.T3-01	0.262	0.216	0.230	0.214	0.227	0.264	0.261	0.222	0.249	0.249	0.248	0.230	0.165	0.213	0.256	0.153	0.054	0.244	0.003	0.006	0.258	0.247	0.242	0.256	0.244	0.246	0.246		0.003	0.003	0.003	0.003	0.016	0.015	0.003	0.015	0.015
KD08 RC15MEB0115.20160915.T2-01	0.264	0.214	0.227	0.215	0.227	0.261	0.258	0.223	0.250	0.250	0.245	0.231	0.168	0.213	0.256	0.152	0.057	0.246	0.006	0.009	0.258	0.247	0.240	0.256	0.249	0.248	0.246	0.006		0.000	0.000	0.000	0.016	0.015	0.004	0.015	0.015
KD09 RC15MEB0115.20160915.T2-01	0.264	0.214	0.227	0.215	0.227	0.261	0.258	0.223	0.250	0.250	0.245	0.231	0.168	0.213	0.256	0.152	0.057	0.246	0.006	0.009	0.258	0.247	0.240	0.256	0.249	0.248	0.246	0.006	0.000		0.000	0.000	0.016	0.015	0.004	0.015	0.015
KD10 RC15MEB0115.20160915.T2-01	0.264	0.214	0.227	0.215	0.227	0.261	0.258	0.223	0.250	0.250	0.245	0.231	0.168	0.213	0.256	0.152	0.057	0.246	0.006	0.009	0.258	0.247	0.240	0.256	0.249	0.248	0.246	0.006	0.000	0.000		0.000	0.016	0.015	0.004	0.015	0.015
KD11 RC15MEB0115.20160915.T2-01	0.264	0.214	0.227	0.215	0.227	0.261	0.258	0.223	0.250	0.250	0.245	0.231	0.168	0.213	0.256	0.152	0.057	0.246	0.006	0.009	0.258	0.247	0.240	0.256	0.249	0.248	0.246	0.006	0.000	0.000	0.000		0.016	0.015	0.004	0.015	0.015
KD12 RC15MEC0103.20160915.T1-01	0.185	0.269	0.197	0.186	0.200	0.191	0.186	0.257	0.170	0.176	0.201	0.182	0.241	0.265	0.215	0.273	0.266	0.164	0.261	0.261	0.188	0.191	0.204	0.181	0.156	0.185	0.192	0.261	0.265	0.265	0.265	0.265		0.008	0.016	0.008	0.013
IV250 RC15MEC0192-20160316-T1-03 DPA006	0.185	0.271	0.197	0.188	0.196	0.175	0.174	0.269	0.172	0.181	0.203	0.186	0.238	0.256	0.215	0.257	0.263	0.169	0.246	0.247	0.191	0.188	0.204	0.190	0.160	0.175	0.196	0.245	0.248	0.248	0.248	0.248	0.050		0.015	0.004	0.012
KD13 RC14MEB0101.20160915.T2-01	0.262	0.214	0.227	0.212	0.227	0.261	0.258	0.222	0.244	0.246	0.245	0.227	0.165	0.215	0.256	0.155	0.048	0.243	0.006	0.000	0.257	0.247	0.242	0.255	0.244	0.242	0.244	0.006	0.009	0.009	0.009	0.009	0.262	0.248		0.015	0.015
KD14 RC16MEC0156.20160915.T3-01	0.189	0.266	0.191	0.183	0.196	0.181	0.183	0.266	0.172	0.184	0.197	0.182	0.234	0.259	0.220	0.255	0.256	0.163	0.243	0.244	0.189	0.189	0.206	0.187	0.153	0.172	0.194	0.242	0.244	0.244	0.244	0.244	0.046	0.015	0.244		0.012
KD15 RC16MEC0118.20160915.T3-01	0.192	0.283	0.189	0.195	0.210	0.181	0.179	0.245	0.189	0.185	0.207	0.191	0.241	0.253	0.188	0.264	0.261	0.163	0.245	0.245	0.204	0.195	0.189	0.191	0.150	0.184	0.197	0.247	0.250	0.250	0.250	0.250	0.150	0.154	0.246	0.155	

1. Tamura K., Stecher G., Peterson D., Filipski A., and Kumar S. (2013). MEGA6: Molecular Evolutionary Genetics Analysis version 6.0. Molecular Biology and Evolution30: 2725-2729.

The number of base differences per site from between sequences are shown. Standard error estimate(s) are shown above the diagonal. The analysis involved 42 nucleotide sequences. Codon positions included were 1st+2nd+3rd+Noncoding. All ambiguous positions were removed for each sequence pair. There were a total of 495 positions in the final dataset. Evolutionary analyses were conducted in MEGA6 [1].

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Table 10. Estimates of Evolutionary Divergence between Sequences

Specimen ID	LI33 MEAWO4086-20170308-04 Thysanura 12S	JQ282164 Trinemura callawa CA0006	JQ282165 Trinemura cundalin CU0060R LN1093	G318 LN8588 Nicoletiidae sp. MC TN001	EXR0919 J16-1 TN001	PROP003 J16-2 Trimenura TN002	G317 LN8923 Nicoletiidae sp. OP TN002	JIN0037R J8 25 Jinaryi TN002	G126 TN003	G205 100101 TN003	G207 107781 TN003	G206 108042 TN004	AY2 BES16311 B10 TN005	AY3 BES15706 S9 Trinemura TN005	BX42 PES-5266 Trinemura MH1 TN006	BX43 PES-5964 Trinemura MH1 TN007	CQ10 Trinemura sp. B18 CC1886 TN008	CQ11 Trinemura sp. B15 CC0179 TN009	CQ12 Trinemura sp. B15 CCMUNK11 TN009	CQ8 Trinemura sp. GNGCUNK011 TN008	CQ9 Trinemura sp. B20 CC3527 TN009	IV227 MEARC4383 TN010	IV333 MEBRC0020T1-20 TN010	IV334 M2ERC0057T1-21 TN011	EJ0245R BHP165 J2 36 OB18 TN011	IV338 GR15MEC0001-20160316-T2-06 TN012	IV339 RC15MEC0197-20160316-T2-01 TN012	CA37 12:0096 Trinemura indet. TN013	CA39 11:1511 Trinemura indet. TN013	FL4 TOBRC0011PIT2-1 B TN014	EXR0983 BHP821 J8 13 Jimblebar W TN015	CQ13 Trinemura sp. B19 CC0748 TN016	JIN0182R BHP465 J2 37 Jinaryi TN016	EXR1136 BHP1364 J8 15 Mudlark TN016	EXR0524 OB21 OB22 TN016
LI33 MEAWO4086-20170308-04		0.022	0.023	0.019	0.019	0.022	0.018	0.020	0.019	0.018	0.018	0.016	0.023	0.019	0.018	0.018	0.017	0.020	0.022	0.018	0.019	0.007	0.003	0.016	0.022	0.015	0.014	0.016	0.017	0.014	0.014	0.021	0.019	0.020	0.020
JQ282164 Trinemura callawa CA0006	0.149		0.014	0.017	0.017	0.022	0.020	0.021	0.021	0.021	0.021	0.021	0.021	0.020	0.020	0.020	0.020	0.022	0.021	0.020	0.022	0.021	0.022	0.021	0.019	0.018	0.019	0.018	0.018	0.020	0.023	0.019	0.019	0.018	0.020
JQ282165 Trinemura cundalin CU0060R LN1093	0.164	0.065		0.018	0.017	0.021	0.019	0.019	0.020	0.020	0.019	0.019	0.023	0.021	0.019	0.018	0.021	0.023	0.022	0.021	0.021	0.022	0.023	0.022	0.019	0.018	0.019	0.020	0.020	0.020	0.021	0.020	0.019	0.018	0.020
G318 LN8588 Nicoletiidae sp. MC TN001	0.194	0.132	0.144		0.006	0.020	0.019	0.018	0.016	0.017	0.017	0.018	0.017	0.013	0.020	0.018	0.021	0.018	0.020	0.021	0.018	0.019	0.019	0.020	0.019	0.018	0.018	0.018	0.018	0.018	0.021	0.018	0.018	0.019	0.018
EXR0919 J16-1 TN001	0.174	0.142	0.151	0.012		0.020	0.018	0.018	0.018	0.019	0.018	0.018	0.017	0.016	0.020	0.017	0.021	0.021	0.020	0.021	0.018	0.019	0.019	0.022	0.019	0.020	0.020	0.019	0.020	0.020	0.020	0.017	0.018	0.018	0.018
PROP003 J16-2 Trimenura TN002	0.169	0.214	0.216	0.185	0.189		0.014	0.014	0.019	0.020	0.019	0.021	0.026	0.024	0.022	0.018	0.024	0.025	0.024	0.024	0.023	0.022	0.022	0.022	0.022	0.023	0.023	0.023	0.023	0.022	0.023	0.021	0.020	0.021	0.021
G317 LN8923 Nicoletiidae sp. OP TN002	0.164	0.207	0.204	0.182	0.172	0.086		0.016	0.015	0.015	0.014	0.016	0.024	0.020	0.020	0.014	0.021	0.022	0.023	0.021	0.020	0.019	0.018	0.021	0.021	0.019	0.019	0.018	0.018	0.020	0.021	0.016	0.018	0.020	0.019
JIN0037R J8 25 Jinaryi TN002	0.141	0.183	0.183	0.163	0.173	0.074	0.089		0.018	0.018	0.018	0.017	0.024	0.022	0.023	0.016	0.021	0.024	0.025	0.021	0.021	0.020	0.020	0.022	0.020	0.022	0.022	0.022	0.022	0.022	0.020	0.020	0.018	0.020	0.018
G126 TN003	0.176	0.215	0.202	0.169	0.180	0.142	0.104	0.123		0.007	0.000	0.016	0.023	0.018	0.019	0.015	0.022	0.019	0.021	0.021	0.016	0.020	0.019	0.020	0.020	0.019	0.020	0.019	0.020	0.020	0.020	0.018	0.017	0.019	0.020
G205 100101 TN003	0.175	0.207	0.201	0.198	0.188	0.153	0.119	0.137	0.023		0.007	0.015	0.023	0.020	0.018	0.014	0.020	0.020	0.022	0.020	0.017	0.019	0.018	0.020	0.019	0.018	0.017	0.018	0.018	0.018	0.019	0.018	0.017	0.018	0.019
G207 107781 TN003	0.168	0.213	0.201	0.190	0.185	0.147	0.106	0.125	0.000	0.022		0.015	0.023	0.019	0.018	0.014	0.020	0.020	0.021	0.020	0.016	0.019	0.018	0.019	0.020	0.018	0.018	0.018	0.019	0.018	0.019	0.017	0.017	0.019	0.019
G206 108042 TN004	0.141	0.196	0.190	0.196	0.183	0.155	0.135	0.131	0.104	0.113	0.097		0.023	0.020	0.017	0.015	0.020	0.021	0.023	0.019	0.019	0.017	0.016	0.019	0.020	0.018	0.017	0.019	0.019	0.017	0.019	0.018	0.017	0.022	0.020
AY2 BES16311 B10 TN005	0.206	0.173	0.187	0.115	0.115	0.203	0.206	0.196	0.208	0.210	0.207	0.218		0.003	0.027	0.022	0.024	0.021	0.020	0.026	0.019	0.023	0.024	0.026	0.022	0.022	0.022	0.022	0.021	0.023	0.024	0.021	0.024	0.023	0.023
AY3 BES15706 S9 Trinemura TN005	0.217	0.160	0.171	0.108	0.117	0.204	0.215	0.182	0.191	0.216	0.211	0.222	0.003		0.020	0.019	0.023	0.020	0.020	0.024	0.018	0.020	0.020	0.021	0.020	0.020	0.019	0.019	0.019	0.020	0.023	0.021	0.022	0.022	0.021
BX42 PES-5266 Trinemura MH1 TN006	0.124	0.177	0.180	0.212	0.192	0.191	0.155	0.172	0.172	0.170	0.163	0.161	0.242	0.244		0.018	0.021	0.021	0.023	0.020	0.019	0.018	0.017	0.016	0.021	0.018	0.017	0.018	0.018	0.017	0.018	0.020	0.020	0.019	0.019
BX43 PES-5964 Trinemura MH1 TN007	0.141	0.180	0.176	0.167	0.154	0.125	0.098	0.119	0.125	0.126	0.119	0.127	0.185	0.196	0.144		0.021	0.020	0.022	0.022	0.018	0.021	0.018	0.020	0.021	0.019	0.018	0.018	0.019	0.019	0.022	0.018	0.016	0.016	0.019
CQ10 Trinemura sp. B18 CC1886 TN008	0.130	0.184	0.206	0.234	0.208	0.203	0.213	0.163	0.204	0.197	0.197	0.195	0.221	0.257	0.181	0.201		0.020	0.020	0.009	0.019	0.016	0.018	0.016	0.022	0.016	0.016	0.019	0.020	0.015	0.019	0.019	0.020	0.021	0.021
CQ11 Trinemura sp. B15 CC0179 TN009	0.152	0.173	0.172	0.155	0.160	0.190	0.155	0.159	0.133	0.145	0.136	0.158	0.173	0.174	0.175	0.151	0.196		0.006	0.022	0.006	0.020	0.020	0.023	0.022	0.022	0.022	0.019	0.020	0.020	0.022	0.018	0.019	0.020	0.020
CQ12 Trinemura sp. B15 CCMUNK11 TN009	0.153	0.160	0.170	0.150	0.151	0.174	0.160	0.156	0.142	0.152	0.145	0.160	0.176	0.176	0.179	0.152	0.187	0.011		0.022	0.008	0.021	0.022	0.023	0.023	0.023	0.024	0.020	0.021	0.021	0.022	0.018	0.020	0.020	0.022
CQ8 Trinemura sp. GNGCUNK011 TN008	0.130	0.184	0.206	0.229	0.205	0.199	0.210	0.160	0.204	0.197	0.197	0.184	0.221	0.254	0.169	0.201	0.031	0.199	0.191		0.020	0.015	0.018	0.017	0.022	0.017	0.018	0.018	0.019	0.015	0.020	0.020	0.021	0.022	0.023
CQ9 Trinemura sp. B20 CC3527 TN009	0.148	0.167	0.163	0.169	0.142	0.174	0.148	0.135	0.124	0.134	0.120	0.151	0.168	0.197	0.160	0.145	0.182	0.016	0.021	0.185		0.018	0.019	0.020	0.021	0.019	0.019	0.017	0.017	0.018	0.020	0.015	0.017	0.020	0.019
IV227 MEARC4383 TN010	0.028	0.161	0.176	0.216	0.193	0.169	0.174	0.147	0.180	0.171	0.168	0.152	0.213	0.232	0.142	0.168	0.110	0.171	0.171	0.104	0.168		0.007	0.017	0.021	0.015	0.015	0.016	0.017	0.013	0.016	0.020	0.019	0.019	0.020
IV333 MEBRC0020T1-20 TN010	0.005	0.152	0.167	0.194	0.177	0.166	0.164	0.141	0.176	0.175	0.168	0.142	0.209	0.217	0.124	0.147	0.135	0.152	0.156	0.130	0.148	0.028		0.017	0.022	0.015	0.015	0.016	0.017	0.015	0.014	0.020	0.019	0.020	0.020
IV334 M2ERC0057T1-21 TN011	0.122	0.185	0.203	0.205	0.190	0.187	0.189	0.162	0.192	0.180	0.183	0.189	0.230	0.242	0.124	0.164	0.136	0.184	0.178	0.133	0.171	0.127	0.127		0.023	0.015	0.014	0.017	0.017	0.016	0.019	0.020	0.021	0.022	0.020
EJ0245R BHP165 J2 36 OB18 TN011	0.187	0.212	0.182	0.182	0.187	0.175	0.165	0.139	0.145	0.144	0.147	0.158	0.218	0.207	0.215	0.168	0.210	0.139	0.136	0.203	0.142	0.193	0.190	0.193		0.021	0.021	0.021	0.021	0.020	0.021	0.023	0.016	0.020	0.016
IV338 GR15MEC0001-20160316-T2-06 TN012	0.119	0.160	0.162	0.192	0.164	0.201	0.197	0.167	0.188	0.171	0.176	0.182	0.187	0.221	0.162	0.175	0.101	0.187	0.188	0.098	0.171	0.122	0.124	0.128	0.189		0.006	0.015	0.015	0.014	0.018	0.019	0.021	0.022	0.022
IV339 RC15MEC0197-20160316-T2-01 TN012	0.113	0.160	0.162	0.184	0.158	0.195	0.189	0.161	0.182	0.163	0.173	0.179	0.190	0.217	0.153	0.166	0.098	0.180	0.184	0.095	0.165	0.116	0.118	0.121	0.186	0.017		0.014	0.014	0.013	0.017	0.019	0.021	0.021	0.022
CA37 12:0096 Trinemura indet. TN013	0.123	0.148	0.163	0.184	0.174	0.183	0.157	0.165	0.163	0.155	0.155	0.169	0.184	0.207	0.148	0.152	0.155	0.158	0.163	0.147	0.154	0.126	0.123	0.141	0.180	0.114	0.111		0.004	0.015	0.018	0.017	0.019	0.019	0.021
CA39 11:1511 Trinemura indet. TN013	0.126	0.152	0.167	0.187	0.177	0.190	0.163	0.171	0.169	0.161	0.161	0.175	0.181	0.205	0.151	0.157	0.156	0.162	0.167	0.147	0.157	0.129	0.126	0.144	0.187	0.114	0.111	0.008		0.015	0.019	0.017	0.019	0.019	0.022
FL4 TOBRC0011PIT2-1 B TN014	0.098	0.172	0.175	0.210	0.188	0.171	0.180	0.152	0.174	0.162	0.168	0.146	0.215	0.233	0.141	0.159	0.098	0.165	0.159	0.096	0.162	0.097	0.103	0.123	0.177	0.090	0.085	0.106	0.109		0.018	0.019	0.021	0.019	0.021
EXR0983 BHP821 J8 13 Jimblebar W TN015	0.091	0.181	0.177	0.157	0.165	0.204	0.188	0.176	0.187	0.195	0.189	0.184	0.211	0.201	0.150	0.182	0.137	0.179	0.176	0.134	0.175	0.097	0.094	0.142	0.189	0.146	0.143	0.137	0.141	0.128		0.020	0.019	0.020	0.021
CQ13 Trinemura sp. B19 CC0748 TN016	0.174	0.181	0.184	0.197	0.175	0.170	0.140	0.157	0.128	0.132	0.124	0.137	0.204	0.233	0.186	0.146	0.191	0.107	0.099	0.185	0.105	0.188	0.169	0.197	0.149	0.185	0.182	0.163	0.169	0.160	0.186		0.015	0.019	0.020
JIN0182R BHP465 J2 37 Jinaryi TN016	0.136	0.181	0.178	0.156	0.166	0.149	0.137	0.128	0.125	0.122	0.128	0.156	0.197	0.183	0.170	0.125	0.193	0.141	0.145	0.190	0.135	0.154	0.139	0.166	0.122	0.165	0.159	0.133	0.139	0.153	0.168	0.142		0.013	0.016
EXR1136 BHP1364 J8 15 Mudlark TN016	0.181	0.175	0.160	0.177	0.184	0.173	0.157	0.154	0.146	0.148	0.145	0.173	0.184	0.177	0.179	0.142	0.224	0.137	0.138	0.215	0.141	0.190	0.184	0.205	0.125	0.207	0.207	0.168	0.169	0.177	0.191	0.154	0.110		0.021
EXR0524 OB21 OB22 TN016	0.186	0.207	0.192	0.178	0.188	0.181	0.165	0.153	0.163	0.162	0.165	0.193	0.205	0.202	0.198	0.156	0.218	0.135	0.136	0.224	0.145	0.192	0.183	0.183	0.086	0.197	0.197	0.185	0.192	0.182	0.185	0.158	0.121	0.132	

1. Tamura K., Stecher G., Peterson D., Filipski A., and Kumar S. (2013). MEGA6: Molecular Evolutionary Genetics Analysis version 6.0. Molecular Biology and Evolution30: 2725-2729.

The number of base differences per site from between sequences are shown. Standard error estimate(s) are shown above the diagonal. The analysis involved 42 nucleotide sequences. Codon positions included were 1st+2nd+3rd+Noncoding. All ambiguous positions were removed for each sequence pair. There were a total of 495 positions in the final dataset. Evolutionary analyses were conducted in MEGA6 [1].

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Table 11. Estimates of Evolutionary Divergence between Sequences

Specimen ID	LI31 RC16MEC0177-20170309-02	LI34 RC16MEK0002-20170321-T2-1	LI35 RC16MEK0002-20170321-T3-1	KD24 GR15MEB0014.20160915.T2-01	KD25 RC15MEC0096.20160915.T2-01	KD26 RC16MEC0005.20160915.T1-01	KD27 GR15MEB0022.20160915.T3-02	KD66 GR15MEB0022-20160727-SC-01	KD67 GR15MEB0022-20160727-SC-02	KD69 GR15MEB0022-20160727-SC-04	AX83 10DDH033P1T1-2 PC042	AX85 ID32P1T1-7 PC045	CP3 RC10KOOD0049T2-4 Schizomida CP008	EA0270R Lag B2 Ophthalmia Range PC033	EAP0178 Tyran B1 Ophthalmia Range PC032	EU559505 Paraliochthonius sp. JM-2008	EXR1148 J20-6 Lagy S4 Hancock Range North PC039	G118 Tyrannochthonius Hamersley Range PC021	G328 LN9199 Tyrannochthonius sp Ophthalmia Range PC029	G428 110726 Chthoniidae sp PC031	G429 110960 Chthoniidae sp PC021	G430 100975 Tyrannochthonius sp PC030	GF0173R Lag B2 Jirrpalpur Range PC040	IS01 PC001	IS05 PC005	IS06 PC004	IS08 PC003	IS10 PC006	IS11 PC007	IS12 PC002	IV203 DD14MRR0004T1-04 PC011	IV210 MEARC3814-20150606-02sc PC012	IV212 DD14MEL0001-20151001-T2-02 PC009	IV226 RC14MRR0020-20151002-T2-01 PC010	IV261 GR15MEB0022-20160115-sc-01 Gp 5 PC047	IV268 RC15MEB0171-20160317-T2-02 Gp 1 PC049	IV269 RC15MEB0171-20160317-T3-01 Gp 2 PC050	IV278 127104 Pseudoscopiones Gp 3 PC051	IV279 127105 Pseudoscopiones Gp 4 PC048	JIN0078R BHP772 Lagynochthonius Hancock Range South PC041	JU07 RC15MEH0335.20160627.T1-01 PC015	JU08 GR15MEH0015.20160627.T2-03 PCO14	JV08 DD15BS40010-20160608-T2-02 PC046	KJ659959 Tyrannochthonius aridus
LI31 RC16MEC0177-20170309-02		0.014	0.014	0.015	0.015	0.016	0.017	0.008	0.009	0.008	0.015	0.015	0.016	0.024	0.025	0.021	0.024	0.021	0.017	0.016	0.014	0.016	0.024	0.018	0.019	0.021	0.019	0.022	0.019	0.018	0.020	0.019	0.021	0.020	0.009	0.016	0.016	0.016	0.015	0.025	0.016	0.014	0.019	0.020
LI34 RC16MEK0002-20170321-T2-1	0.201		0.000	0.013	0.016	0.017	0.015	0.015	0.015	0.015	0.015	0.014	0.016	0.022	0.024	0.016	0.022	0.024	0.018	0.016	0.016	0.016	0.025	0.018	0.019	0.020	0.020	0.019	0.019	0.019	0.021	0.019	0.013	0.014	0.015	0.017	0.016	0.016	0.015	0.024	0.013	0.013	0.018	0.019
LI35 RC16MEK0002-20170321-T3-1	0.202	0.000		0.013	0.016	0.017	0.015	0.016	0.015	0.016	0.015	0.014	0.016	0.022	0.024	0.016	0.022	0.024	0.018	0.016	0.016	0.016	0.025	0.018	0.019	0.020	0.020	0.019	0.019	0.019	0.021	0.019	0.013	0.014	0.015	0.017	0.016	0.016	0.015	0.024	0.013	0.013	0.018	0.019
KD24 GR15MEB0014.20160915.T2-01	0.207	0.102	0.102		0.016	0.016	0.015	0.015	0.015	0.015	0.016	0.014	0.016	0.024	0.022	0.017	0.023	0.024	0.020	0.017	0.016	0.016	0.024	0.018	0.017	0.020	0.019	0.020	0.019	0.018	0.021	0.018	0.015	0.017	0.015	0.015	0.014	0.025	0.014	0.013	0.019	0.019
KD25 RC15MEC0096.20160915.T2-01	0.238	0.201	0.202	0.191		0.003	0.015	0.015	0.015	0.015	0.016	0.016	0.017	0.022	0.025	0.020	0.023	0.024	0.017	0.018	0.016	0.018	0.025	0.017	0.013	0.015	0.016	0.021	0.019	0.019	0.018	0.018	0.019	0.021	0.015	0.017	0.015	0.016	0.015	0.024	0.016	0.014	0.018	0.022
KD26 RC16MEC0005.20160915.T1-01	0.241	0.206	0.206	0.196	0.004		0.016	0.016	0.015	0.016	0.015	0.016	0.017	0.022	0.025	0.020	0.023	0.024	0.018	0.018	0.016	0.019	0.024	0.017	0.014	0.015	0.016	0.021	0.020	0.019	0.017	0.018	0.020	0.022	0.015	0.017	0.015	0.016	0.015	0.023	0.016	0.015	0.018	0.023
KD27 GR15MEB0022.20160915.T3-02	0.205	0.201	0.201	0.189	0.201	0.204		0.017	0.017	0.017	0.016	0.015	0.016	0.021	0.024	0.020	0.022	0.024	0.020	0.016	0.015	0.017	0.025	0.019	0.017	0.017	0.018	0.021	0.017	0.018	0.019	0.013	0.020	0.021	0.017	0.013	0.010	0.016	0.016	0.024	0.014	0.014	0.021	0.021
KD66 GR15MEB0022-20160727-SC-01	0.061	0.209	0.209	0.197	0.232	0.235	0.202		0.001	0.000	0.016	0.015	0.015	0.025	0.025	0.020	0.024	0.022	0.016	0.016	0.015	0.016	0.024	0.018	0.019	0.020	0.018	0.020	0.019	0.017	0.019	0.020	0.020	0.020	0.002	0.017	0.015	0.016	0.015	0.026	0.016	0.014	0.019	0.020
KD67 GR15MEB0022-20160727-SC-02	0.063	0.207	0.208	0.199	0.231	0.234	0.201	0.001		0.001	0.015	0.015	0.015	0.025	0.025	0.020	0.024	0.022	0.016	0.016	0.015	0.016	0.024	0.017	0.019	0.020	0.018	0.020	0.019	0.017	0.019	0.020	0.019	0.021	0.002	0.017	0.016	0.017	0.015	0.026	0.015	0.014	0.019	0.020
KD69 GR15MEB0022-20160727-SC-04	0.061	0.209	0.209	0.197	0.232	0.235	0.202	0.000	0.001		0.016	0.015	0.015	0.025	0.025	0.020	0.024	0.022	0.016	0.016	0.015	0.016	0.024	0.018	0.019	0.020	0.018	0.020	0.019	0.017	0.019	0.020	0.020	0.020	0.002	0.017	0.015	0.016	0.015	0.026	0.016	0.014	0.019	0.020
AX83 10DDH033P1T1-2 PC042	0.193	0.181	0.182	0.192	0.209	0.206	0.194	0.206	0.205	0.206		0.015	0.016	0.021	0.024	0.017	0.021	0.026	0.020	0.015	0.017	0.016	0.023	0.018	0.021	0.020	0.018	0.021	0.019	0.019	0.021	0.022	0.019	0.021	0.015	0.017	0.016	0.016	0.018	0.025	0.015	0.014	0.020	0.021
AX85 ID32P1T1-7 PC045	0.190	0.191	0.192	0.186	0.219	0.219	0.178	0.189	0.190	0.189	0.180		0.016	0.023	0.024	0.017	0.023	0.025	0.019	0.016	0.018	0.015	0.023	0.020	0.018	0.019	0.019	0.020	0.016	0.019	0.019	0.020	0.019	0.018	0.015	0.016	0.016	0.015	0.015	0.023	0.015	0.014	0.019	0.017
CP3 RC10KOOD0049T2-4 Schizomida CP008	0.193	0.206	0.206	0.207	0.238	0.239	0.213	0.190	0.191	0.190	0.199	0.184		0.021	0.023	0.019	0.022	0.025	0.020	0.018	0.017	0.015	0.020	0.020	0.020	0.021	0.021	0.021	0.020	0.018	0.021	0.021	0.021	0.021	0.015	0.016	0.016	0.016	0.015	0.020	0.016	0.015	0.022	0.021
EA0270R Lag B2 Ophthalmia Range PC033	0.241	0.232	0.232	0.253	0.244	0.244	0.244	0.259	0.259	0.259	0.220	0.232	0.223		0.024	0.021	0.024	0.023	0.021	0.025	0.023	0.022	0.023	0.024	0.022	0.023	0.025	0.024	0.021	0.023	0.019	0.022	0.022	0.025	0.025	0.022	0.022	0.024	0.022	0.020	0.021	0.022	0.022	0.020
EAP0178 Tyran B1 Ophthalmia Range PC032	0.253	0.215	0.215	0.194	0.250	0.250	0.256	0.262	0.262	0.262	0.250	0.256	0.265	0.274		0.022	0.026	0.021	0.023	0.028	0.021	0.025	0.026	0.022	0.024	0.025	0.021	0.027	0.025	0.021	0.024	0.025	0.024	0.025	0.025	0.026	0.025	0.022	0.022	0.025	0.023	0.022	0.024	0.023
EU559505 Paraliochthonius sp. JM-2008	0.197	0.197	0.197	0.215	0.223	0.223	0.177	0.197	0.195	0.197	0.199	0.140	0.188	0.204	0.264		0.021	0.023	0.018	0.019	0.020	0.021	0.021	0.019	0.019	0.019	0.019	0.020	0.016	0.019	0.017	0.021	0.017	0.021	0.020	0.021	0.020	0.019	0.019	0.023	0.017	0.018	0.019	0.018
EXR1148 J20-6 Lagy S4 Hancock Range North PC039	0.219	0.219	0.219	0.222	0.243	0.243	0.231	0.237	0.237	0.237	0.225	0.189	0.192	0.231	0.267	0.206		0.023	0.022	0.022	0.022	0.025	0.025	0.025	0.023	0.024	0.025	0.024	0.021	0.024	0.024	0.021	0.023	0.023	0.024	0.023	0.024	0.023	0.024	0.023	0.023	0.024	0.025	0.023
G118 Tyrannochthonius Hamersley Range PC021	0.202	0.276	0.276	0.267	0.273	0.276	0.238	0.208	0.208	0.208	0.243	0.240	0.255	0.277	0.247	0.234	0.219		0.023	0.021	0.006	0.021	0.026	0.022	0.025	0.023	0.024	0.027	0.024	0.023	0.023	0.025	0.026	0.026	0.022	0.023	0.026	0.023	0.024	0.028	0.024	0.024	0.024	0.026
G328 LN9199 Tyrannochthonius sp Ophthalmia Range PC029	0.172	0.187	0.187	0.187	0.199	0.199	0.198	0.178	0.178	0.178	0.199	0.176	0.170	0.202	0.226	0.188	0.178	0.217		0.022	0.020	0.020	0.022	0.019	0.018	0.020	0.020	0.020	0.019	0.017	0.021	0.021	0.020	0.020	0.017	0.021	0.020	0.019	0.018	0.021	0.020	0.019	0.020	0.021
G428 110726 Chthoniidae sp PC031	0.210	0.216	0.217	0.208	0.231	0.228	0.211	0.203	0.205	0.203	0.223	0.199	0.235	0.262	0.279	0.201	0.219	0.150	0.227		0.014	0.014	0.026	0.022	0.021	0.021	0.019	0.019	0.020	0.021	0.021	0.018	0.022	0.021	0.015	0.016	0.016	0.016	0.015	0.029	0.016	0.016	0.019	0.021
G429 110960 Chthoniidae sp PC021	0.204	0.230	0.231	0.224	0.237	0.240	0.213	0.203	0.202	0.203	0.220	0.210	0.241	0.271	0.250	0.212	0.207	0.012	0.195	0.125		0.014	0.027	0.019	0.021	0.020	0.021	0.022	0.021	0.020	0.021	0.021	0.023	0.022	0.015	0.016	0.016	0.016	0.015	0.028	0.016	0.015	0.022	0.023
G430 100975 Tyrannochthonius sp PC030	0.177	0.213	0.213	0.208	0.233	0.234	0.186	0.188	0.189	0.188	0.203	0.169	0.192	0.217	0.276	0.199	0.222	0.199	0.199	0.169	0.172		0.024	0.020	0.019	0.020	0.021	0.019	0.019	0.020	0.021	0.018	0.021	0.020	0.016	0.016	0.014	0.017	0.016	0.024	0.015	0.014	0.021	0.021
GF0173R Lag B2 Jirrpalpur Range PC040	0.217	0.235	0.235	0.226	0.261	0.258	0.235	0.229	0.229	0.229	0.246	0.223	0.185	0.238	0.265	0.210	0.189	0.235	0.155	0.261	0.238	0.205		0.024	0.024	0.025	0.026	0.024	0.021	0.023	0.022	0.024	0.026	0.025	0.024	0.024	0.025	0.024	0.023	0.018	0.017	0.024	0.025	0.024	0.023
IS01 PC001	0.222	0.196	0.196	0.184	0.140	0.140	0.229	0.231	0.229	0.231	0.212	0.238	0.240	0.259	0.206	0.227	0.240	0.258	0.199	0.234	0.241	0.256	0.258		0.017	0.016	0.014	0.020	0.020	0.011	0.020	0.018	0.018	0.019	0.018	0.020	0.018	0.018	0.019	0.024	0.017	0.018	0.018	0.020
IS05 PC005	0.233	0.196	0.196	0.169	0.107	0.107	0.204	0.247	0.249	0.247	0.220	0.214	0.222	0.274	0.224	0.221	0.246	0.296	0.215	0.232	0.258	0.238	0.264	0.167		0.014	0.018	0.021	0.018	0.016	0.019	0.018	0.020	0.020	0.019	0.020	0.017	0.018	0.020	0.022	0.018	0.018	0.019	0.021
IS06 PC004	0.231	0.204	0.204	0.202	0.138	0.138	0.196	0.244	0.242	0.244	0.216	0.220	0.224	0.256	0.238	0.203	0.249	0.282	0.199	0.216	0.247	0.236	0.273	0.149	0.116		0.016	0.021	0.020	0.016	0.021	0.018	0.020	0.021	0.020	0.020	0.018	0.021	0.021	0.025	0.018	0.019	0.017	0.021
IS08 PC003	0.222	0.207	0.207	0.184	0.129	0.129	0.227	0.224	0.222	0.224	0.229	0.243	0.240	0.268	0.221	0.232	0.246	0.276	0.224	0.232	0.252	0.252	0.267	0.093	0.149	0.136		0.019	0.019	0.015	0.020	0.019	0.019	0.019	0.018	0.021	0.021	0.018	0.018	0.025	0.017	0.018	0.017	0.020
IS10 PC006	0.211	0.227	0.227	0.242	0.220	0.222	0.204	0.200	0.198	0.200	0.223	0.174	0.224	0.253	0.268	0.191	0.228	0.252	0.217	0.223	0.236	0.207	0.238	0.227	0.231	0.258	0.222		0.016	0.020	0.019	0.021	0.019	0.018	0.021	0.022	0.021	0.019	0.017	0.023	0.018	0.020	0.020	0.020
IS11 PC007	0.180	0.189	0.189	0.198	0.200	0.200	0.169	0.191	0.189	0.191	0.189	0.158	0.189	0.241	0.294	0.178	0.225	0.270	0.192	0.234	0.245	0.178	0.194	0.229	0.209	0.227	0.222	0.176		0.020	0.016	0.018	0.019	0.018	0.019	0.018	0.019	0.018	0.017	0.018	0.019	0.019	0.020	0.019
IS12 PC002	0.222	0.198	0.198	0.178	0.149	0.149	0.231	0.220	0.222	0.220	0.225	0.238	0.222	0.250	0.197	0.218	0.240	0.261	0.192	0.243	0.243	0.241	0.249	0.053	0.147	0.147	0.091	0.236	0.233		0.019	0.018	0.019	0.018	0.017	0.021	0.017	0.019	0.017	0.023	0.017	0.018	0.018	0.020
IV203 DD14MRR0004T1-04 PC011	0.184	0.200	0.200	0.222	0.207	0.202	0.158	0.191	0.189	0.191	0.189	0.169	0.182	0.208	0.253	0.167	0.216	0.220	0.180	0.194	0.209	0.194	0.208	0.204	0.236	0.193	0.216	0.200	0.144	0.204		0.018	0.020	0.022	0.019	0.019	0.018	0.018	0.017	0.022	0.018	0.019	0.021	0.019
IV210 MEARC3814-20150606-02sc PC012	0.198	0.218	0.218	0.213	0.196	0.198	0.096	0.207	0.209	0.207	0.212	0.189	0.218	0.235	0.250	0.205	0.207	0.246	0.194	0.198	0.227	0.189	0.235	0.198	0.222	0.216	0.207	0.193	0.187	0.204	0.156		0.020	0.020	0.021	0.014	0.014	0.016	0.017	0.024	0.015	0.016	0.021	0.020
IV212 DD14MEL0001-20151001-T2-02 PC009	0.222	0.076	0.076	0.104	0.202	0.207	0.218	0.236	0.233	0.236	0.194	0.220	0.218	0.253	0.218	0.221	0.234	0.279	0.203	0.247	0.256	0.238	0.255	0.187	0.204	0.187	0.189	0.240	0.193	0.196	0.204	0.218		0.016	0.020	0.020	0.020	0.020	0.019	0.024	0.019	0.019	0.018	0.019
IV226 RC14MRR0020-20151002-T2-01 PC010	0.216	0.102	0.102	0.144	0.198	0.202	0.231	0.229	0.231	0.229	0.194	0.214	0.218	0.256	0.221	0.223	0.234	0.287	0.208	0.238	0.256	0.234	0.249	0.207	0.202	0.189	0.216	0.238	0.193	0.202	0.207	0.238	0.111		0.021	0.021	0.019	0.019	0.021	0.024	0.019	0.018	0.019	0.019
IV261 GR15MEB0022-20160115-sc-01 Gp 5 PC047	0.061	0.209	0.209	0.202	0.228	0.231	0.199	0.004	0.003	0.004	0.202	0.187	0.189	0.259	0.262	0.192	0.237	0.208	0.181	0.202	0.199	0.186	0.229	0.225	0.245	0.238	0.218	0.194	0.185	0.218	0.185	0.205	0.229	0.227		0.017	0.016	0.016	0.015	0.026	0.015	0.014	0.019	0.020
IV268 RC15MEB0171-20160317-T2-02 Gp 1 PC049	0.205	0.215	0.215	0.205	0.219	0.219	0.111	0.216	0.215	0.216	0.205	0.187	0.232	0.232	0.256	0.194	0.237	0.243	0.215	0.218	0.228	0.198	0.243	0.220	0.218	0.212	0.225	0.203	0.180	0.232	0.180	0.111	0.216	0.234	0.212		0.014	0.015	0.016	0.024	0.013	0.013	0.022	0.020
IV269 RC15MEB0171-20160317-T3-01 Gp 2 PC050	0.190	0.202	0.202	0.187	0.202	0.205	0.075	0.187	0.189	0.187	0.200	0.177	0.201	0.232	0.250	0.203	0.228	0.246	0.199	0.211	0.208	0.172	0.235	0.209	0.212	0.220	0.236	0.205	0.194	0.214	0.158	0.085	0.216	0.227	0.186	0.117		0.016	0.016	0.024	0.014	0.013	0.020	0.021
IV278 127104 Pseudoscopiones Gp 3 PC051	0.190	0.199	0.199	0.192	0.228	0.230	0.158	0.195	0.196	0.195	0.196	0.179	0.213	0.235	0.256	0.201	0.207	0.235	0.190	0.212	0.223	0.202	0.214	0.218	0.227	0.227	0.216	0.187	0.156	0.223	0.125	0.143	0.212	0.209	0.193	0.165	0.154		0.012	0.025	0.013	0.012	0.021	0.019
IV279 127105 Pseudoscopiones Gp 4 PC048	0.185	0.204	0.204	0.201	0.220	0.222	0.166	0.182	0.181	0.182	0.203	0.185	0.195	0.238	0.259	0.172	0.225	0.235	0.183	0.210	0.211	0.203	0.185	0.214	0.225	0.218	0.216	0.192	0.151	0.212	0.122	0.163	0.209	0.212	0.178	0.175	0.175	0.104		0.021	0.015	0.013	0.020	0.020
JIN0078R BHP772 Lagynochthonius Hancock Range South PC041	0.264	0.252	0.252	0.261	0.270	0.267	0.223	0.267	0.267	0.267	0.232	0.229	0.208	0.232	0.315	0.207	0.192	0.282	0.191	0.282	0.282	0.226	0.147	0.287	0.284	0.284	0.305	0.243	0.196	0.282	0.185	0.246	0.261	0.252	0.267	0.235	0.229	0.217	0.211		0.025	0.026	0.025	0.021
JU07 RC15MEH0335.20160627.T1-01 PC015	0.183	0.199	0.199	0.191	0.212	0.213	0.157	0.186	0.184	0.186	0.191	0.172	0.210	0.241	0.253	0.173	0.213	0.261	0.176	0.209	0.231	0.172	0.240	0.198	0.218	0.202	0.204	0.187	0.191	0.189	0.158	0.133	0.204	0.229	0.181	0.162	0.157	0.157	0.160	0.243		0.007	0.019	0.017
JU08 GR15MEH0015.20160627.T2-03 PCO14	0.172	0.193	0.193	0.181	0.201	0.204	0.149	0.178	0.177	0.178	0.189	0.178	0.211	0.244	0.253	0.178	0.222	0.261	0.178	0.206	0.224	0.175	0.249	0.200	0.222	0.211	0.207	0.191	0.198	0.196	0.164	0.136	0.211	0.224	0.174	0.159	0.146	0.148	0.154	0.246	0.029		0.020	0.017
JV08 DD15BS40010-20160608-T2-02 PC046	0.211	0.171	0.171	0.187	0.160	0.160	0.200	0.220	0.222	0.220	0.194	0.205	0.213	0.256	0.250	0.212	0.249	0.284	0.201	0.216	0.256	0.238	0.264	0.162	0.162	0.164	0.167	0.218	0.200	0.164	0.189	0.204	0.187	0.184	0.218	0.194	0.187	0.189	0.185	0.279	0.173	0.184		0.019
KJ659959 Tyrannochthonius aridus	0.191	0.157	0.157	0.179	0.216	0.216	0.211	0.211	0.213	0.211	0.189	0.191	0.189	0.214	0.235	0.191	0.237	0.258	0.194	0.238	0.252	0.199	0.232	0.201	0.218	0.216	0.211	0.235	0.181	0.199	0.184	0.208	0.169	0.184	0.213	0.203	0.196	0.191	0.191	0.243	0.186	0.194	0.172	

1. Tamura K., Stecher G., Peterson D., Filipski A., and Kumar S. (2013). MEGA6: Molecular Evolutionary Genetics Analysis version 6.0. Molecular Biology and Evolution30: 2725-2729.

The number of base differences per site from between sequences are shown. Standard error estimate(s) are shown above the diagonal. The analysis involved 42 nucleotide sequences. Codon positions included were 1st+2nd+3rd+Noncoding. All ambiguous positions were removed for each sequence pair. There were a total of 495 positions in the final dataset.
Evolutionary analyses were conducted in MEGA6 [1].

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Table 14. Estimates of Evolutionary Divergence between Sequences

Specimen ID	LI32 RC16MEC0102-170308-2 Schizomida	LI38 RC16MEA004-20170322-T1-3 Schizomida	LI39 RC16MEA004-20170322-T1-4 Schizomida	C119 ex T95543 SCH018	C37 T92541B SCH016	C58 T98320 SCH017	GH7 Draculoides Dra-PES16433 SCH026	GH8 Draculoides Dra-PES16447 SCH027	HE17 BHRC151-20141216-T3-01c SCH028	HE4 BHRC001-20141028-SC01 SCH029	IS15 KBRC1389 20150909 04 SCH032	IS33 Kbrc116720150809t2 05 SCH031	IT67 BHRC401-151013-T1-01 SCH033	IV07 Budgie20150604-06 SCH002	IV09 DD14MEL0001-t2-01 SCH004a	IV289 110827 SCH001	IV293 140982 SCH034	IV295 133446 SCH036	IV61 DD14MEC0002-20150929-T3-03 SCH001	IV76 MELUNK11-20151001-T2-01 SCH004	IV82 TOBRC0023-20151001-T1-01 SCH003	KD29 GR15MEC0018.20160915.T1-01 Schizomida	KD31 RC15MEB0216.20160915.T3-01 Schizomida	KD36 GR15MEB0009.20160915.T2-01 Schizomida	Panachoretus WAM T66236 Paradraculoides	Pbythius WAM T63344 Paradraculoides byth	Pgnophicola WAM T63371 3 Paradraculoides	Pkryptus WAM T65802 Paradraculoides kryp	Psp OFB 2007 Paradraculoides sp. OFB-200	T93233 C17 CBRC099P5T1-3 Paradraculoides sp cardo
LI32 RC16MEC0102-170308-2 Schizomida		0.010	0.012	0.012	0.015	0.013	0.015	0.014	0.013	0.016	0.014	0.014	0.014	0.009	0.014	0.003	0.011	0.012	0.000	0.013	0.012	0.003	0.003	0.002	0.013	0.002	0.013	0.014	0.011	0.015
LI38 RC16MEA004-20170322-T1-3 Schizomida	0.082		0.008	0.013	0.016	0.016	0.015	0.013	0.014	0.017	0.016	0.015	0.015	0.011	0.013	0.012	0.000	0.010	0.012	0.014	0.011	0.012	0.012	0.011	0.010	0.012	0.013	0.013	0.011	0.015
LI39 RC16MEA004-20170322-T1-4 Schizomida	0.094	0.056		0.014	0.015	0.016	0.015	0.014	0.014	0.017	0.016	0.015	0.013	0.011	0.013	0.014	0.009	0.003	0.013	0.014	0.012	0.014	0.014	0.013	0.004	0.014	0.014	0.014	0.012	0.014
C119 ex T95543 SCH018	0.137	0.149	0.154		0.015	0.015	0.014	0.012	0.013	0.013	0.014	0.013	0.013	0.012	0.014	0.012	0.012	0.013	0.012	0.014	0.013	0.012	0.012	0.012	0.013	0.012	0.014	0.013	0.013	0.016
C37 T92541B SCH016	0.144	0.140	0.144	0.156		0.013	0.014	0.013	0.013	0.013	0.014	0.012	0.015	0.014	0.013	0.015	0.014	0.013	0.015	0.013	0.013	0.014	0.014	0.014	0.013	0.014	0.014	0.014	0.012	0.015
C58 T98320 SCH017	0.105	0.133	0.144	0.141	0.120		0.014	0.015	0.012	0.013	0.013	0.012	0.014	0.014	0.014	0.014	0.015	0.016	0.013	0.016	0.013	0.013	0.013	0.013	0.016	0.013	0.013	0.013	0.013	0.014
GH7 Draculoides Dra-PES16433 SCH026	0.146	0.137	0.139	0.135	0.138	0.133		0.007	0.013	0.014	0.016	0.015	0.014	0.014	0.015	0.015	0.013	0.013	0.015	0.016	0.014	0.016	0.015	0.015	0.013	0.015	0.014	0.016	0.015	0.014
GH8 Draculoides Dra-PES16447 SCH027	0.146	0.126	0.124	0.119	0.141	0.130	0.038		0.014	0.014	0.015	0.014	0.013	0.013	0.013	0.014	0.012	0.014	0.014	0.014	0.013	0.015	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.015
HE17 BHRC151-20141216-T3-01c SCH028	0.126	0.140	0.137	0.148	0.115	0.118	0.137	0.137		0.014	0.013	0.013	0.012	0.012	0.013	0.014	0.013	0.014	0.013	0.013	0.012	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.013	0.015
HE4 BHRC001-20141028-SC01 SCH029	0.137	0.145	0.149	0.144	0.121	0.118	0.145	0.145	0.115		0.013	0.012	0.012	0.016	0.015	0.016	0.016	0.015	0.016	0.014	0.014	0.016	0.016	0.016	0.014	0.015	0.015	0.014	0.015	0.015
IS15 KBRC1389 20150909 04 SCH032	0.124	0.135	0.139	0.138	0.135	0.109	0.152	0.144	0.124	0.124		0.012	0.012	0.013	0.013	0.014	0.015	0.015	0.014	0.013	0.012	0.014	0.013	0.014	0.015	0.014	0.012	0.014	0.013	0.014
IS33 Kbrc116720150809t2 05 SCH031	0.121	0.128	0.125	0.124	0.114	0.108	0.138	0.122	0.104	0.099	0.100		0.013	0.013	0.013	0.015	0.013	0.014	0.014	0.013	0.014	0.014	0.014	0.013	0.014	0.014	0.014	0.013	0.014	0.015
IT67 BHRC401-151013-T1-01 SCH033	0.116	0.131	0.117	0.130	0.132	0.113	0.139	0.127	0.115	0.110	0.099	0.105		0.014	0.013	0.015	0.013	0.012	0.014	0.013	0.013	0.014	0.015	0.014	0.013	0.015	0.014	0.014	0.012	0.015
IV07 Budgie20150604-06 SCH002	0.069	0.070	0.078	0.130	0.127	0.119	0.131	0.121	0.129	0.138	0.122	0.124	0.114		0.011	0.009	0.011	0.011	0.009	0.012	0.009	0.009	0.009	0.009	0.011	0.009	0.010	0.012	0.010	0.013
IV09 DD14MEL0001-t2-01 SCH004a	0.117	0.105	0.114	0.143	0.127	0.130	0.139	0.136	0.124	0.143	0.127	0.130	0.121	0.108		0.015	0.012	0.013	0.014	0.008	0.012	0.014	0.015	0.014	0.014	0.014	0.012	0.012	0.012	0.015
IV289 110827 SCH001	0.008	0.084	0.105	0.132	0.146	0.108	0.146	0.142	0.129	0.137	0.131	0.122	0.121	0.070	0.122		0.011	0.012	0.003	0.014	0.012	0.003	0.000	0.003	0.013	0.003	0.014	0.014	0.012	0.015
IV293 140982 SCH034	0.086	0.000	0.058	0.141	0.133	0.127	0.136	0.125	0.137	0.143	0.131	0.125	0.125	0.074	0.102	0.085		0.009	0.011	0.012	0.011	0.011	0.011	0.011	0.009	0.011	0.012	0.012	0.010	0.015
IV295 133446 SCH036	0.108	0.060	0.010	0.144	0.139	0.142	0.138	0.128	0.135	0.143	0.135	0.128	0.114	0.078	0.116	0.110	0.056		0.012	0.014	0.011	0.012	0.012	0.012	0.003	0.012	0.014	0.013	0.011	0.014
IV61 DD14MEC0002-20150929-T3-03 SCH001	0.000	0.086	0.104	0.137	0.144	0.105	0.146	0.146	0.126	0.137	0.124	0.121	0.116	0.069	0.117	0.008	0.086	0.108		0.013	0.012	0.003	0.003	0.002	0.013	0.002	0.013	0.014	0.011	0.015
IV76 MELUNK11-20151001-T2-01 SCH004	0.102	0.109	0.120	0.130	0.129	0.132	0.139	0.130	0.127	0.134	0.122	0.121	0.111	0.111	0.034	0.103	0.105	0.119	0.102		0.012	0.014	0.014	0.013	0.014	0.014	0.013	0.011	0.011	0.015
IV82 TOBRC0023-20151001-T1-01 SCH003	0.081	0.077	0.088	0.146	0.133	0.119	0.136	0.135	0.123	0.129	0.124	0.119	0.116	0.063	0.110	0.086	0.080	0.088	0.081	0.107		0.012	0.012	0.012	0.012	0.012	0.009	0.012	0.008	0.013
KD29 GR15MEC0018.20160915.T1-01 Schizomida	0.005	0.088	0.105	0.138	0.139	0.103	0.150	0.147	0.131	0.138	0.121	0.117	0.121	0.070	0.122	0.009	0.088	0.110	0.005	0.107	0.086		0.003	0.003	0.013	0.002	0.013	0.014	0.011	0.015
KD31 RC15MEB0216.20160915.T3-01 Schizomida	0.008	0.084	0.105	0.132	0.141	0.106	0.146	0.142	0.129	0.137	0.129	0.118	0.121	0.070	0.122	0.000	0.085	0.110	0.008	0.103	0.086	0.010		0.003	0.013	0.003	0.014	0.014	0.012	0.015
KD36 GR15MEB0009.20160915.T2-01 Schizomida	0.003	0.082	0.100	0.133	0.138	0.105	0.146	0.142	0.126	0.137	0.126	0.118	0.119	0.066	0.117	0.005	0.083	0.105	0.003	0.102	0.081	0.007	0.006		0.013	0.001	0.013	0.013	0.011	0.015
Panachoretus WAM T66236 Paradraculoides	0.113	0.063	0.010	0.150	0.142	0.150	0.140	0.132	0.141	0.147	0.142	0.129	0.121	0.085	0.121	0.115	0.063	0.005	0.113	0.124	0.095	0.115	0.115	0.110		0.013	0.014	0.014	0.011	0.015
Pbythius WAM T63344 Paradraculoides byth	0.002	0.087	0.105	0.137	0.140	0.108	0.148	0.147	0.128	0.137	0.127	0.118	0.119	0.069	0.119	0.006	0.087	0.110	0.002	0.103	0.085	0.003	0.006	0.002	0.111		0.013	0.013	0.011	0.015
Pgnophicola WAM T63371 3 Paradraculoides	0.100	0.108	0.113	0.134	0.116	0.118	0.152	0.139	0.123	0.131	0.121	0.111	0.116	0.087	0.095	0.105	0.102	0.116	0.100	0.090	0.076	0.105	0.105	0.103	0.121	0.102		0.012	0.010	0.014
Pkryptus WAM T65802 Paradraculoides kryp	0.110	0.088	0.113	0.148	0.123	0.123	0.142	0.132	0.111	0.132	0.127	0.111	0.108	0.102	0.100	0.111	0.087	0.113	0.110	0.095	0.111	0.111	0.111	0.106	0.118	0.108	0.092		0.011	0.015
Psp OFB 2007 Paradraculoides sp. OFB-200	0.089	0.081	0.084	0.147	0.119	0.121	0.145	0.145	0.121	0.132	0.126	0.121	0.111	0.074	0.103	0.094	0.084	0.089	0.089	0.097	0.039	0.094	0.094	0.089	0.094	0.090	0.084	0.098		0.013
T93233 C17 CBRC099P5T1-3 Paradraculoides sp cardo	0.123	0.119	0.119	0.161	0.130	0.106	0.139	0.125	0.121	0.135	0.116	0.114	0.105	0.117	0.126	0.132	0.119	0.119	0.123	0.134	0.125	0.128	0.132	0.126	0.119	0.123	0.115	0.112	0.114	

1. Tamura K., Stecher G., Peterson D., Filipski A., and Kumar S. (2013). MEGA6: Molecular Evolutionary Genetics Analysis version 6.0. Molecular Biology and Evolution30: 2725-2729.

The number of base differences per site from between sequences are shown. Standard error estimate(s) are shown above the diagonal. The analysis involved 42 nucleotide sequences. Codon positions included were 1st+2nd+3rd+Noncoding. All ambiguous positions were removed for each sequence pair. There were a total of 495 positions in the final dataset. Evolutionary analyses were conducted in MEGA6 [1].

Disclaimer: Although utmost care has been taken to ensure the correctness of the caption, the caption text is provided "as is" without any warranty of any kind. Authors advise the user to carefully check the caption prior to its use for any purpose and report any errors or problems to the authors immediately (www.megasoftware.net). In no event shall the authors and their employers be liable for any damages, including but not limited to special, consequential, or other damages. Authors specifically disclaim all other warranties expressed or implied, including but not limited to the determination of suitability of this caption text for a specific purpose, use, or application.

Appendix 3

Desktop Analysis Results and Study Comparisons

Area	Order	Family	Species Names	Number	Identification Method	Drillhole	Date	Species Status / Notes
Mesa A	Araneae	Oonopidae	*Prethopalpus scanloni*	1	Morphological	MEARC4279	2016	
Mesa A	Araneae	Pholcidae	*Trichocyclus* sp. 'Mesa A'	1	Morphological	MEADC2493	2005	
Mesa A	Araneae	Indeterminate	Araneae sp. 'indet'	1	Morphological	MEADC2517A	2005	
Mesa A	Araneae	Indeterminate	Araneae sp. 'indet'	1	Morphological	MEARC4283	2012	
Mesa A	Araneae	Indeterminate	Araneae sp. 'indet'	1	Morphological	MEARC4305	2012	
Mesa A	Pseudoscorpiones	Chthoniidae	Chthoniidae sp. 'indet'	1	Morphological	MEARC4279	2012	
Mesa A	Pseudoscorpiones	Chthoniidae	*Lagynochthonius asema*	1	Morphological	MEA4026	2007	Conservation Significant, Listed as Priority 1 in WA
Mesa A	Pseudoscorpiones	Chthoniidae	*Lagynochthonius asema*	1	Morphological	MEA4306	2007	Conservation Significant, Listed as Priority 1 in WA
Mesa A	Pseudoscorpiones	Chthoniidae	*Lagynochthonius asema*	1	Morphological	MEARC4278	2014	Conservation Significant, Listed as Priority 1 in WA
Mesa A	Pseudoscorpiones	Chthoniidae	*Lagynochthonius asema*	2	Morphological	MEARC4284	2014	Conservation Significant, Listed as Priority 1 in WA
Mesa A	Pseudoscorpiones	Chthoniidae	*Lagynochthonius asema*	1	Morphological	MEARC4287	2016	Conservation Significant, Listed as Priority 1 in WA
Mesa A	Pseudoscorpiones	Chthoniidae	*Lagynochthonius asema*	1	Morphological	MEARC4292	2012	Conservation Significant, Listed as Priority 1 in WA
Mesa A	Pseudoscorpiones	Chthoniidae	*Lagynochthonius asema*	1	Morphological	MEARC4296	2014	Conservation Significant, Listed as Priority 1 in WA
Mesa A	Pseudoscorpiones	Chthoniidae	*Tyrannochthonius aridus*	1	Morphological	MEARC4296	2006	
Mesa A	Pseudoscorpiones	Chthoniidae	*Tyrannochthonius* sp. 'indet'	1	Morphological	MEARC4047	2005	
Mesa A	Pseudoscorpiones	Chthoniidae	*Tyrannochthonius* sp. 'Mesa A'	1	Morphological	MEA4476	2007	Conservation Significant, Listed as Priority 1 in WA
Mesa A	Pseudoscorpiones	Syarinidae	*Ideoblothrus linnaei*	1	Morphological	MEA4316	2007	Conservation Significant, Listed as Priority 1 in WA
Mesa A	Pseudoscorpiones	Syarinidae	*Ideoblothrus linnaei*	1	Morphological	MEARC2927	2014	Conservation Significant, Listed as Priority 1 in WA
Mesa A	Pseudoscorpiones	Syarinidae	*Ideoblothrus linnaei*	1	Morphological	MEARC4018	2014	Conservation Significant, Listed as Priority 1 in WA
Mesa A	Pseudoscorpiones	Syarinidae	*Ideoblothrus linnaei*	1	Morphological	MEARC4281	2014	Conservation Significant, Listed as Priority 1 in WA
Mesa A	Pseudoscorpiones	Syarinidae	Ideoblothrus sp. 'indet'	1	Morphological	MEARC2856	2005	

Area	Order	Family	Species Names	Number	Identification Method	Drillhole	Date	Species Status / Notes
Mesa A	Pseudoscorpiones	Syarinidae	Ideoblothrus sp. 'indet'	1	Morphological	MEARC2927	2012	
Mesa A	Pseudoscorpiones	Syarinidae	Ideoblothrus sp. 'indet'	1	Morphological	MEARC4284	2006	
Mesa A	Pseudoscorpiones	Syarinidae	Ideoblothrus sp. 'indet'	1	Morphological	MEARC4290	2012	
Mesa A	Pseudoscorpiones	Syarinidae	Ideoblothrus sp. 'indet'	1	Morphological	MEARC4291	2012	
Mesa A	Pseudoscorpiones	Syarinidae	*Ideoblothrus* sp. 'Mesa A'	1	Morphological	MEA2988	2007	Conservation Significant, Listed as Priority 1 in WA
Mesa A	Pseudoscorpiones	Syarinidae	*Ideoblothrus* sp. 'Mesa A'	1	Morphological	MEA4063	2007	Conservation Significant, Listed as Priority 1 in WA
Mesa A	Pseudoscorpiones	Syarinidae	*Ideoblothrus* sp. 'Mesa A'	1	Morphological	MEA2856	2005	Conservation Significant, Listed as Priority 1 in WA
Mesa A	Pseudoscorpiones	Syarinidae	*Ideoblothrus* sp. 'Mesa A'	1	Morphological	MEA2988	2007	Conservation Significant, Listed as Priority 1 in WA
Mesa A	Pseudoscorpiones	Syarinidae	*Ideoblothrus* sp. 'Mesa A'	1	Morphological	MEARC4063	2007	Conservation Significant, Listed as Priority 1 in WA
Mesa A	Pseudoscorpiones	Syarinidae	*Ideoblothrus* sp. 'Mesa A'	1	Morphological	MEARC4301	2016	Conservation Significant, Listed as Priority 1 in WA
Mesa A	Pseudoscorpiones	Syarinidae	*Ideoblothrus* sp. 'Mesa A2'	1	Morphological	MEARC4038	2012	
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	A1149	2005	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEA11	2016	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEA2504	2007	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	2	Morphological and Molecular	MEA2827	2007	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEA2828	2007	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEA2927	2007	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	2	Morphological and Molecular	MEA2927	2007	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEA2988	2007	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological	MEA3092	2007	Conservation Significant,

Area	Order	Family	Species Names	Number	Identification Method	Drillhole	Date	Species Status / Notes
					and Molecular			Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEA4026	2007	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEA4026	2007	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEA4027	2007	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	5	Morphological and Molecular	MEA4144	2007	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	2	Morphological and Molecular	MEA4150	2007	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEA4151	2007	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEA4151	2007	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEA4151	2007	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	2	Morphological and Molecular	MEA4155	2007	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEA4284	2007	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEA4284	2007	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	2	Morphological and Molecular	MEA4296	2007	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEA4306	2007	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEA4307	2007	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEADC2492	2005	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEADC2492	2005	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological	MEADC2497	2005	Conservation Significant,

Area	Order	Family	Species Names	Number	Identification Method	Drillhole	Date	Species Status / Notes
					and Molecular			Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEADC2500	2003	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEADC2501	2005	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEADC2501	2005	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEADC2501	2005	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	2	Morphological and Molecular	MEADC2501	2005	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEADC2501	2005	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEADC2501	2005	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEADC2501	2005	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEADC2517A	2005	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEADC2517A	2005	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEADC2517A	2005	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEADC2517A	2005	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEADC2582	2005	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEADC2582	2005	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEADC2582	2005	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEADC3188	2005	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides* sp. 'SCH034'	1	Molecular	MEADC4151	2014	Conservation Significant,

Area	Order	Family	Species Names	Number	Identification Method	Drillhole	Date	Species Status / Notes
								Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEARC2497	2005	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEARC2497	2005	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEARC2582	2005	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	5	Morphological and Molecular	MEARC2611	2005	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEARC2702	2005	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEARC2740	2014	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	2	Morphological and Molecular	MEARC2858	2005	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEARC2934	2005	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEARC3066	2005	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEARC3073	2005	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides* sp. 'SCH034'	1	Molecular	MEARC4018	2014	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEARC4018	2014	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	2	Morphological and Molecular	MEARC4018	2016	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEARC4018	2006	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEARC4018	2006	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEARC4018	2006	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological	MEARC4026	2006	Conservation Significant,

Area	Order	Family	Species Names	Number	Identification Method	Drillhole	Date	Species Status / Notes
					and Molecular			Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEARC4151	2005	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	2	Morphological and Molecular	MEARC4280	2014	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEARC4281	2014	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	2	Morphological and Molecular	MEARC4283	2016	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEARC4284	2014	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEARC4284	2006	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEARC4284	2006	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEARC4290	2014	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEARC4290	2014	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEARC4290	2006	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEARC4290	2006	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	3	Morphological and Molecular	MEARC4291	2012	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	4	Morphological and Molecular	MEARC4291	2012	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEARC4291	2014	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	4	Morphological and Molecular	MEARC4291	2016	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEARC4292	2014	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological	MEARC4293	2012	Conservation Significant,

Area	Order	Family	Species Names	Number	Identification Method	Drillhole	Date	Species Status / Notes
					and Molecular			Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	4	Morphological and Molecular	MEARC4293	2016	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEARC4293	2006	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEARC4294	2016	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEARC4294	2006	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEARC4295	2014	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEARC4295	2014	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	3	Morphological and Molecular	MEARC4296	2014	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEARC4299	2016	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEARC4304	2006	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEARC4304	2006	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	3	Morphological and Molecular	MEARC4305	2016	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	Morphological and Molecular	MEARC4306	2006	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	2	Morphological and Molecular	MEARC4422	2016	Conservation Significant, Listed as Schedule 3 in WA
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides* sp. 'indet'	1	Morphological	MEADC2517a	2012	
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides* sp. 'indet'	4	Morphological	MEADC4151	2016	
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides* sp. 'indet'	1	Morphological	MEARC2740	2012	
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides* sp. 'indet'	3	Morphological	MEARC2740	2012	
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides* sp. 'indet'	2	Morphological	MEARC2927	2012	
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides* sp. 'indet'	2	Morphological	MEARC3042	2005	
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides* sp. 'indet'	1	Morphological	MEARC3042	2005	

Area	Order	Family	Species Names	Number	Identification Method	Drillhole	Date	Species Status / Notes
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides* sp. 'indet'	1	Morphological	MEARC4038	2012	
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides* sp. 'indet'	1	Morphological	MEARC4278	2012	
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides* sp. 'indet'	1	Morphological	MEARC4279	2012	
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides* sp. 'indet'	1	Morphological	MEARC4280	2016	
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides* sp. 'indet'	1	Morphological	MEARC4280	2012	
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides* sp. 'indet'	2	Morphological	MEARC4281	2012	
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides* sp. 'indet'	3	Morphological	MEARC4281	2012	
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides* sp. 'indet'	1	Morphological	MEARC4283	2016	
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides* sp. 'indet'	1	Morphological	MEARC4284	2012	
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides* sp. 'indet'	1	Morphological	MEARC4290	2012	
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides* sp. 'indet'	1	Morphological	MEARC4292	2012	
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides* sp. 'indet'	1	Morphological	MEARC4293	2012	
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides* sp. 'indet'	1	Morphological	MEARC4294	2012	
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides* sp. 'indet'	1	Morphological	MEARC4294	2012	
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides* sp. 'indet'	5	Morphological	MEARC4296	2012	
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides* sp. 'indet'	1	Morphological	MEARC4296	2012	
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides* sp. 'indet'	2	Morphological	MEARC4296	2012	
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides* sp. 'indet'	1	Morphological	MEARC4298	2012	
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides* sp. 'indet'	1	Morphological	MEARC4299	2012	
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides* sp. 'indet'	2	Morphological	MEARC4299	2012	
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides* sp. 'indet'	1	Morphological	MEARC4301	2012	
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides* sp. 'indet'	1	Morphological	MEARC4304	2012	
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides* sp. 'indet'	1	Morphological	MOB3a	2016	
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides* sp. 'indet'	1	Morphological	MOB3b	2016	
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides* sp. 'indet'	1	Morphological	MOB3b	2016	
Mesa A	Schizomida	Hubbardiidae	*Paradraculoides* sp. 'SCH034'	1	Molecular	RC16MEA004	2016	
Mesa A	Scolopendrida	Cryptopidae	*Cryptops* sp. 'indet'	1	Morphological	MEADC2497	2003	
Mesa A	Scolopendrida	Cryptopidae	*Cryptops* sp. 'indet'	1	Morphological	MEARC2858	2005	
Mesa A	Scolopendrida	Cryptopidae	*Cryptops* sp. 'indet'	1	Morphological	MEARC4284	2006	
Mesa A	Scolopendrida	Cryptopidae	*Cryptops* sp. 'indet'	1	Morphological	MEARC4285	2006	
Mesa A	Scolopendrida	Cryptopidae	*Cryptops* sp. 'indet'	1	Morphological	MEARC4296	2006	

Area	Order	Family	Species Names	Number	Identification Method	Drillhole	Date	Species Status / Notes
Mesa A	Scolopendrida	Cryptopidae	*Cryptops* sp. 'indet'	1	Morphological	MEARC4307	2006	
Mesa A	Scolopendrida	Cryptopidae	*Cryptops* sp. 'nov'	2	Morphological	MEADC2500	2003	
Mesa A	Scolopendrida	Indeterminate	Scolopendrida sp. 'indet'	1	Morphological	MEARC2560	2005	
Mesa A	Scolopendrida	Indeterminate	Scolopendrida sp. 'indet'	1	Morphological	MEARC3073	2005	
Mesa A	Scolopendrida	Indeterminate	Scolopendrida sp. 'indet'	1	Morphological	MEARC4016	2005	
Mesa A	Polydesmida	Haplodesmidae	Haplodesmidae sp. 'indet'	1	Morphological	MEA4296	2007	
Mesa A	Polydesmida	Haplodesmidae	Haplodesmidae nov. gen. sp. '1'	1	Morphological	MEADC2497	2003	
Mesa A	Polyxenida	Indeterminate	Polyxenida sp. 'indet'	6	Morphological	MEA2513	2007	
Mesa A	Polyxenida	Indeterminate	Polyxenida sp. 'indet'	1	Morphological	MEA2513	2007	
Mesa A	Polyxenida	Indeterminate	Polyxenida sp. 'indet'	28	Morphological	MEA2513	2007	
Mesa A	Polyxenida	Indeterminate	Polyxenida sp. 'indet'	1	Morphological	MEA4318	2007	
Mesa A	Polyxenida	Indeterminate	Polyxenida sp. 'indet'	1	Morphological	MEA4318	2007	
Mesa A	Polyxenida	Indeterminate	Polyxenida sp. 'indet'	1	Morphological	MEA2999	2007	
Mesa A	Polyxenida	Lophoproctidae	Lophoproctidae sp. 'indet'	7	Morphological	MEARC4026	2012	Widespread
Mesa A	Polyxenida	Lophoproctidae	Lophoproctidae sp. 'indet'	7	Morphological	MEARC4282	2012	Widespread
Mesa A	Polyxenida	Lophoproctidae	Lophoproctidae sp. 'indet'	1	Morphological	MEARC4296	2012	Widespread
Mesa A	Polyxenida	Lophoproctidae	Lophoproctidae sp. 'indet'	2	Morphological	MEARC4298	2012	Widespread
Mesa A	Polyxenida	Lophoproctidae	Lophoproctidae sp. 'indet'	1	Morphological	MEARC4298	2012	Widespread
Mesa A	Polyxenida	Lophoproctidae	Lophoproctidae sp. 'indet'	5	Morphological	MEARC4299	2012	Widespread
Mesa A	Polyxenida	Lophoproctidae	Lophoproctidae sp. 'indet'	2	Morphological	MEARC4301	2012	Widespread
Mesa A	Polyxenida	Lophoproctidae	Lophoproctidae sp. 'indet'	7	Morphological	MEARC4301	2012	Widespread
Mesa A	Polyxenida	Lophoproctidae	Lophoproctidae sp. 'indet'	20	Morphological	MEARC4303	2012	Widespread

Area	Order	Family	Species Names	Number	Identification Method	Drillhole	Date	Species Status / Notes
Mesa A	Polyxenida	Lophoproctidae	Lophoproctidae sp. 'indet'	10	Morphological	MEARC4303	2012	Widespread
Mesa A	Polyxenida	Lophoproctidae	Lophoproctidae sp. 'indet'	4	Morphological	MEARC4303	2012	Widespread
Mesa A	Polyxenida	Lophoproctidae	*Lophoturus madecassus*	1	Morphological	MEARC4281	2016	Widespread
Mesa A	Polyxenida	Lophoproctidae	*Lophoturus madecassus*	1	Morphological	MEARC4304	2016	Widespread
Mesa A	Diplura	Campodeidae	Campodeidae sp. 'nov. gen.'	1	Morphological	MEARC2656	2005	
Mesa A	Diplura	Campodeidae	Campodeidae sp. 'OES3'	1	Morphological	MEARC4279	2014	
Mesa A	Diplura	Japygidae	Japygidae sp. 'indet'	1	Morphological	MEADC2496	2005	
Mesa A	Diplura	Japygidae	Japygidae sp. 'indet'	1	Morphological	MEADC2497	2003	
Mesa A	Diplura	Japygidae	*Japyx* sp. 'indet'	1	Morphological	MEARC2740	2005	
Mesa A	Diplura	Projapygidae	Projapygidae sp. 'nov. gen.'	1	Morphological	MEA4318	2007	
Mesa A	Diplura	Propjapygidae	Projapygidae sp. 'nov. gen.'	1	Morphological	MEARC4024	2005	
Mesa A	Diplura	Indeterminate	Diplura sp. 'indet'	1	Morphological	MEARC2702	2005	
Mesa A	Blattodea	Nocticolidae	*Nocticola* sp. 'indet'	1	Morphological	MEARC4018	2016	Widespread
Mesa A	Blattodea	Nocticolidae	*Nocticola* sp. 'OES11'	1	Morphological	MEARC4305	2014	Widespread
Mesa A	Blattodea	Nocticolidae	*Nocticola* sp. 'OES11'	1	Morphological	MEARC4305	2014	Widespread
Mesa A	Blattodea	Indeterminate	Blattodea sp. 'indet'	1	Morphological	MEARC4294	2012	Widespread
Mesa A	Blattodea	Indeterminate	Blattodea sp. 'indet'	2	Morphological	MEARC4304	2012	Widespread
Mesa A	Coleoptera	Curculionidae	Curculionidae sp. 'B02'	1	Morphological	MEARC4279	2016	
Mesa A	Coleoptera	Curculionidae	Curculionidae sp. 'B02'	1	Morphological	MEARC4297	2016	
Mesa A	Coleoptera	Curculionidae	Curculionidae sp. 'OES10'	4	Morphological	MEARC4294	2014	
Mesa A	Coleoptera	Curculionidae	Curculionidae sp. 'OES10'	1	Morphological	MEARC4304	2014	
Mesa A	Coleoptera	Staphylinidae	Staphylinidae sp. 'indet'	9	Morphological	MEA4155	2007	
Mesa A	Coleoptera	Staphylinidae	Staphylinidae sp. 'MesaKOES2'	1	Morphological	MEARC4297	2014	
Mesa A	Coleoptera	Indeterminate	Coleoptera sp. 'indet'	1	Morphological	MEARC4038	2006	
Mesa A	Thysanura	Indet.	Thysanura sp. 'Indet'	1	Morphological	MEA2513	2007	
Mesa A	Thysanura	Nicoletiidae	Nicoletiidae sp. 'indet'	1	Morphological	MEADC4151	2016	
Mesa A	Thysanura	Nicoletiidae	Nicoletiidae sp. 'indet'	1	Morphological	MEARC4305	2016	
Mesa A	Thysanura	Nicoletiidae	*Trinemura* sp. 'nov. Mesa A 1'	1	Morphological	MEADC2496	2005	

Area	Order	Family	Species Names	Number	Identification Method	Drillhole	Date	Species Status / Notes
Mesa A	Thysanura	Nicoletiidae	*Trinemura* sp. 'nov. Mesa A 1'	1	Morphological	MEADC2501	2005	
Mesa A	Thysanura	Nicoletiidae	*Trinemura* sp. 'nov. Mesa A 1'	1	Morphological	MEADC2517A	2005	
Mesa A	Thysanura	Nicoletiidae	*Trinemura* sp. 'nov. Mesa A 1'	1	Morphological	MEADC2523	2005	
Mesa A	Thysanura	Nicoletiidae	*Trinemura* sp. 'nov. Mesa A 1'	1	Morphological	MEADC2582	2005	
Mesa A	Thysanura	Nicoletiidae	*Trinemura* sp. 'nov. Mesa A 1'	1	Morphological	MEARC3098	2005	
Mesa A	Thysanura	Nicoletiidae	*Trinemura* sp. 'nov. Mesa A 1'	1	Morphological	MEARC3098	2005	
Mesa A	Thysanura	Nicoletiidae	*Trinemura* sp. 'nov. Mesa A 2'	1	Morphological	MEARC4296	2006	
Mesa A	Thysanura	Nicoletiidae	*Trinemura* sp. 'nov. Mesa A 2'	3	Morphological	MEARC4296	2006	
Mesa A	Thysanura	Nicoletiidae	*Trinemura* sp. 'nov. Mesa A 2'	1	Morphological	MEARC4305	2006	
Mesa A	Isopoda	Armadillidae	Armadillidae sp. 'MesaAOES19'	1	Morphological	MEARC4293	2014	
Mesa A	Isopoda	Oniscidae	*Hanoniscus* sp. 'MesaAOES22'	1	Morphological	MEARC4290	2014	
Mesa A	Isopoda	Oniscidae	*Hanoniscus* sp. 'MesaAOES22'	1	Morphological	MEARC4299	2014	
Mesa A	Isopoda	Oniscidae	*Hanoniscus* sp. 'MesaAOES22'	3	Morphological	MEARC4304	2014	
Mesa A	Isopoda	Indeterminate	Isopoda sp. 'indet'	1	Morphological	MEADC2517a	2012	
Mesa A	Isopoda	Indeterminate	Isopoda sp. 'indet'	1	Morphological	MEARC4281	2012	
Mesa A	Isopoda	Indeterminate	Isopoda sp. 'indet'	1	Morphological	MEARC4295	2012	
Mesa A	Isopoda	Indeterminate	Isopoda sp. 'indet'	1	Morphological	MEARC4295	2012	
Mesa A	Isopoda	Indeterminate	Isopoda sp. 'indet'	1	Morphological	MEARC4303	2012	
Mesa K	Araneae	Micropholcommatidae	Micropholcommatidae sp. 'WAMARA001'	1	Morphological	MEKRC1703	2014	
Mesa K	Blattodea	Nocticolidae	Nocticola sp. ‘OES11’	1	Morphological	K0989	2014	
Mesa K	Blattodea	Nocticolidae	Nocticola sp. ‘OES11’	1	Morphological	K0996	2014	
Mesa K	Blattodea	Nocticolidae	Nocticola sp. ‘OES11’	1	Morphological	MEK1718	2014	
Mesa K	Blattodea	Nocticolidae	Nocticola sp. ‘OES11’	1	Morphological	MEK1731	2014	
Mesa K	Blattodea	Nocticolidae	Nocticola sp. ‘OES11’	1	Morphological	K0740	2015	
Mesa K	Blattodea	Nocticolidae	Nocticola sp. ‘OES11’	1	Morphological	K0996	2015	
Mesa K	Blattodea	Nocticolidae	Nocticola sp. ‘OES11’	1	Morphological	K0996	2016	
Mesa K	Coleoptera	Curculionidae	Curculionidae gen. nov. sp. 'B01'	1	Morphological	MEK1486	2015	
Mesa K	Coleoptera	Curculionidae	Cryptorhynchinae sp. 'B04'	1	Morphological	MEK1478	2016	
Mesa K	Coleoptera	Curculionidae	Cryptorhynchinae sp. 'B04'	1	Morphological	MEK1486	2015	
Mesa K	Coleoptera	Curculionidae	Curculionidae sp. 'OES10'	1	Morphological	MEK1486	2014	

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Mesa K	Coleoptera	Ptiliidae	*Ptinella* sp. 'B01'	4	Morphological	MEK1718	2015	
Mesa K	Coleoptera	Ptiliidae	*Ptinella* sp. 'B01'	5	Morphological	MEK1718	2015	
Mesa K	Coleoptera	Ptiliidae	*Ptinella* sp. 'B01'	4	Morphological	MEK1735	2016	
Mesa K	Diplura	Japygidae	Heterojapyx sp. 'nov'	1	Morphological	MEK1478	2006	
Mesa K	Isopoda	Oniscidae	Hanoniscus sp. '1'	1	Morphological	MEK1337	2010	
Mesa K	Isopoda	Oniscidae	Hanoniscus sp. '1'	1	Morphological	MEK1074	2013	
Mesa K	Isopoda	Oniscidae	Hanoniscus sp. '1'	1	Morphological	MEK1486	2013	
Mesa K	Isopoda	Oniscidae	Hanoniscus sp. '1'	1	Morphological	MEK1074	2016	
Mesa K	Isopoda	Philosciidae	*Andricophiloscia* sp. 'B19'	1	Morphological	K0739	2015	
Mesa K	Polydesmida	Dalodesmidae	Dalodesmidae sp. 'B08'	5	Morphological	MEK1703	2015	
Mesa K	Polydesmida	Dalodesmidae	Dalodesmidae sp. 'B08'	2	Morphological	MEK1609	2015	
Mesa K	Polydesmida	Dalodesmidae	Dalodesmidae sp. 'B08'	24	Morphological	MEK1703	2015	
Mesa K	Polydesmida	Dalodesmidae	Dalodesmidae sp. 'B08'	3	Morphological	MEK1703	2016	
Mesa K	Polydesmida	Indeterminate	Polydesmida sp. 'indet'	1	Morphological	MEK1712	2011	
Mesa K	Polyxenida	Lophoproctidae	Lophoturus madecassus	1	Morphological	MEK1712	2011	Widespread
Mesa K	Polyxenida	Lophoproctidae	Lophoturus madecassus	2	Morphological	MEK1718	2011	Widespread
Mesa K	Polyxenida	Lophoproctidae	Lophoturus madecassus	1	Morphological	MEK1718	2011	Widespread
Mesa K	Polyxenida	Lophoproctidae	Lophoturus madecassus	2	Morphological	MEK1731	2011	Widespread
Mesa K	Polyxenida	Lophoproctidae	Lophoturus madecassus	1	Morphological	MEK1731	2011	Widespread
Mesa K	Polyxenida	Lophoproctidae	Lophoturus madecassus	1	Morphological	MEK1478	2011	Widespread
Mesa K	Polyxenida	Lophoproctidae	Lophoturus madecassus	1	Morphological	K0502	2014	Widespread
Mesa K	Polyxenida	Lophoproctidae	Lophoturus madecassus	1	Morphological	K0502	2014	Widespread
Mesa K	Polyxenida	Lophoproctidae	Lophoturus madecassus	1	Morphological	MEK1486	2014	Widespread
Mesa K	Polyxenida	Lophoproctida	Lophoturus madecassus	3	Morphological	K0607	2014	Widespread

Area	Order	Family	Species Names	Number	Identification Method	Drillhole	Date	Species Status / Notes
		e						
Mesa K	Polyxenida	Lophoproctidae	Lophoturus madecassus	1	Morphological	K0989	2014	Widespread
Mesa K	Polyxenida	Lophoproctidae	Lophoturus madecassus	6	Morphological	MEK1486	2014	Widespread
Mesa K	Polyxenida	Lophoproctidae	Lophoturus madecassus	2	Morphological	MEK1486	2014	Widespread
Mesa K	Polyxenida	Lophoproctidae	Lophoturus madecassus	1	Morphological	MEK1718	2014	Widespread
Mesa K	Polyxenida	Lophoproctidae	Lophoturus madecassus	12	Morphological	MEK1731	2014	Widespread
Mesa K	Polyxenida	Lophoproctidae	Lophoturus madecassus	3	Morphological	MEK1703	2015	Widespread
Mesa K	Polyxenida	Lophoproctidae	Lophoturus madecassus	1	Morphological	MEK1703	2015	Widespread
Mesa K	Polyxenida	Lophoproctidae	Lophoturus madecassus	1	Morphological	MEK1731	2015	Widespread
Mesa K	Polyxenida	Lophoproctidae	Lophoturus madecassus	1	Morphological	K0672	2016	Widespread
Mesa K	Polyxenida	Lophoproctidae	Lophoturus madecassus	3	Morphological	K0996	2016	Widespread
Mesa K	Polyxenida	Lophoproctidae	Lophoturus madecassus	5	Morphological	MEK1478	2016	Widespread
Mesa K	Polyxenida	Lophoproctidae	Lophoturus madecassus	1	Morphological	MEK1558	2016	Widespread
Mesa K	Polyxenida	Lophoproctidae	Lophoturus madecassus	8	Morphological	MEK1712	2016	Widespread
Mesa K	Polyxenida	Lophoproctidae	Lophoturus madecassus	1	Morphological	MEK1731	2016	Widespread
Mesa K	Pseudoscorpiones	Atemnidae	Oratemnus sp. 'PSE081'	1	Morphological	MEK1735	2013	
Mesa K	Pseudoscorpiones	Atemnidae	Oratemnus sp. 'PSE081'	1	Morphological	K0996	2013	
Mesa K	Pseudoscorpiones	Atemnidae	Oratemnus sp. 'PSE081'	1	Morphological	K1074	2014	
Mesa K	Pseudoscorpiones	Atemnidae	Paratemnoides sp. 'indet'	1	Morphological	k0607	2007	
Mesa K	Pseudoscorpiones	Chthoniidae	Lagynochthonius sp. 'Mesa K'	1	Morphological	MEK1689	2006	

Area	Order	Family	Species Names	Number	Identification Method	Drillhole	Date	Species Status / Notes
Mesa K	Pseudoscorpiones	Chthoniidae	Lagynochthonius sp. 'Mesa K'	1	Morphological	MEK1685	2007	
Mesa K	Pseudoscorpiones	Chthoniidae	Lagynochthonius sp. 'Mesa K'	1	Morphological	MEK1735	2011	
Mesa K	Pseudoscorpiones	Chthoniidae	Lagynochthonius sp. 'Mesa K'	1	Morphological	MEK1731	2014	
Mesa K	Pseudoscorpiones	Hyidae	Indohya sp. 'Mesa K'	1	Morphological	MEK1696	2006	
Mesa K	Pseudoscorpiones	Hyidae	Indohya sp. 'Mesa K'	1	Morphological	K0740	2011	
Mesa K	Pseudoscorpiones	Hyidae	Indohya sp. 'Mesa K'	1	Morphological	MEK1558	2013	
Mesa K	Pseudoscorpiones	Hyidae	Indohya sp. 'Mesa K'	1	Morphological	MEK1558	2013	
Mesa K	Pseudoscorpiones	Hyidae	Indohya sp. 'Mesa K'	1	Morphological	K0502	2014	
Mesa K	Pseudoscorpiones	Hyidae	Indohya sp. 'Mesa K'	1	Morphological	K0607	2014	
Mesa K	Pseudoscorpiones	Olpiidae	Linnaeolpium linnaei	1	Morphological	K0502	2007	
Mesa K	Pseudoscorpiones	Syarinidae	Ideoblothrus sp. 'indet'.	1	Morphological	K0996	2012	
Mesa K	Pseudoscorpiones	Syarinidae	Ideoblothrus sp. 'nov'	1	Morphological	MEK1721	2006	
Mesa K	Pseudoscorpiones	Syarinidae	Ideoblothrus sp. ‘Mesa K'	1	Morphological	MEK1685A	2010	
Mesa K	Pseudoscorpiones	Syarinidae	Ideoblothrus sp. ‘Mesa K'	1	Morphological	K0996	2013	
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	2	Morphological	K0502	2012	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	5	Morphological	K0502	2014	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	1	Morphological	K0502	2014	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	2	Morphological	K0502	2014	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	5	Morphological	k0607	2007	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	1	Morphological	k0607	2007	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	1	Morphological	K0607	2011	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	2	Morphological	K0607	2012	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	3	Morphological	K0607	2013	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	1	Morphological	K0607	2014	Conservation Significant,

Area	Order	Family	Species Names	Number	Identification Method	Drillhole	Date	Species Status / Notes
								Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	1	Morphological	K0607	2014	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	1	Morphological	K0607	2015	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	1	Morphological	K0607	2016	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	3	Morphological	K0672	2014	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	2	Morphological	K0672	2015	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	2	Morphological	K0672	2016	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	1	Morphological	K0739	2015	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	1	Morphological	K0740	2012	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	2	Morphological	K0740	2015	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	2	Morphological	K0740	2016	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	1	Morphological	K0948	2011	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	1	Morphological	K0968	2014	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	1	Morphological	K0968	2015	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	1	Morphological	K0989	2011	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	2	Morphological	K0989	2012	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	1	Morphological	K0989	2016	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	1	Morphological	K0996	2016	Conservation Significant,

Area	Order	Family	Species Names	Number	Identification Method	Drillhole	Date	Species Status / Notes
								Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	2	Morphological	K1074	2014	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	5	Morphological	K1074	2015	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	2	Morphological	K1328	2015	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	1	Morphological	K1328	2016	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	1	Morphological	K1337	2015	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	3	Morphological	MEK0672	2010	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	1	Morphological	MEK0739	2010	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	3	Morphological	MEK1337	2010	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	1	Morphological	MEK1478	2011	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	1	Morphological	MEK1478	2012	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	1	Morphological	MEK1478	2014	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	2	Morphological	MEK1478	2016	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	1	Morphological	MEK1486	2013	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	1	Morphological	MEK1486	2013	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	1	Morphological	MEK1486	2014	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	1	Morphological	MEK1486	2015	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	2	Morphological	MEK1558	2014	Conservation Significant,

Area	Order	Family	Species Names	Number	Identification Method	Drillhole	Date	Species Status / Notes
								Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	2	Morphological	MEK1558	2014	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	3	Morphological	MEK1558	2015	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	1	Morphological	MEK1570A	2015	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	1	Morphological	MEK1685	2007	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	1	Morphological	MEK1685	2007	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	1	Morphological	MEK1685	2007	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	3	Morphological	MEK1685	2010	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	4	Morphological	MEK1685A	2010	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	2	Morphological	MEK1689A	2010	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	1	Morphological	MEK1689A	2011	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	1	Morphological	MEK1689A	2014	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	2	Morphological	MEK1696	2007	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	4	Morphological	MEK1697	2014	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	1	Morphological	MEK1697	2014	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	2	Morphological	MEK1697	2015	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	3	Morphological	MEK1697	2016	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	1	Morphological	MEK1702	2011	Conservation Significant,

Area	Order	Family	Species Names	Number	Identification Method	Drillhole	Date	Species Status / Notes
								Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	1	Morphological	MEK1703	2016	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	3	Morphological	MEK1712	2012	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	1	Morphological	MEK1712	2014	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	2	Morphological	MEK1712	2014	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	3	Morphological	MEK1712	2014	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	1	Morphological	MEK1712	2016	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	1	Morphological	MEK1718	2007	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	1	Morphological	MEK1718	2013	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	1	Morphological	MEK1724	2015	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	1	Morphological	MEK1728	2016	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	1	Morphological	MEK1731	2012	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	1	Morphological	MEK1731	2014	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	5	Morphological	MEK1731	2014	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	1	Morphological	MEK1732	2015	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	1	Morphological	MEK1735	2014	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	6	Morphological	MEK1735	2016	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	1	Morphological	MEK1735A	2010	Conservation Significant,

Area	Order	Family	Species Names	Number	Identification Method	Drillhole	Date	Species Status / Notes
								Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	1	Morphological	MEK1735A	2014	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	8	Morphological	MEK1735A	2016	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	*Paradraculoides kryptus*	1	Morphological	MEKRC1703	2014	Conservation Significant, Listed as Schedule 3 in WA
Mesa K	Schizomida	Hubbardiidae	Paradraculoides sp. 'indet'	1	Morphological	K0557	2011	
Mesa K	Schizomida	Hubbardiidae	Paradraculoides sp. 'indet'	1	Morphological	K1068	2011	
Mesa K	Schizomida	Hubbardiidae	Paradraculoides sp. 'indet'	1	Morphological	MEK1685	2011	
Mesa K	Schizomida	Hubbardiidae	Paradraculoides sp. 'indet'	1	Morphological	MEK1697	2011	
Mesa K	Schizomida	Hubbardiidae	Paradraculoides sp. 'indet'	1	Morphological	K0607	2011	
Mesa K	Schizomida	Hubbardiidae	Paradraculoides sp. 'indet'	1	Morphological	K1066	2011	
Mesa K	Schizomida	Hubbardiidae	Paradraculoides sp. 'indet'	1	Morphological	K1068	2011	
Mesa K	Schizomida	Hubbardiidae	Paradraculoides sp. 'indet'	1	Morphological	K1074	2011	
Mesa K	Schizomida	Hubbardiidae	Paradraculoides sp. 'indet'	2	Morphological	MEK1703	2011	
Mesa K	Schizomida	Hubbardiidae	Paradraculoides sp. 'indet'	1	Morphological	MEK1689A	2011	
Mesa K	Schizomida	Hubbardiidae	Paradraculoides sp. 'indet'	3	Morphological	MEK1718	2011	
Mesa K	Schizomida	Hubbardiidae	Paradraculoides sp. 'indet'	1	Morphological	MEK1721	2011	
Mesa K	Schizomida	Hubbardiidae	Paradraculoides sp. 'indet'	1	Morphological	MEK1724	2011	
Mesa K	Schizomida	Hubbardiidae	Paradraculoides sp. 'indet'	1	Morphological	MEK1731	2011	
Mesa K	Schizomida	Hubbardiidae	Paradraculoides sp. 'indet'	2	Morphological	MEK1735	2011	
Mesa K	Schizomida	Hubbardiidae	Paradraculoides sp. 'indet'	2	Morphological	MEK1735A	2011	
Mesa K	Schizomida	Hubbardiidae	Paradraculoides sp. 'indet'	1	Morphological	MEK1609	2011	
Mesa K	Schizomida	Hubbardiidae	Paradraculoides sp. 'indet'	1	Morphological	MEK1570	2011	
Mesa K	Schizomida	Hubbardiidae	Paradraculoides sp. 'indet'	3	Morphological	K1598	2011	
Mesa K	Schizomida	Hubbardiidae	Paradraculoides sp. 'indet'	4	Morphological	K1337	2012	
Mesa K	Schizomida	Hubbardiidae	Paradraculoides sp. 'indet'	1	Morphological	K0672	2012	
Mesa K	Schizomida	Hubbardiidae	Paradraculoides sp. 'indet'	1	Morphological	K0607	2012	
Mesa K	Schizomida	Hubbardiidae	Paradraculoides sp. 'indet'	3	Morphological	K0672	2012	
Mesa K	Schizomida	Hubbardiidae	Paradraculoides sp. 'indet'	1	Morphological	K1074	2012	
Mesa K	Schizomida	Hubbardiidae	Paradraculoides sp. 'indet'	1	Morphological	K1074	2012	

Area	Order	Family	Species Names	Number	Identification Method	Drillhole	Date	Species Status / Notes
Mesa K	Schizomida	Hubbardiidae	Paradraculoides sp. 'indet'	2	Morphological	MEK1712	2012	
Mesa K	Schizomida	Hubbardiidae	Paradraculoides sp. 'indet'	3	Morphological	MEK1721	2012	
Mesa K	Schizomida	Hubbardiidae	Paradraculoides sp. 'indet'	1	Morphological	MEK1732	2012	
Mesa K	Schizomida	Hubbardiidae	Paradraculoides sp. 'indet'	1	Morphological	MEK1732	2012	
Mesa K	Schizomida	Hubbardiidae	Paradraculoides sp. 'indet'	2	Morphological	MEK1735	2012	
Mesa K	Schizomida	Hubbardiidae	Paradraculoides sp. 'indet'	1	Morphological	MEK1735a	2012	
Mesa K	Schizomida	Hubbardiidae	Paradraculoides sp. 'indet'	2	Morphological	MEK1735a	2012	
Mesa K	Schizomida	Hubbardiidae	Paradraculoides sp. 'indet'	1	Morphological	K0502	2012	
Mesa K	Schizomida	Hubbardiidae	Paradraculoides sp. 'indet'	1	Morphological	K0740	2012	
Mesa K	Schizomida	Hubbardiidae	Paradraculoides sp. 'indet'	1	Morphological	K0989	2012	
Mesa K	Schizomida	Hubbardiidae	Paradraculoides sp. 'indet'	1	Morphological	K0996	2012	
Mesa K	Schizomida	Hubbardiidae	Paradraculoides sp. 'indet'	4	Morphological	MEK1558	2012	
Mesa K	Schizomida	Hubbardiidae	Paradraculoides sp. 'indet'	1	Morphological	MEK1609	2012	
Mesa K	Schizomida	Hubbardiidae	Paradraculoides sp. 'indet'	1	Morphological	OPK01	2012	
Mesa K	Scolopendrida	Cryptoptidae	Cryptops sp. '1'	1	Morphological	MEK1302	2007	
Mesa K	Scolopendromorpha	Cryptopidae	Cryptops sp. '1'	1	Morphological	K0502	2013	
Mesa K	Scolopendromorpha	Cryptopidae	Cryptops sp. '1'	1	Morphological	MEK1731	2013	
Mesa K	Scolopendromorpha	Cryptopidae	Cryptops sp. 'B47'	1	Morphological	MEK1735	2016	
Mesa K	Scolopendromorpha	Scolopendridae	Scolopendridae sp. 'B03'	1	Morphological	K0502	2015	
Mesa K	Spirobolida	Indeterminate	Spirobolida sp. 'indet'	1	Morphological	K0502	2011	
Mesa K	Thysanura	Indeterminate	Thysanura sp. 'indet'	1	Morphological	MEK1731	2011	
Mesa K	Indeterminate	Indeterminate	Ballophilus australiae	1	Morphological	MEK1731	2016	Widespread
Mesa K	Indeterminate	Indeterminate	Symphyla sp. ‘Indet’	1	Morphological	MEK1731	2006	

Appendix 4

Recorded Fauna

Phase	Drillhole	Easting	Northing	Order	Family	Species	N	WAM ID	Identified	Notes / Specimen Status
Mesa A										
P2	RC16MEA004	385836	7604623	Schizomida	Hubbardiidae	Paradraculoides sp. 'SCH034'	1	T144230	Molecular Analysis	Potential SRE Species
P2	RC16MEA004	385836	7604623	Schizomida	Hubbardiidae	Paradraculoides sp. 'SCH034'	1	T144232	Molecular Analysis	Potential SRE Species
P2	RC16MEA004	385836	7604623	Schizomida	Hubbardiidae	Paradraculoides sp. 'SCH034'	1	T144231	Molecular Analysis	Potential SRE Species
P2	RC16MEA004	385836	7604623	Schizomida	Hubbardiidae	*Paradraculoides anachoretus*	1	T144233	Molecular Analysis	Conservation Significant, Listed as Schedule 3 in WA
P2	RC16MEA008	385934	7603716	Blattodea	Indeterminate	Blattodea sp. 'indet'	1	-	Morphology	Surface fauna; Eyes and pigment present
Mesa K										
P2	RC16MEK0002	423800	7597741	Pseudoscorpiones	Chthoniidae	Chthoniidae sp. 'PC059'	1	T144225	Molecular Analysis	Surface fauna
P2	RC16MEK0002	423800	7597741	Pseudoscorpiones	Chthoniidae	Chthoniidae sp. 'PC059'	1	T144226	Molecular Analysis	Surface fauna
P2	RC16MEK0002	423800	7597741	Blattodea	Indeterminate	Blattodea sp. 'indet'	1	-	Morphology	Surface fauna; Eyes and pigment present

Appendix 5

WAM Short Range Endemic Categories Guidelines

WAM SHORT-RANGE ENDEMIC CATEGORIES

	Taxonomic Certainty	Taxonomic Uncertainty
Distribution < 10 000km^2	**Confirmed SRE** • *A known distribution of < 10 000km².* • *The taxonomy is well known.* • *The group is well represented in collections and/ or via comprehensive sampling.*	**Potential SRE** • *Patchy sampling has resulted in incomplete knowledge of the geographic distribution of the group.* • *We have incomplete taxonomic knowledge.* • *The group is not well represented in collections.* • *This category is most applicable to situations where there are gaps in our knowledge of the taxon.* **Sub-categories for this SRE designation are outlined below**
Distribution > 10 000km^2	**Widespread (not an SRE)** • *A known distribution of > 10 000km².* • *The taxonomy is well known.* • *The group is well represented in collections and/ or via comprehensive sampling.*	

SRE SUB-CATEGORIES

If a taxon is determined to be a "Potential SRE", the following sub-categories will further elucidate this status.

A. *Data Deficient:*
- There is insufficient data available to determine SRE status.
- Factors that fall under this category include:
  - New species.
  - Lack of geographic information.
  - Lack of taxonomic information.
  - The group may be poorly represented in collections.
  - The individuals sampled (e.g. juveniles) may prevent identification to species level.

B. *Habitat Indicators:*
- It is becoming increasingly clear that habitat data can elucidate SRE status.
- Where habitat is known to be associated with SRE taxa and vice versa, it will be noted here.

C. *Morphology Indicators:*
- A suite of morphological characters are characteristic of SRE taxa.
- Where morphological characters are known to be associated with SRE taxa and vice-versa, it will be noted here.

D. *Molecular Evidence:*
- If molecular work has been done on this taxon (or a close relative), it may reveal patterns congruent or incongruent with SRE status.

E. *Research & Expertise:*
- Previous research and/ or WAM expertise elucidates taxon SRE status.
- This category takes into account the expert knowledge held within the WAM.

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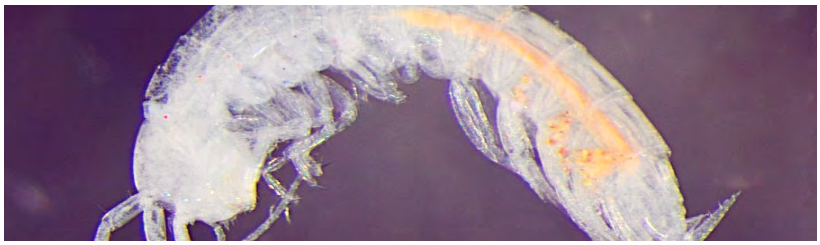
Mesa H Subterranean Fauna Assessment



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1.0 Executive Summary

Rio Tinto is evaluating the potential development of a number of iron ore deposits within the Robe Valley in the Pilbara region of Western Australia. This includes the development of the Mesa H deposit (15 km southwest of Pannawonica). The development has the potential to impact subterranean fauna, including both troglofauna (air-breathing subterranean fauna living above the water table) and stygofauna (aquatic fauna of the groundwater). Biota Environmental Sciences was therefore commissioned to conduct a detailed subterranean fauna survey at Mesa H. While the location of the proposed mine pits and other infrastructure, and the extent of the dewatering needed for the project to access below water table ore, are considered here, their use in this report is limited to a framework to categorise the subterranean fauna records arising from the survey.

A total of six phases of troglofauna sampling and five phases of stygofauna sampling were undertaken through nine field mobilisations occurring between October 2015 and December 2017. Stygofauna were sampled using modified plankton haul nets, and troglobitic fauna were sampled using two methods: baited colonisation traps and haul net scraping. A total of 53 sites were sampled for stygofauna across five phases and 136 sites were sampled for troglofauna using colonisation traps across six phases, with 57 sites sampled for troglofauna with haul nets. Environmental DNA (eDNA) sampling was also conducted at 16 sites in December 2017, with groundwater samples collected to target the specially protected Blind Cave Eel (*Ophisternon candidum*), which is not readily detectable with conventional sampling methods.

Molecular analysis was conducted to determine the number of species present, and to compare the results with data from elsewhere in the Pilbara. Morphological identifications of specimens were undertaken where mature, intact specimens and suitable taxonomic frameworks were available.

A total of 855 stygofauna specimens were recorded over the five phases of sampling, comprising at least 43 species-level taxa. As is typical of the Pilbara bioregion, the fauna recorded was numerically dominated by the Crustacea, which accounted for 98% of the specimens.

With the survey results, and the additional species previously known from desktop records, 46 stygofauna species are known from the immediate locality of Mesa H and the stygofauna of the drawdown extent itself currently stands at a total of 32 species, with half of these taxa recorded occur more widely in the locality or the bioregion. Thirteen of the species within the drawdown extent were identified as potential Short-range Endemic (SRE) fauna and six of these are restricted to the Mesa H drawdown extent based on the currently available data (the snail Hydrobiidae sp. 2, the ostracod Candoninae sp. 'BOS541', the copepod *Parastenocaris* sp. 'B28', the isopod *Haptolana* sp. 'B01', and the amphipod species Paramelitidae sp. 'AMP003' and Paramelitidae sp. 'AMP037').

Three stygofauna species of conservation significance have been recorded within the Mesa H groundwater drawdown extent during previous surveys: the Blind Cave Eel *Ophisternon candidum* (Vulnerable; Schedule 3), and the Schedule 3 amphipod species *Nedsia hurlberti* and *Nedsia sculptilis*. No additional records of the latter two species were obtained during the current survey, but further sampling targeting this species during the current study resulted in the detection of *Ophisternon* DNA at five locations, both along Jimmawurruda Creek and the Robe River, including at two sites within the drawdown extent and three outside of the drawdown extent along the Robe River. An additional specimen was also collected during surface water alluvium sampling along the Robe River, bringing the number of locations outside of the drawdown extent that the species has been recorded at to five (including Cape Range). The significantly improved distributional data indicate that the species occurs more widely in the locality, probably in association with the major alluvial aquifers of the Bungaroo-Jimmawurruda-Robe system.

A total of 150 troglobitic fauna specimens were collected across the six phases of sampling, representing five classes, nine orders and at least 32 species-level taxa. The orders Coleoptera and Schizomida were the greatest contributors to troglofaunal composition, accounting for 33% and 25% of the specimens collected, respectively. One other troglobitic taxon was previously known from the development envelope, bring the current known troglofauna assemblage to 33 species.

No troglofauna of conservation significance (i.e. listed as Priority, Schedule or Vulnerable at State or Federal levels) were recorded during the survey at Mesa H. A total of 27 troglofauna taxa classified as potential SREs are now known solely from within the Mesa H development envelope and do not currently have wider documented distributions (26 species from the current survey and one from historical records).

Twenty of these potential SRE taxa were represented by singleton records (single specimen records), making determination of their true distributions difficult. This overall pattern of short-range endemism is consistent with the findings of previous comprehensive surveys of the troglofauna of pisolitic mesas elsewhere within the Robe River valley.

2.0 Introduction

2.1 Project Background

Rio Tinto is evaluating the potential development of a number of iron ore deposits within the Robe River valley, in the Pilbara region of Western Australia. This includes the development of the Mesa H deposit (15 km southwest of Pannawonica) (Figure 2.1).

Previous studies have documented the occurrence of troglobitic and stygobitic fauna communities within the Robe River valley, with many of the documented troglofauna species isolated to individual mesa formations (Biota 2006a, Harvey et al. 2008). Troglofauna, in particular, demonstrate extreme short-range endemism as a result of geological barriers, and are therefore of significance to the environmental impact assessment (EIA) of any proposed developments affecting their habitat.

The development of the Mesa H deposit has the potential to impact subterranean fauna, and Rio Tinto therefore wishes to improve knowledge of these communities at Mesa H by collating existing data, determining information gaps and completing additional phases of sampling. Rio Tinto commissioned Biota Environmental Sciences (Biota) to complete the required subterranean fauna surveys to achieve this.

2.2 Terminology

This report primarily addresses the outcomes of the subterranean fauna surveys, with the assessment of impacts on subterranean fauna species, communities and habitats considered in a separate report (Biota 2018). While the location of the proposed mine pits and other infrastructure, and the extent of the dewatering needed for the project to access below water table ore, are considered here, their use in this report is limited to a framework to categorise subterranean fauna occurrence. For the purposes of this report then, the following terms are used as defined below:

- Development envelope – The Mesa H project boundary, which will accommodate the full extent of the physical components of the project (Figure 2.1);
- Drawdown extent – the spatial extent of the maximum groundwater dewatering influence for the Mesa H project, which extends beyond the development envelope to the east and southeast, and is primarily of relevance to stygofauna from an EIA perspective (Biota 2018) (Figure 2.1);
- Survey area – The area surveyed for subterranean fauna, including the development envelope and reference sites outside of the development envelope at the Pannawonica bore field and Pannawonica Road (Figure 2.1); and
- Desktop review area – An area encompassing the development envelope and a 15 km square around it to include previous surveys undertaken adjacent to Mesa H (Figure 2.1).

2.3 Objectives and Scope

The overall scope of this study was to document the subterranean fauna from the proposed Mesa H development envelope, consolidating the data with existing records from the locality, and placing the findings into wider regional context and assessing conservation status, where possible.

The specific objectives of this study were to:

1. conduct molecular analyses of troglobitic fauna specimens previously collected in the vicinity of Mesa H;
2. conduct a multiple phase sampling programme to document troglofauna and stygofauna present within the survey area; and
3. place the recorded fauna into a regional context and discuss their potential conservation significance.

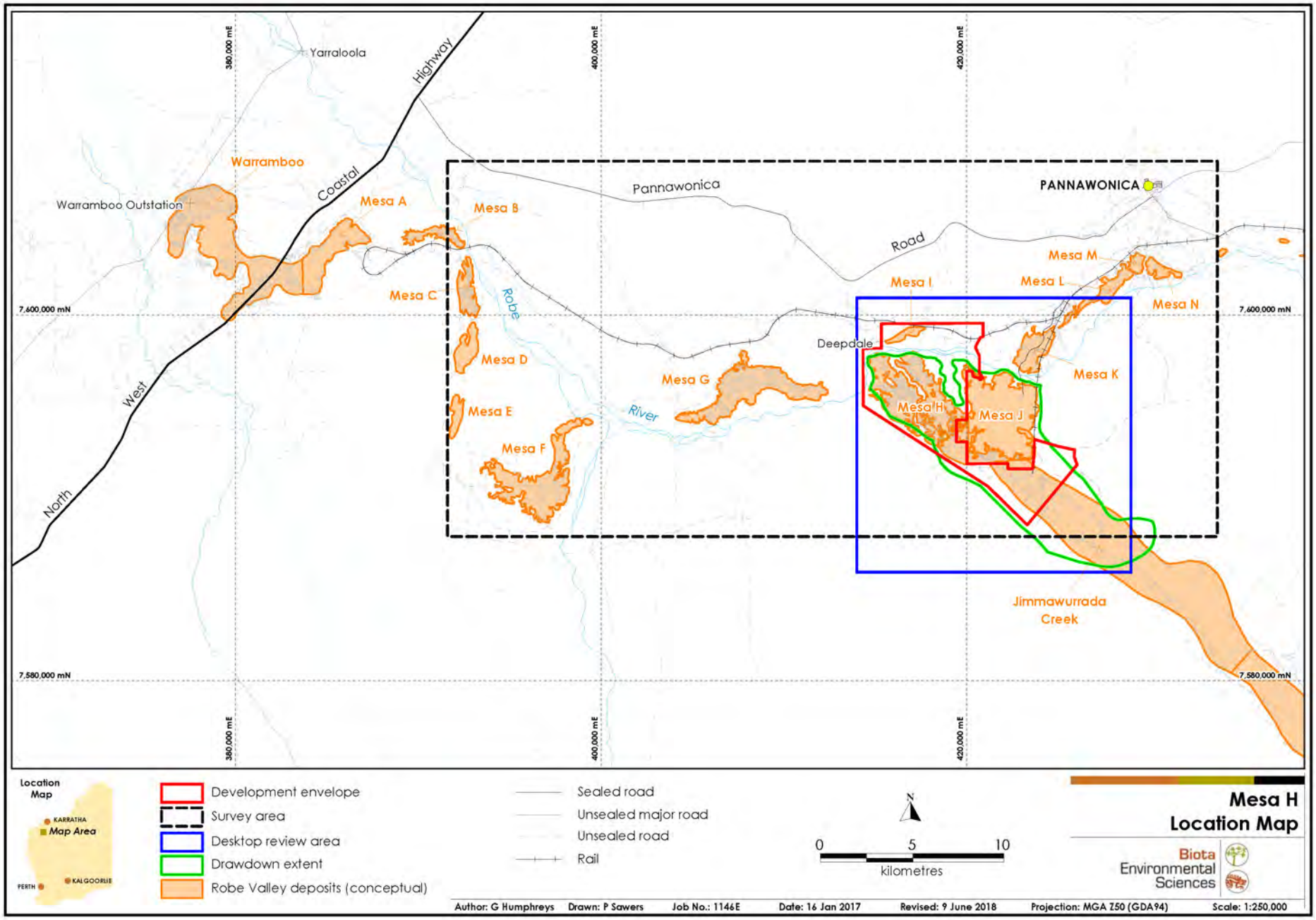

Figure 2.1: Location map of the Mesa H survey area.

The study was planned and implemented as far as practicable in accordance with the following:

- EPA Statement of Environmental Principles, Factors and Objectives (EPA 2016a);
- Environmental Factor Guideline – Subterranean Fauna (EPA 2016b);
- Technical Guidance - Subterranean fauna survey (EPA 2016c); and
- Technical Guidance - Sampling methods for subterranean fauna (EPA 2016d).

2.4 Purpose of this Report

The purpose of this report is to provide consolidated baseline survey information to inform the EIA of proposed mining activities within the development envelope.

This report documents the methodology, sampling effort and results of the subterranean fauna sampling programme completed within the survey area. Both the field sampling and report are subject to specific limitations that are discussed in Section 3.11.

2.5 Subterranean Fauna Overview

Until recently, Australia was thought to lack habitat suitable for subterranean fauna. However, recent research (mostly with an emphasis on impact assessment) has revealed Australia to be highly diverse in subterranean fauna, with numerous areas of interest throughout the continent (Guzik et al. 2010). In Western Australia these zones of subterranean biodiversity can be found at Cape Range, Barrow Island, the Pilbara bioregion, the Yilgarn and the Nullarbor (Humphreys 2001a, Page et al. 2008, Guzik et al. 2010).

Recent surveys in the Pilbara have collected subterranean fauna from a range of geological units such as pisolitic iron formations, channel iron deposits, unconsolidated alluvium and sedimentary basalt (Marmonier et al. 1993, Biota 2004, 2006a, 2010a, 2011a, 2013). This indicates that the suitability of a formation as habitat for subterranean fauna is mostly a function of the availability of habitable space (Marmonier et al. 1993, Humphreys 1999, Biota 2006a), rather than a specific geological unit.

Subterranean fauna habitats are characterised by shared physical parameters that include a lack of light, stable temperature, limited nutrient infiltration from surface environments and a constant humidity (Juberthie 2000, Romero 2009). These habitat characteristics have resulted in convergence in body morphology evolution amongst many subterranean fauna. Morphological characteristics common to most subterranean fauna include reduced or lack of pigmentation, reduced or lack of eyes, and elongate body morphology and appendages adapted for sensory movement (Culver and Pipan 2009, Romero 2009).

Subterranean fauna can be categorised into two distinct ecological groups based on habitat: troglofauna and stygofauna. Troglofauna are a suite of fauna that survive only in air-filled cavities and interstices between the surface and the water table. Stygofauna comprise aquatic taxa occurring in groundwater aquifers and subterranean water bodies. Troglobites and stygobites are obligatory subterranean habitat dwellers, and while they may occur close to surface environments, are strongly adapted to subterranean environments. This makes such fauna unable or highly unlikely to survive surface conditions. A range of similarly adapted fauna known as troglophiles, trogloxenes and edaphobites also occur; these fauna use subterranean habitats opportunistically but are able to survive outside these stable environments. Studies from the Pilbara bioregion have demonstrated that these suites of fauna are not similarly restricted in range and are therefore unlikely to be impacted by small-scale developments (Biota and Helix 2012, Helix 2012).

2.5.1 Troglofauna

Troglofauna in semi-arid Australia are thought to be relictual rainforest fauna; fauna adapted to humid environments, which retreated underground to cave systems during the aridification of

Australia (In the late Miocene; Humphreys 1993). This is inferred from affinities of the taxonomic groups represented amongst the troglofauna with other extant taxa in tropical climates. Some invertebrate groups with troglobitic representatives include the Arachnida (e.g. Schizomida, Pseudoscorpiones and Araneae), Chilopoda (e.g. Scolopendrida), Diplopoda (e.g. Polydesmida and Haplodesmida), and Insecta (e.g. Diplura, Zygentoma, Coleoptera and Blattodea). A single troglobitic vertebrate species of blind snake (*Anilios longissimus*) is known from Australia, collected from Barrow Island (Aplin 1998, Humphreys et al. 2013).

Due to their dependence on constant humidity, the dispersal and distribution of troglobitic fauna species tends to remain limited to individual blocks of inter-connected habitat, leading to long periods of population isolation and speciation. As a result, troglobitic fauna are considered to be of conservation significance, given that species often display extreme short-range endemism and may therefore be affected by relatively small-scale developments such as mining and construction.

2.5.2 Stygofauna

Stygal communities in Western Australia are predominantly Crustacean (e.g. Amphipoda, Isopoda, Decapoda, Syncarida, Ostracoda and Copepoda), however Annelida (e.g. Oligochaeta), Arachnida (e.g. Hydracarina) and Platyhelminthes are also commonly collected. Three species of stygal vertebrates have been recorded from Australia. This includes two species of blind gudgeon (*Milyeringa veritas* and *M. justitia*) as well as a blind cave eel, *Ophisternon candidum* (Humphreys 2001b, DSEWPaC 2008, Foster and Humphreys 2011, Larson et al. 2013).

3.0 Methodology

3.1 Desktop Review and Database Searches

3.1.1 Desktop Review

A desktop review of relevant existing information was undertaken in order to provide context to the assessment of subterranean fauna at Mesa H. The review considered:

1. previous relevant studies conducted within 40 km of the development envelope;
2. Threatened Ecological Communities (TECs) and Priority Ecological Communities (PECs) listed by the Department of Biodiversity, Conservation and Attractions (DBCA) that are of relevance to subterranean fauna and within 40 km of the development envelope; and
3. assessment of the surface geology of the development envelope in a local context.

3.1.2 Database Searches

The following databases were searched to assist with compilation of a list of potential species for the development envelope:

1. NatureMap: a collaboration between DBCA and the Western Australian Museum (WAM). This database represents the most comprehensive source of information on the distribution of Western Australia's fauna, comprising records from the Fauna Survey Returns database and Western Australian Threatened Fauna Database (both maintained by the Department of Biodiversity, Conservation and Attractions) and the WAM Specimen Database. The search was conducted 06/02/2017 within a 20 km radius of a central point (421372 m E, 7597354 m S).
2. Atlas of Living Australia (ALA): a collaborative project between academic collecting institutions, private individual collectors and community groups. The atlas contains occurrence records, environmental data, images and the conservation status of species throughout Australia. The search was conducted 06/02/2017 within a 10 km radius of a central point (421372 m E, 7597354 m S).
3. WAM's Arachnida, Myriapoda, Crustacea and Mollusca databases: The search request was submitted 14/03/2017 using the following bounding co-ordinates: 405138 m E, 7607948 m S (top left corner), 435642 m E, 7582695 m S (bottom right corner).
4. Biota Internal Database: This database includes all of the subterranean fauna data collected by Biota within Western Australia, which includes the majority of the past records from the Robe River valley. The search was conducted 06/02/2017 within 15 km from a central point in the development envelope (421490 m E, 7593430 m S).

3.2 Survey Timing and Personnel

A total of six phases of troglofauna sampling and five phases of stygofauna sampling were undertaken over the course of nine field mobilisations occurring between October 2015 and December 2017.

The field work was completed under "Regulation 17: Licence to Take Fauna for Scientific Purposes", licence numbers SF010536 (30/09/2015 – 30/06/2016) and SF010915 (22/07/2016 – 30/06/2017), both issued to Mr Chris Cole of Biota (Appendix 1). Phases 4- 6 were completed under "Licence to Take Fauna for Scientific Purposes" No. 08-001539-1 issued to Jason Alexander (Appendix 1).

A summary of survey timing, survey components and survey personnel is presented in Table 3.1.

Table 3.1: Summary of field sampling undertaken during the survey.

Sampling Dates	Survey Component	Survey Personnel
23 - 29 October 2015	Phase 1 trap installation Phase 1 stygofauna sampling	David Keirle and Chris Cole
9 -12 December 2015	Phase 1 trap retrieval Phase 2 trap installation	David Keirle, Tim Sachse
18 – 21 January 2016	Phase 2 trap retrieval Phase 2 stygofauna sampling	Penny Brooshooft, Scott Werner
3 – 7 May 2016	Phase 3 trap installation Phase 3 stygofauna sampling	Chris Cole, Nicola Watson
27 – 28 June 2016	Phase 3 trap retrieval	Chris Cole, Nicola Watson
9 – 14 September 2016	Phase 4 trap installation Phase 4 stygofauna sampling	Nicola Watson, Penny Brooshooft
25 – 27 October 2016	Phase 4 trap retrieval Phase 5 trap installation	Penny Brooshooft, Jason Alexander
12 – 14 December 2016	Phase 5 trap retrieval Phase 6 trap installation	Nicola Watson, Jacinta King
30 -31 January 2017	Phase 6 trap retrieval	Jason Alexander, Greg Richter (Rio Tinto)
11-15 December 2017	eDNA and Phase 5 stygofauna sampling (reference areas)	Jason Alexander, Jacinta King, Michael Greenham

3.2.1 Weather Conditions

Temperature and rainfall data were obtained from the Mesa J mining operations adjacent to the east end of Mesa H (Figure 2.1). Long-term climate data (rainfall from 1971 – 2014, temperature data from 1971 – 2005) were obtained from the Bureau of Meteorological (BOM) weather station in Pannawonica (station number 5069), approximately 15 km northeast of Mesa H.

The phases of sampling within the development envelope occurred between October 2015 and the end of January 2017. Several major rainfall events occurred throughout that sampling period (Figure 3.1). Past observations suggest the approximate timing of sampling after significant rainfall creates suitable conditions for sampling for troglofauna (Biota 2006a). Weather data from Pannawonica show that no rainfall was recorded during the three months preceding the Phase 5 reference area stygofauna sampling in December 2017.

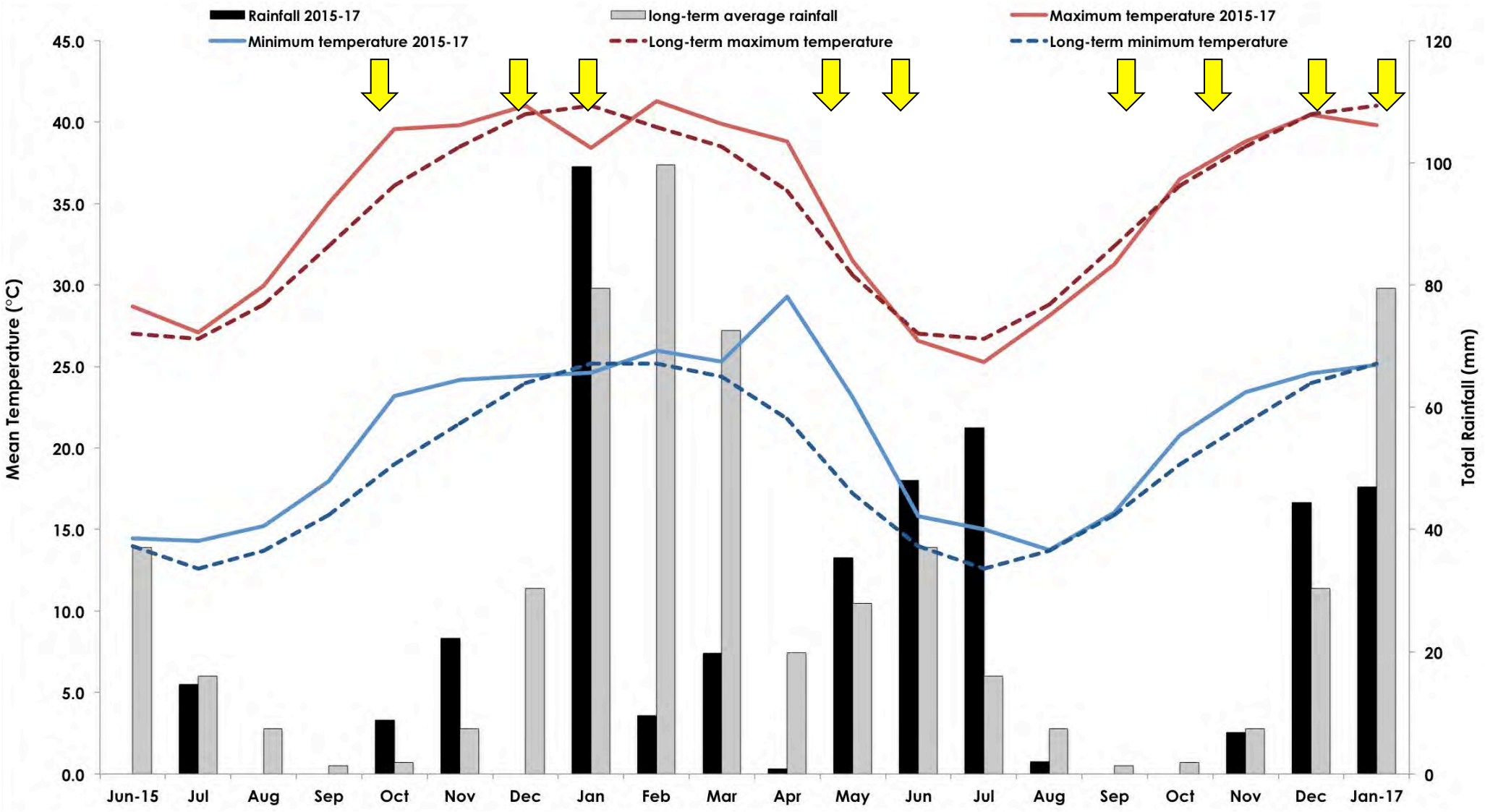

Figure 3.1: Climate and weather graph depicting long-term and monthly averages for 6 months preceding and during subterranean fauna sampling. Long-term temperature data 1971-2005, rainfall data 1971-2014; arrows indicate field mobilisation timing.

3.3 Stygofauna Sampling

Stygofauna were sampled using modified plankton haul nets, constructed from 70 μm plankton mesh, with 50 mm and 100 mm apertures attached to a stainless steel catch cylinder. Nets were lowered to the bottom of water bores and drill holes before being hauled slowly through the water column to the surface, where the contents of the cylinder were flushed into a uniquely labelled container. Each monitoring site was sampled in this way a minimum of five times. On the final haul, the net was agitated gently to stir the benthos layer and mobilise any fauna present for more effective specimen collection. Specimens were stored in a shaded esky in order to keep the samples cool prior to sorting and identification.

Following sampling of each monitoring site, the nets were thoroughly rinsed with water, inspected and (where possible) left to dry before using on another site. This prevented cross-contamination of specimens between sampling sites.

3.4 eDNA Sampling

Environmental DNA (eDNA) sampling took place on completion of stygofauna haul net sampling during Phase 5 in December 2017 (Table 3.1). The environmental samples were collected to target the Blind Cave Eel (*Ophisternon candidum*) (Section 4.4.1.1), which is not readily detectable with conventional sampling methods (Biota and Helix 2014).

This sampling initially included agitation of the benthos at the base of the borehole, to mobilise DNA molecules and fragments of tissues within the water column. Then, wearing nitrile gloves, a 1 L bailer, attached to the same line used for haul net sampling at that specific site, was lowered into the bore until approximately 1 m from the bottom of the hole. The bailer was then removed from the bore and the contents of the bailer emptied into a brand new and uniquely labeled 1 L container. This step was repeated twice more. The line was then discarded after bailing to prevent contamination of eDNA between sites.

A further two 1 L containers were filled using a specialised downhole pump (a GEOsub 12 V purging pump) attached to brand new HDPE tubing. The pump was lowered to approximately 1 m from the benthos and activated. The pump was allowed to run for three minutes, which acts to purge the bore and draw in groundwater, and potential eDNA, from the surrounding aquifer. After this, the remaining two labeled containers were filled in the same fashion. All filled containers were stored in the field an ice-filled esky until arrival at the on-site laboratory in Pannawonica.

3.5 Troglofauna Sampling

Troglobitic fauna were sampled using two methods; baited colonisation traps and haul net scraping.

3.5.1 Colonisation Trapping

Custom-built litter colonisation traps were suspended at intervals within drillholes located within the survey area. Traps were constructed from 60 mm internal diameter PVC irrigation pipe cut to a length of 180 mm. Each trap had a series of 20 mm holes drilled into the side, and traps remained open at the upper end. Up to three traps were installed such that they were in contact with the interior of the sampled drillhole, facilitating fauna entry into the trap.

Leaf litter was gathered locally from the ground surface in the survey area, particularly from the bases of *Acacia* shrubs. The collected litter was soaked in water and irradiated in a microwave oven for two minutes on maximum power setting. The microwave acted to kill any surface invertebrates present and assisted in the breakdown of organic matter. Microwaved leaf litter was added to the traps, which were kept in sealed containers until immediately prior to insertion into the drillholes to avoid desiccation of the litter. After the installation of traps, the opening of each drillhole was sealed to maintain humidity and to avoid entry of surface fauna.

Traps were recovered from each drillhole after a minimum of six weeks and stored in labelled zip-lock bags in order to maintain humidity and prevent desiccation of potential troglofauna specimens during transportation to Perth.

Fauna specimens were recovered from the traps using specially designed Tullgren funnel units. The leaf litter from each trap was placed in a sieve under an aluminium lamp containing a 25-watt globe. This created a temperature of approximately 30°C at the surface of the leaf litter. A funnel situated below the leaf litter collected the fauna as they fell, directing them into an attached vial of 100% ethanol. Leaf litter was left in the Tullgren funnels for a period of 24 hours, or until dry, after which time the bulked invertebrate sample was removed.

3.5.2 Troglofauna Scraping

Troglofauna were also sampled using reinforced stygofauna haul nets. These nets were constructed from 70 µm plankton mesh and had 100 mm apertures attached to a weighted catch jar. Sampling took place by lowering the net to the bottom of the site before being hauled slowly to the surface whilst scraping the edge of the drillhole. This dislodged any fauna on the vertical surface of the drillhole interior. Each site was scraped a minimum of four times, scraping each side of the drillhole. On completion, fauna specimens were preserved in-situ in 100% ethanol and individually labelled. The contents of the net, which included dry soil and root matter, were emptied into a uniquely labelled container. The container was then filled with 100% ethanol to preserve any specimens that may have been in the soil and root matter for later sorting in the field laboratory.

3.6 Morphological Identifications

Preliminary identification of subterranean fauna involved identification of specimens to order level, where possible, or separation of specimens into distinct morphotypes. Sorting was completed using dissecting microscopes (Olympus SZ40 and SZ61, magnification up to 40x). Specimens were preserved in 100% ethanol once separated out into morphotypes, which allows for both morphological and molecular analyses. Specialist morphological identifications of copepods, ostracods and isopods were undertaken by Jane McRae and Stuart Halse of Bennelongia Environmental Consultants (Appendix 2).

3.7 Specimen Molecular Analysis

Molecular analysis of selected groups was conducted to determine the number of species present, and to compare the results with data from elsewhere in the Pilbara. These were taxonomic groups for which past studies have shown morphological identifications to species level are generally not possible or reliable for most specimens, where inadequate taxonomic expertise is readily available for the groups in question, and/or where well established phylogenetic frameworks exist to more adequately place the specimens into regional context. Yvette Hitchen of Helix Molecular Solutions (Helix) completed DNA sequencing of the collected Amphipoda, Schizomida, Diplura, Thysanura, Isopoda and Pseudoscorpiones. Terrie Finston (Helix) and Rachael King (South Australian Museum) provided analysis and interpretation of the molecular data.

The collected specimens were sequenced for variation at the mitochondrial cytochrome oxidase subunit 1 gene (CO1). Where larger numbers of specimens of the same morphotype (i.e. more than five) were recorded from the same sampling site, a subsample of five specimens was typically taken for sequencing. Schizomid specimens recorded during previous surveys at Mesa J (Biota 2009) were also sequenced as part of the current study to improve local context. A complete account of the molecular analysis methodology is provided in Appendix 3.

On the basis of existing literature and past molecular studies of Pilbara troglofauna (Hebert et al. 2003a, 2003b, Harvey et al. 2008), lineages with a divergence of less than 4.0% were considered a single species, whereas lineages with a divergence greater than 6.0% were considered separate distinct species for the purpose of this report, subject to a review of the relative variation within each putative species, unless advised otherwise by Helix based on other data for the relevant taxonomic group. Lineages with intermediate divergences ranging from 4.0 – 6.0% were resolved to a preliminary level for the purposes of this report, with further input from Helix, and consideration to collection proximity, habitat, geology and past results from the same taxonomic groups.

3.8 eDNA Sample Analysis

3.8.1 Sample Processing

Groundwater samples collected for eDNA analysis were filtered through 0.45 μm sterile filter membranes, using both Sentino Microbiology Pumps and manually using specialised Nalgene Filter Flasks and a hand pump. One container of groundwater (1 L) was processed per membrane and on completion of this process, the membrane was folded in half then cut vertically. These halves were placed in separate sterile storage bags and frozen with the remaining filters for that site depending on which lab the membrane would be despatched to for further analysis (Section 3.8.2). All laboratory equipment was sterilised between samples using a bleach solution.

3.8.2 Sample Analysis

eDNA sample filters were analysed by two different molecular methods, each of which was undertaken independently by two separate laboratories. The objectives of both methods were to detect residual DNA from the Blind Cave Eel (*Ophisternon candidum*) (Section 4.4.1.1) in the environmental samples.

3.8.2.1 qPCR

Helix Molecular Solutions analysed half of the replicate membranes from each sample site using a real-time qPCR method developed previously for the Blind Cave Eel (Biota and Helix 2014). Sequence data from past collections of *Ophisternon* from the Jimmawurrada and Bungaroo Creek locality was used to design a species-specific probe using the Integrated DNA Technology (IDT) design tool PrimerQuest and further edited using Oligo Primer analysis software version 6 (Molecular Biology Insights, Cascade, USA). The resulting assay amplified a diagnostic 80 bp fragment of the mitochondrial cytochrome c oxidase subunit I gene (COI) (Biota and Helix 2014).

Samples were extracted using the QIAGEN Blood and Tissue Kit (QIAGEN, Hilden, Germany) and as with previous studies all starting volumes were doubled to ensure that the filter membrane was covered during incubation. All samples had two elutes of 50 μl each.

The specifically designed qPCR assay was then used to detect the presence of *Ophisternon* DNA. Quantitative real-time PCR assays were performed using the Applied Biosystems StepOne Plus real-time PCR system and software (Biota and Helix 2014). The assay identifies the presence of the target species by the unique fluorescent signal produced during the polymerase chain reaction when both the species-specific primers as well as species-specific probes match DNA present in the sample. The fluorescent response can be visualised in real time as amplification proceeds. Only samples that showed a positive CT value (the number of cycles required for the fluorescent signal to exceed the background level of fluorescence) and amplification plot were considered to test positive for the target *Ophisternon* DNA.

3.8.2.2 Next Generation Sequencing Metabarcoding

The matching halves of the filters from each site were despatched to the Trace and Environmental DNA laboratory at Curtin University. The molecular analysis undertaken by Curtin University also involved a QIAGEN Blood and Tissue Kit to extract eDNA from the samples, and then utilised a metabarcoding to simultaneously sequence the resultant environmental DNA. A fish 16S assay as used amplified using PCR followed by sequencing to obtain data relevant to *Ophisternon* (Appendix 4). This was then subsequently refined using specific assays developed for the purposes of this study (Appendix 4).

The sequence data were then analysed against both publicly available reference sequence data on GenBank and other sources, in addition to comparisons with sequences obtained from *Ophisternon* specimens collected previously from the locality (Appendix 4).

3.9 Categories of Conservation Significance

For the purpose of this report, the conservation significance of the fauna collected during this study, or records collated during the desktop review, was categorised as follows:

- Confirmed short-range endemic (SRE) species: Species where sufficient taxonomic expertise is available, and with adequate representation in WAM collections or genetic databases, that are known to be limited in distribution.
- Potential SRE species: Species where there is insufficient taxonomic knowledge or too limited a number of collections to determine SRE status. Habitat, morphology, molecular or taxonomic data deficient, but belonging to groups that may display short-range endemism.
- Widespread species (Not an SRE): Well-collected species, that are typically taxonomically well resolved.

SRE categories are based on WAM SRE guidelines (see Appendix 4 for more detail).

3.10 Sampling Effort

3.10.1 Stygofauna

A total of 53 sites were sampled for stygofauna across the five phases (Table 3.2, Figure 3.2 and Figure 3.3). The majority of sites (n=39) were sampled on at least two separate phases. Fourteen sites were sampled only once, 10 sites were sampled across three phases and one site (WB13MEJ003) was sampled across four of the five phases (Table 3.2). Eighteen of the 53 sites were located outside of the development envelope (denoted by an asterisk in Table 3.2) (Figure 3.2; Figure 3.3).

Table 3.2: Stygofauna sampling sites at Mesa H (*site outside of the drawdown extent).

Site Name	Easting (m E)	Northing (m N)	Sampling Phase				
			1	2	3	4	5
DD13MEH0007	419635	7593002	✔	✔		✔	
MB12MEJ004	421046	7591683	✔	✔		✔	
RC13MEH0007	419642	7592603	✔			✔	
RC13MEH0040	419893	7592704	✔	✔		✔	
RC13MEH0041	419940	7592705	✔	✔			
RC13MEH0097	420086	7592803	✔			✔	
RC13MEH0099	420088	7592901	✔			✔	
RC14MEH0018	419088	7593299	✔	✔		✔	
RC14MEH0053	419092	7592752	✔	✔		✔	
WB13MEJ003	420717	7591683	✔	✔	✔	✔	
RC12JIM0019	421396	7591472		✔			
RC15MEJ0018	419893	7592052		✔		✔	
WB12MEJ004	421773	7591276		✔	✔	✔	
158*	406804	7597112			✔	✔	
199*	402701	7606147			✔	✔	
Dave Bore*	392512	7607436			✔	✔	✔
25*	432152	7602229			✔	✔	✔
31*	432929	7603179			✔	✔	✔
32*	432452	7602673			✔	✔	
34*	432423	7602432			✔	✔	
87*	410739	7604138			✔	✔	
MB12MEJ001	421763	7591266			✔	✔	
RC15MEH0178	415934	7595048			✔	✔	
RC15MEH0284	416632	7597202			✔	✔	
RC15MEH0286	416840	7597576			✔	✔	
RC15MEH0295	417235	7597402			✔	✔	
RC15MEH0296	418179	7595152			✔	✔	
RC15MEH0297	417884	7594252			✔	✔	
RC15MEH0298	419285	7594350			✔	✔	
RC15MEH0299	419291	7593101			✔	✔	
RC15MEH0349	415635	7597550			✔	✔	
RC15MEH0350	418585	7592350			✔	✔	

Site Name	Easting (m E)	Northing (m N)	Sampling Phase				
			1	2	3	4	5
RC15MEH0351	417838	7593554			✔	✔	
RC15MEH0352	416535	7595450			✔	✔	
RC15MEH0353	416735	7595950			✔	✔	
RC15MEH0354	416335	7596450			✔	✔	
RC15MEH0355	415335	7596050			✔	✔	
RC15MEH0356	415335	7597550			✔	✔	
RC15MEJ0017	420087	7591940			✔	✔	
RR1*	419176	7597904			✔	✔	✔
RC16JIM0019	423011	7590291				✔	
BC186	429578	7587212					✔
BC401*	443563	7574126					✔
Budgie Bore*	382495	7615587					✔
JW023	426138	7590140					✔
JW024	427126	7590154					✔
MB16MEC0008*	393565	7600580					✔
MB16MEC0009*	393590	7601145					✔
MB17MEH0007*	417664	7600421					✔
MB17MEH0008*	417120	7600417					✔
MB17MEH0009*	416436	7599848					✔
MB17MEH0010*	416440	7599848					✔
MB17MEH0015	416041	7597690					✔
		Total	10	10	29	39	16

Sixteen of the bores sampled for fauna were also sampled for eDNA during the December 2017 Phase 5 stygofauna sampling (Table 3.3; Figure 3.2; Figure 3.3). These were selected primarily on the basis of having been past confirmed eel record sites (Section 4.4.1.1) or being situated in equivalent hydrogeological settings along Bungaroo Creek, Jimmawurrada Creek and the Robe River (Table 3.3). In addition, a 3 L sample of surface water as taken as a Control sample from standing water within a pool along the Robe River (Table 3.3; Figure 3.2). The majority of the eDNA sampling sites were outside of the drawdown extent, within five located within (Table 3.3; Figure 3.3).

Table 3.3: eDNA sites sampled during December 2017 (*site outside of the drawdown extent).

Site Name	Easting (m E)	Northing (m N)	Notes
Control*	424478	7597147	Equivalent hydrogeology to confirmed eel sites
25*	432152	7602229	Equivalent hydrogeology to confirmed eel sites
31*	432929	7603179	Equivalent hydrogeology to confirmed eel sites
Dave Bore*	392512	7607436	Equivalent hydrogeology to confirmed eel sites
BC186	429578	7587212	Confirmed eel record 2009
BC401	443563	7574126	Equivalent hydrogeology to confirmed eel sites
Budgie Bore*	382495	7615587	Equivalent hydrogeology to confirmed eel sites
JW023	426138	7590140	Confirmed eel record 2016
JW024	427126	7590154	Confirmed eel record 2017
MB16MEC0008*	393565	7600580	Equivalent hydrogeology to confirmed eel sites
MB16MEC0009*	393590	7601145	Equivalent hydrogeology to confirmed eel sites
MB17MEH0007*	417664	7600421	Equivalent hydrogeology to confirmed eel sites; Bailer only for eDNA
MB17MEH0008*	417120	7600417	Equivalent hydrogeology to confirmed eel sites; Bailer only for eDNA
MB17MEH0009*	416436	7599848	Equivalent hydrogeology to confirmed eel sites
MB17MEH0010*	416440	7599848	Equivalent hydrogeology to confirmed eel sites
MB17MEH0015	416041	7597690	Equivalent hydrogeology to confirmed eel sites; Bailer only for eDNA
RR1*	419176	7597904	Equivalent hydrogeology to confirmed eel sites; Bailer only for eDNA

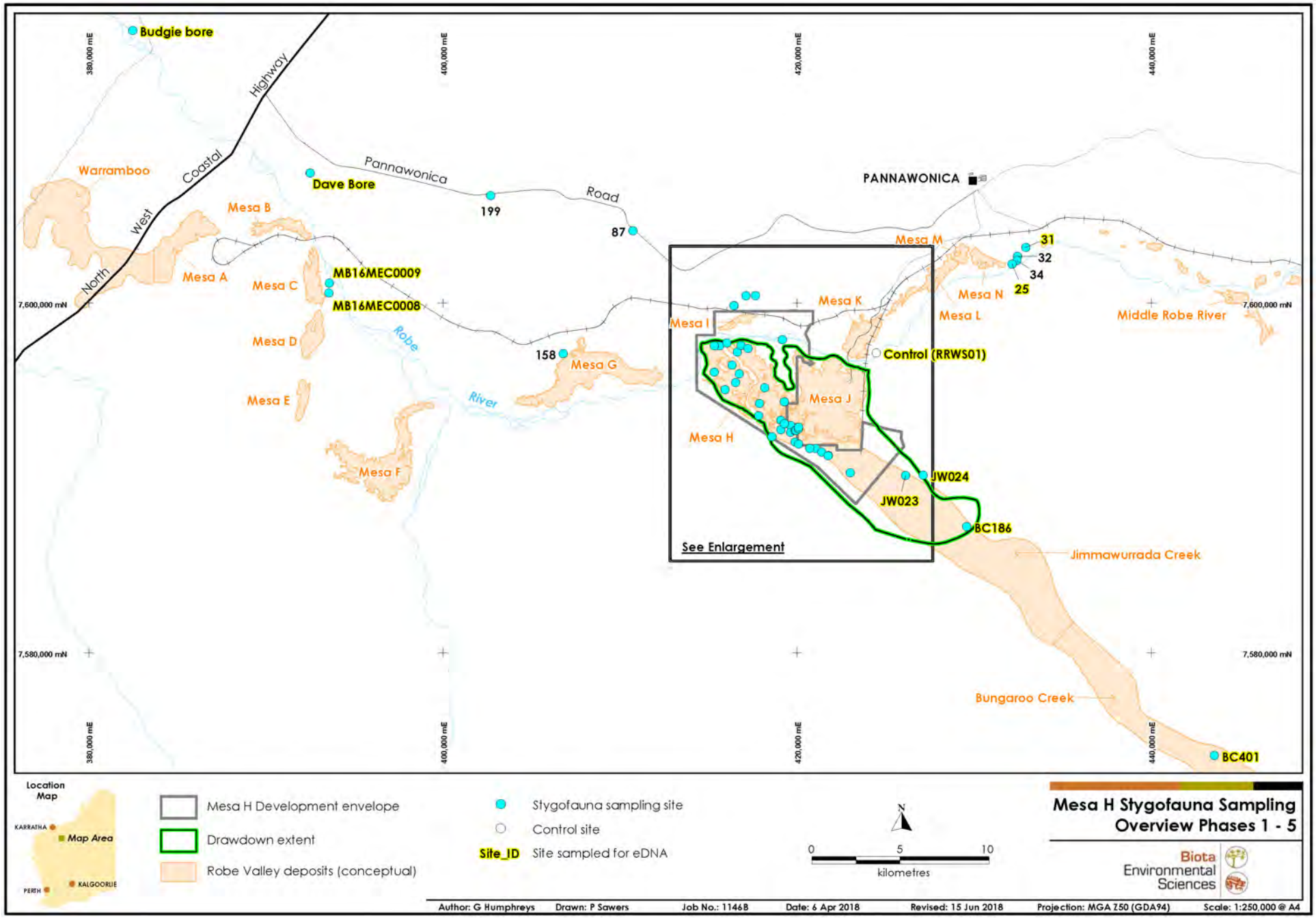

Figure 3.2: Overview of stygofauna sampling sites Phases 1 - 5.

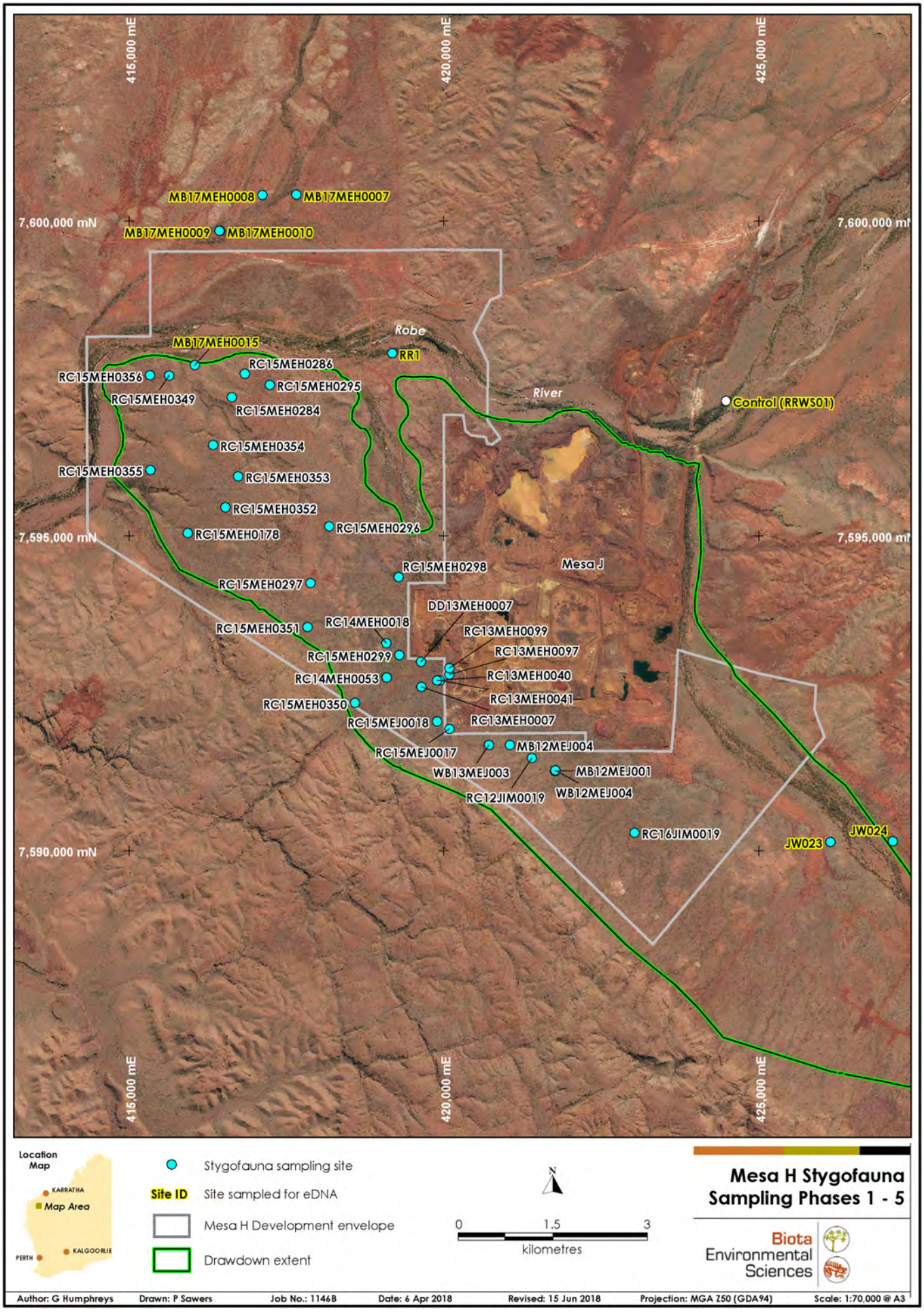

Figure 3.3: Stygofauna sampling sites within and adjacent to the Mesa H development envelope Phases 1-5.

3.10.2 Troglofauna

A total of 136 sites were sampled for troglofauna across six phases (Table 3.4, Figure 3.4). Two thirds of the sites were sampled were sampled at least twice (n=86), with the remaining 50 sampled once (Table 3.4). A total of 57 sites had additional haul net sampling completed (denoted by 'S' in Table 3.4), with nine sites being scraped with haul nets twice.

Table 3.4: Troglofauna sampling sites at Mesa H.

Site Name	Easting (m E)	Northing (m N)	Sampling Phase					
			1	2	3	4	5	6
DD15MEH0003	419342	7592303	✔	✔				
GR15MEH0013	415736	7595443	✔	✔				
MEHRC0957	415437	7596556	✔	✔				
MEHRD0386	415141	7596155	✔	✔				
RC12JIM0019	421396	7591472	✔(S)	✔(S)				
RC12JIM0027	421626	7591084	✔	✔				
RC12MEH0075	419894	7592163	✔	✔				
RC12MEH0120	419988	7592302	✔(S)	✔(S)				
RC12MEH0221	419349	7593105	✔	✔		✔	✔(S)	
RC13MEH0007	419642	7592603	✔	✔				
RC13MEH0041	419940	7592705	✔	✔				
RC13MEH0135	419288	7593902	✔	✔				
RC14MEH0051	419391	7593448	✔	✔				
RC14MEH0053	419092	7592752	✔	✔				
RC14MEH0109	418837	7593804	✔	✔				
RC14MEH0169	418888	7593560	✔	✔				
RC14MEH0238	418846	7592802	✔(S)	✔(S)				
RC14MEH0252	418789	7593304	✔	✔		✔	✔(S)	
RC14MEH0270	418381	7593102			✔	✔	✔(S)	
RC14MEH0308	418987	7592556	✔	✔				
RC14MEH0315	418894	7592510			✔			
RC14MEH0326	418389	7593354	✔	✔				
RC14MEH0339	418393	7594004	✔	✔				
RC14MEH0388	418088	7593504			✔			
RC15MEH0007	417793	7593659	✔	✔				
RC15MEH0060	418487	7594750	✔(S)	✔(S)				
RC15MEH0083	417880	7594552	✔	✔				
RC15MEH0097	417536	7594447	✔	✔				
RC15MEH0114	416434	7594352	✔(S)	✔(S)				
RC15MEH0166	416933	7594851	✔(S)	✔(S)				
RC15MEH0175	416434	7594944	✔	✔				
RC15MEH0190	416733	7595253	✔	✔				
RC15MEH0196	416733	7595748	✔	✔				
RC15MEH0202	416934	7595650	✔	✔				
RC15MEH0230	416334	7595650	✔	✔				
RC15MEH0236	415737	7595850	✔	✔				
RC15MEH0261	418438	7595599	✔	✔				
RC15MEH0268	417695	7596007	✔	✔				
RC15MEH0272	417638	7596399	✔	✔				
RC15MEH0283	417234	7596996	✔(S)	✔(S)				
RC15MEH0289	416840	7597402	✔	✔				
RC15MEH0302	416333	7596351	✔(S)	✔(S)				
RC15MEH0317	415542	7596657	✔	✔				
RC15MEH0329	415435	7596950	✔	✔				

Site Name	Easting (m E)	Northing (m N)	Sampling Phase					
			1	2	3	4	5	6
RC15MEH0375	415035	7597350	✔(S)	✔(S)				
RC15MEH0379	417985	7594250	✔	✔				
RC15MEH0382	418985	7594650	✔	✔				
RC15MEJ0018	419893	7592052	✔	✔				
GR15MEH0009	415533	7594947			✔			
GR15MEH0015	416035	7596750			✔			
GR15MEH0029	417035	7594450			✔			
GR15MEH0032	419085	7594650			✔			
RC15MEH0014	419085	7595251			✔			
RC15MEH0048	417785	7594946			✔			
RC15MEH0049	417787	7594846			✔			
RC15MEH0087	418387	7594450			✔			
RC15MEH0100	418187	7594347			✔			
RC15MEH0109	416933	7594150			✔			
RC15MEH0127	416233	7594350			✔			
RC15MEH0132	415935	7594551			✔			
RC15MEH0153	415736	7594754			✔			
RC15MEH0227	416135	7596248			✔			
RC15MEH0245	415835	7596150			✔			
RC15MEH0274	418038	7596599			✔			
RC15MEH0284	416632	7597202			✔			
RC15MEH0286	416840	7597576			✔			
RC15MEH0306	416431	7596648			✔			
RC15MEH0315	415738	7596650			✔			
RC15MEH0335	415237	7597151			✔			
RC15MEH0339	415735	7597150			✔			
RC15MEH0349	415635	7597550			✔			
RC15MEH0362	415240	7597754			✔			
RC15MEH0371	417035	7594350			✔			
RC15MEH0373	414835	7597450			✔			
RC15MEH0381	418785	7595250			✔			
RC16JIM0001	420285	7591800				✔	✔(S)	
RC16JIM0002	420662	7591812				✔	✔(S)	
RC16JIM0003	420714	7591537				✔	✔(S)	
RC16JIM0004	420900	7591450				✔	✔(S)	
RC16JIM0005	421198	7591536				✔	✔(S)	
RC16JIM0006	421360	7591830	✔	✔			✔	
RC16JIM0007	421774	7591708				✔	✔(S)	
RC16JIM0008	422167	7591581				✔	✔(S)	
RC16JIM0009	422061	7591411				✔	✔(S)	
RC16JIM0010	422450	7591660					✔(S)	
RC16JIM0013	422231	7591306				✔	✔(S)	
RC16JIM0014	423237	7591031					✔(S)	
RC16JIM0015	423273	7590714					✔(S)	
RC16JIM0016	422909	7590883				✔	✔(S)	
RC16JIM0017	422460	7590180				✔	✔(S)	
RC16JIM0018	422698	7590543					✔(S)	
RC16JIM0019	423011	7590291				✔	✔(S)	
RC16JIM0020	423345	7590441				✔	✔(S)	
RC16JIM0021	423110	7591582				✔	✔(S)	
RC16JIM0022	422898	7591243				✔	✔(S)	

Site Name	Easting (m E)	Northing (m N)	Sampling Phase					
			1	2	3	4	5	6
RC16JIM0023	422125	7591136				✔	✔(S)	
RC16JIM0024	421457	7591199				✔	✔(S)	
RC16JIM0025	421176	7591102				✔	✔(S)	
RC16JIM0026	420035	7591850				✔	✔(S)	
RC16JIM0027	419885	7591750				✔	✔(S)	
RC16JIM0028	419885	7591750				✔	✔(S)	
RC16JIM0029	419585	7591850				✔	✔(S)	
RC16JIM0030	419585	7591850				✔	✔(S)	
RC16JIM0031	419789	7591694				✔	✔(S)	
RC16JIM0032	419885	7591627				✔	✔(S)	
RC16MEH0427	415131	7597113				✔	✔(S)	
RC16MEH0428	414786	7597621				✔	✔(S)	
RC16MEH0429	415037	7597616				✔	✔(S)	
RC16MEH0430	414766	7597254				✔	✔(S)	
RC16MEH0431	415143	7597821				✔	✔(S)	
RC16MEH0432	415239	7597832				✔	✔(S)	
RC16MEH0433	415439	7597649				✔	✔(S)	
RC16MEH0434	415641	7597739				✔	✔(S)	
RC16MEH0435	415662	7597625				✔	✔(S)	
RC16MEH0436	415708	7597254				✔	✔(S)	
RC16MEH0437	415892	7597032				✔	✔(S)	
RC16MEH0572	415845	7594449				✔	✔(S)	
RC16MEH0573	415455	7595243				✔	✔(S)	
RC16MEH0574	419335	7593100				✔	✔(S)	
RC16MEH0575	418785	7593300				✔	✔(S)	
MEHRD0577	417838	7593855						✔
MEHRD0757	415139	7596014						✔
MEHRD0758	414937	7595953						✔
MEHRD0834	418837	7592555						✔
MEHRD1021	419587	7594252						✔
DD16MEH0056	415646	7596307						✔
RC15MEJ0019	419264	7592144						✔
RC16MEH0041	417186	7594957						✔
RC16MEH0042	417243	7594901						✔
RC16MEH0255	417229	7594246						✔
RC16MEH0258	417236	7594454						✔
RC16MEH0261	417233	7594651						✔
RC16MEH0264	417476	7594964						✔
RC16MEH0707	415586	7596302						✔
RC16MEH0712	415188	7596057						✔

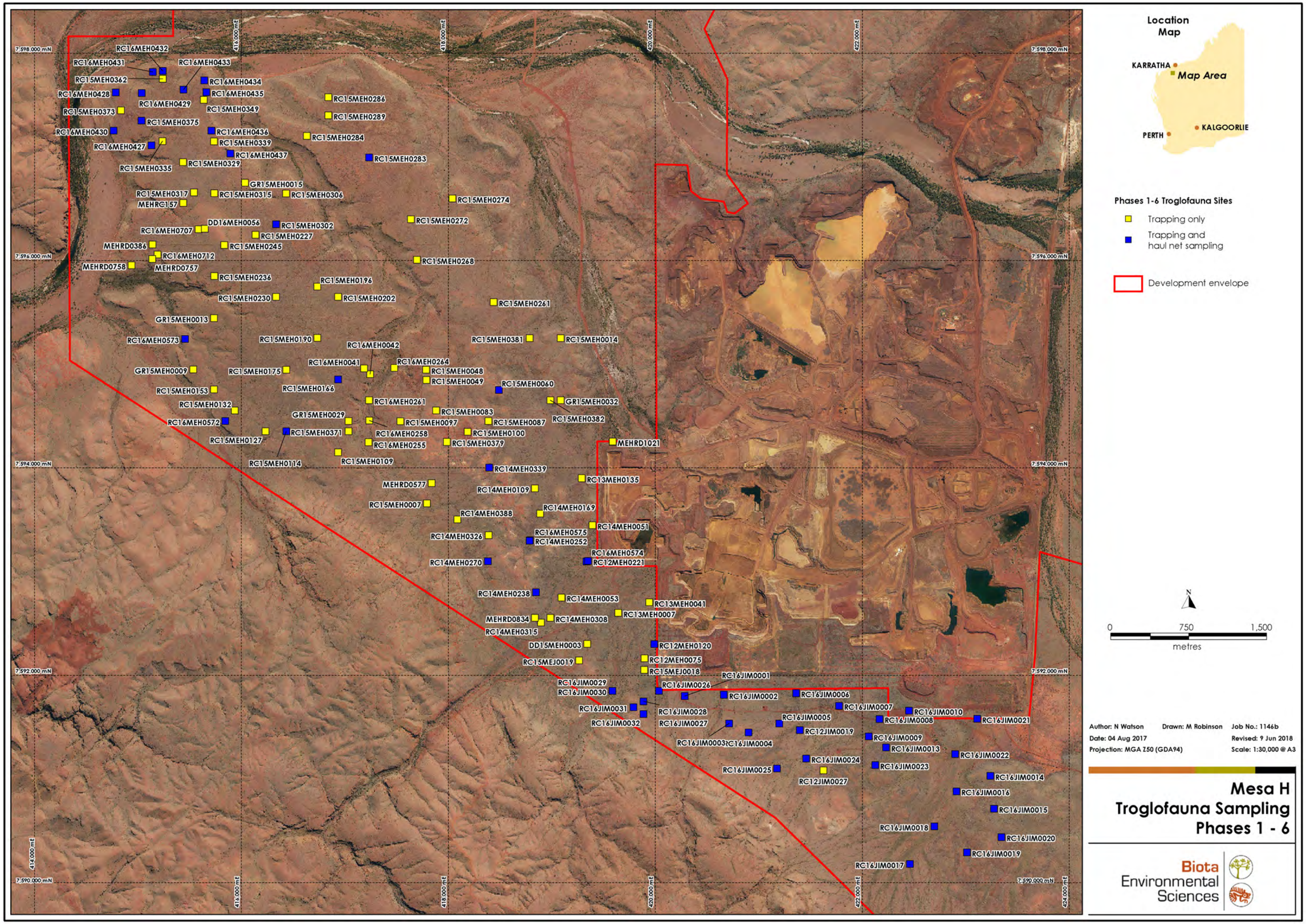

Figure 3.4: Troglofauna sampling sites at Mesa H.

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3.11 Study Limitations

A number of limitations apply to this study that are not necessarily functions of this specific survey, but rather relate to work on subterranean fauna in general. These limitations include:

- There is a lack of adequate taxonomic framework and specialist expertise for some faunal groups, both within Australia and internationally. This often limits the conclusiveness of some of the findings in regards to both taxonomic placement and ecological status.
- Sampling points are often limited to locations of interest for geological exploration: as most drill holes have been sited in areas of mining interest, there is often a lack of sampling points in neighbouring geological units, which may limit interpretations of available subterranean fauna habitat.
- Conservation significance could not be assigned to many taxa which could not be identified to species level, as these specimens may correspond to taxa already known from elsewhere and/or may represent species complexes. The records for these indeterminate specimens are still presented from both desktop and field survey sources, but they are excluded from final tallies of taxa for stygofauna or troglofauna.
- All genetic analysis was completed using the CO1 gene only. This gene was used because it has proved to be relatively fast evolving across many taxonomic groups and a typically reliable indicator of likely species boundaries (Hebert et al. 2003b). Recent studies, however, have indicated that using specific genes for different taxa, or using multiple genes, may provide for more informative results.
- Detailed morphological analysis was not completed for the specimens subject to molecular analysis, and the phylogenetic analysis was based on sequence data from a single mitochondrial gene. Therefore, all species arrived at by this approach should be considered putative unless previously described and fully determined by taxonomic specialists.

Despite these limitations, the survey meets current EPA guidance and is adequate to inform the forthcoming EIA for the Mesa H proposal.

4.0 Desktop Review

4.1 Priority and Threatened Ecological Communities

Threatened Ecological Communities (TECs) are described by DBCA as biological assemblages occurring in a particular habitat, which are under threat of modification or destruction from various processes (DEC 2013). Priority Ecological Communities (PECs) are biological (flora or fauna) communities that are recognised to be of significance, but do not meet the criteria for a TEC.

A total of seven PECs occur within 50 km of the Mesa H development envelope, of which three are relevant to subterranean fauna; all of which overlap the development envelope (Figure 2.1, Table 4.1). No TECs are known within 50 km of the development envelope.

Table 4.1: Priority Ecological Communities within 50 km of the development envelope relevant to subterranean fauna.

Community	Priority
Subterranean invertebrate community of pisolitic hills in the Pilbara A series of isolated low undulating hills occur in the state's Pilbara region. The troglofauna are being identified as having very short range distributions. Threats include mining" (Department of Parks and Wildlife 2016).	Priority 1
Subterranean invertebrate communities of mesas in the Robe Valley region "A series of isolated mesas occur in the Robe Valley in the state's Pilbara Region. The mesas are remnants of old valley infill deposits of the paleo Robe River. The troglobitic faunal communities occur in an extremely specialised habitat and appear to require the particular structure and hydrogeology associated with mesas to provide a suitable humid habitat. Short range endemism is common in the fauna. The habitat is the humidified pisolitic strata. Threats include mining" (Department of Parks and Wildlife 2016).	Priority 1
Stygofaunal Community of the Bungaroo Aquifer "A unique assemblage of aquatic subterranean fauna including eels, snails and other stygofauna. Threats include groundwater drawdown and mining" (Department of Parks and Wildlife 2016).	Priority 1

All three PECs are classified as Priority One, "Poorly-known ecological communities", defined as: "*Ecological communities that are known from very few occurrences with a very restricted distribution (generally ≤5 occurrences or a total area of ≤ 100ha). Occurrences are believed to be under threat either due to limited extent, or being on lands under immediate threat (e.g. within agricultural or pastoral lands, urban areas, active mineral leases) or for which current threats exist. May include communities with occurrences on protected lands. Communities may be included if they are comparatively well-known from one or more localities but do not meet adequacy of survey requirements, and/or are not well defined, and appear to be under immediate threat from known threatening processes across their range"* (DEC 2013).

4.2 Surface Geology

Mesa H is one of several channel iron deposits (CID), which form the Robe Pisolite Formation, a series of paleodrainage channels that meanders through the Robe River valley. CIDs are often preserved in an inverted topography as remnant mesas in the centre of the palaeochannels (Ramanaidou et al. 2003).

The Mesa H development envelope comprises 13 surface geological units (Table 4.2). By area, the majority of the development envelope is accounted for by just two surface geological units: colluvium, covering 34%, and Robe Pisolite Formation, covering 32%. Both of these geological units have been shown to represent suitable habitat for subterranean fauna in the Robe valley and the wider Pilbara region, with Robe Pisolite in particular recognised as core habitat for troglofauna. A more detailed review of the subterranean fauna habitats is presented in Biota (2018).

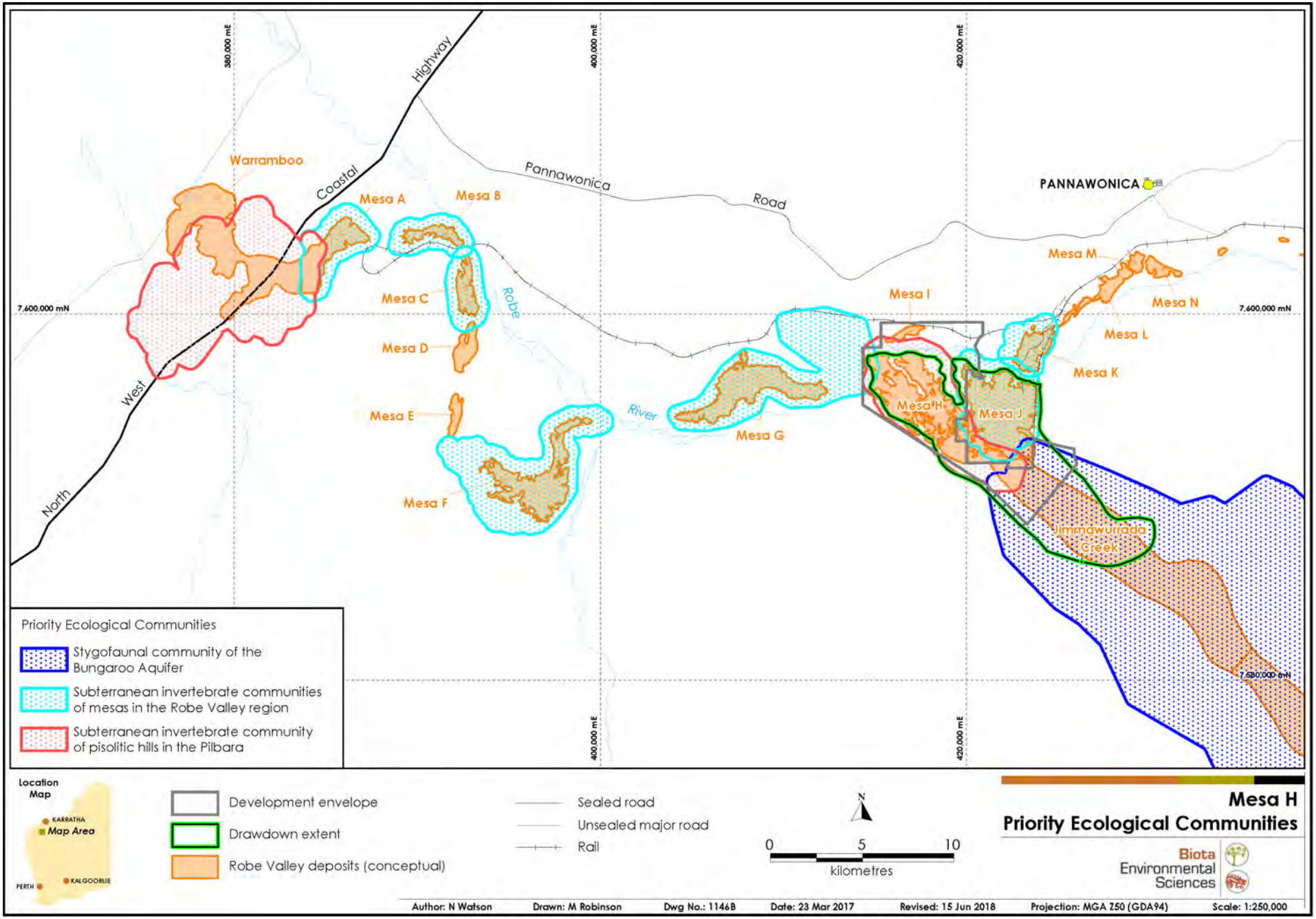

Figure 4.1: PECs relevant to subterranean fauna within 50 km of the Mesa H development envelope.

Table 4.2: Surface geology units of the development envelope and representative sampling effort (units previously identified as subterranean fauna habitat highlighted in yellow).

Eon	Era	Unit code	Description	Surface area (ha)	Proportion of development envelope (%)	Number of stygofauna sites	Number of troglofauna sites
Precambrian	Archaean	Hm	Marra Mamba Iron Formation: Chert, ferruginous chert and banded iron with minor shale; jaspilite with pronounced 'pinch and swell' structures, small occurrences of manganese.	302.1	7.1	-	-
	Proterozoic	Hb	Brockman Iron Formation: Banded jaspilite and chert with some shale dolomitic with riebeckite and crocidolite at Wittenoom Gorge and Dales Gorge. Contains stromatolites.	85.2	2.0	-	-
		Hd	Wittenoom Dolomite Formation: Thin to medium-bedded grey crystalline dolomite, intercalations of chert, dolomitic shale, and metatuff in upper part.	39.4	0.9	-	1
		Hr	Mt Mcrae Shale Formation: Shale, siltstone and dolomitic shale some and some chert.	44.4	1.0	-	-
		Hw	Woongarra Volcanics Formation: rhyolitic and dacitic volcanics, commonly porphyritic, some tuff. Some phases are intrusive.	21.1	0.5	-	-
	-	Wa	Ashburton Formation: wacke, mudstone, ferruginous mudstone interbedded with sandstone and dolomite intruded by doleritic sills.	98.1	2.4	1	6
Phanerozoic	Mesozoic	Kny	Yarraloola Conglomerate: Poorly sorted conglomerate with shale, claystone lenses and interbedded sandstone.	4.1	0.1	-	-
	Cenozoic	Czc	Colluvium: Partly consolidated valley-fill deposits.	51.6	1.2	1	6
		Czd	Duricrust: Indurated crust on older rocks; relict texture and structure preserved in some places	10.1	0.2	-	-
		Qg	Colluvium: Unconsolidated to loosely consolidated slope deposits.	1,471.6	34.5	20	55
		Ql	Lacustrine deposits: Clay, silt; saline in part, flood deposits. Unconsolidated fluviatile and sheet - flood deposits in levees and river terraces.	351.8	8.3	4	2
		Qr	Alluvium: Unconsolidated fluviatile deposits, mostly sand.	382.0	8.9	2	-
		Tp	Robe Pisolite Formation: Pisolitic limonite deposits. Occurs along old river channels.	1,403.3	32.9	13	66
			Total	4,264.8	100	41	136

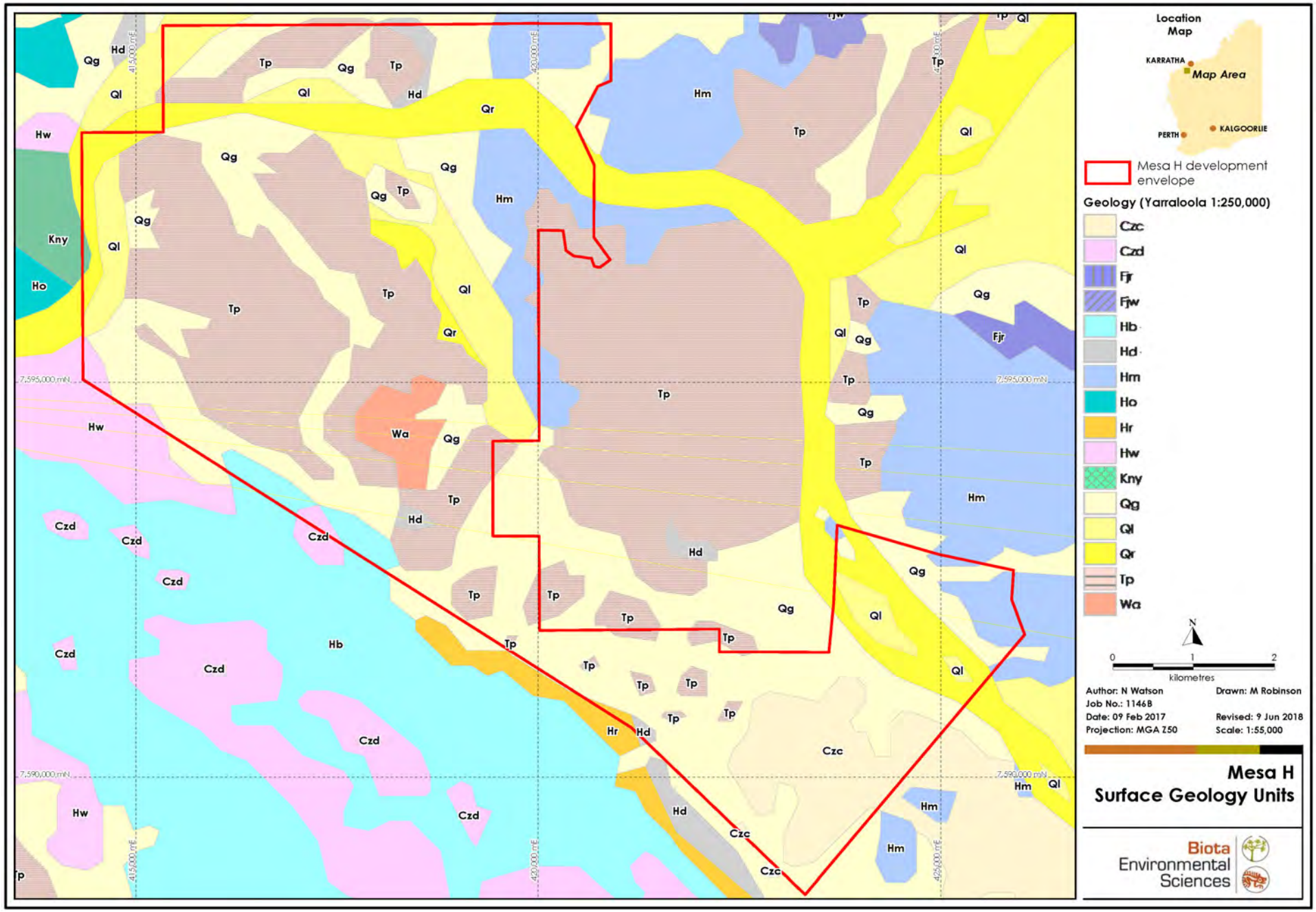

Figure 4.2: Surface geology mapping of the Mesa H development envelope.

4.3 Previous Relevant Surveys

Extensive sampling for troglofauna and stygofauna has been undertaken in areas of proposed development throughout the Robe River valley. Multiple-phase sampling programmes have been undertaken on tenements neighbouring Mesa H, including at Bungaroo (Biota 2010b), Mesa K (Biota 2007) and on Australian Premium Iron's West Pilbara Iron Ore Project (Biota 2010c, 2010d).

Due to the highly localised distributions of subterranean fauna and often mesa-specific species distributions, searches for past survey records were limited to within a desktop review area of a 15 km square around a central point in the development envelope (see Figure 2.1).

A total of seven troglobitic and eight stygobitic fauna surveys have been conducted within the search area (Table 4.3; Figure 4.3; Figure 4.4). The fauna recorded from these surveys within the desktop review area were reviewed and collated and are presented in Section 4.4.

Table 4.3: Summary of surveys completed within 15 km of the Mesa H development envelope (source: Biota database).

Survey	Number of sites within desktop search area	Number of records within desktop search area	Reference
Stygofauna			
Bungaroo Trial Pit Stygofauna Assessment	0	0	Biota (2006b, 2006b)
Bungaroo Creek Subterranean Fauna Summary Phases 1 - 7	10	27	Biota (2010b)
Bungaroo Subterranean Fauna Collections, Phases 1-11 Summary	22	246	Biota (2013)
Bungaroo Coastal Waters Project Stygofauna Monitoring 2014	7	232	Biota (2014)
Bungaroo Coastal Waters Project Stygofauna Monitoring 2015	8	131	Biota (2016a)
Bungaroo Coastal Waters Project Stygofauna Monitoring 2016	8	118	Biota (2016b)
Pilbara Stygofauna Survey	1	1	Halse et al. (2014)
Troglofauna			
Mesa K Remnant Mining Project Troglobitic Fauna Survey	56	174	Biota (2007)
Mesa J Extension Mining Troglofauna Survey*	33	0	Biota (2009)
Bungaroo Creek Subterranean Fauna Summary Phases 1 - 7	3	0	Biota (2010b)
Mesa K Troglobitic Fauna Compliance Monitoring 2010	30	22	Biota (2011b)
Mesa K Troglobitic Fauna Compliance Monitoring 2011	33	54	Biota (2012a)
Mesa K Troglobitic Fauna Compliance Monitoring 2012	33	26	Biota (2012b)
Robe Valley Mesas Troglobitic Fauna Survey 2010	23	26	Biota (2011c)
Bungaroo Subterranean Fauna Collections, Phases 1-11 Summary	4	1	Biota (2013)

*Specimens from this survey were sequenced with specimens from the current survey and included in analysis in Section 5.3.4.

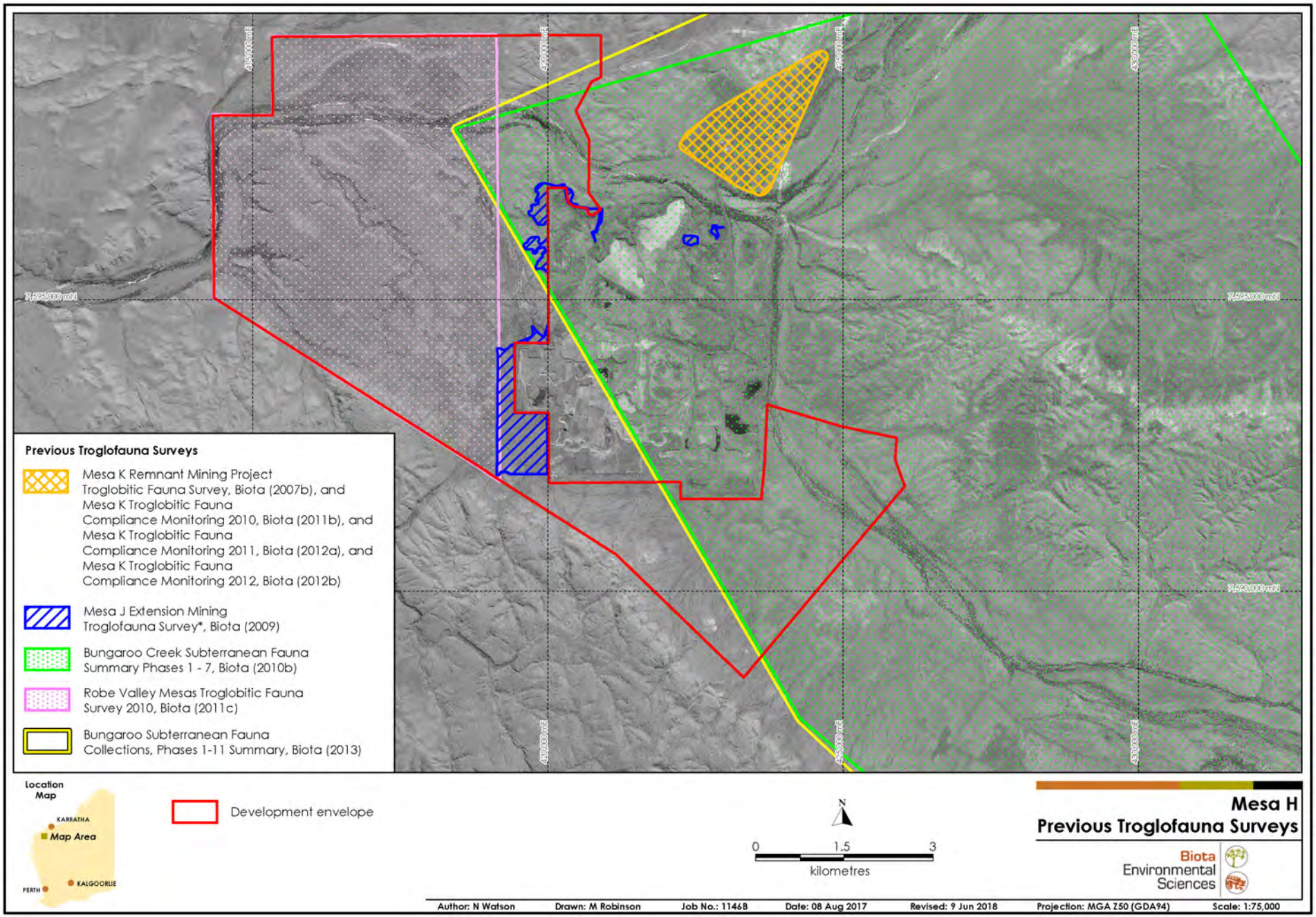

Figure 4.3: Previous troglofauna surveys within 15 km of the Mesa H development envelope.

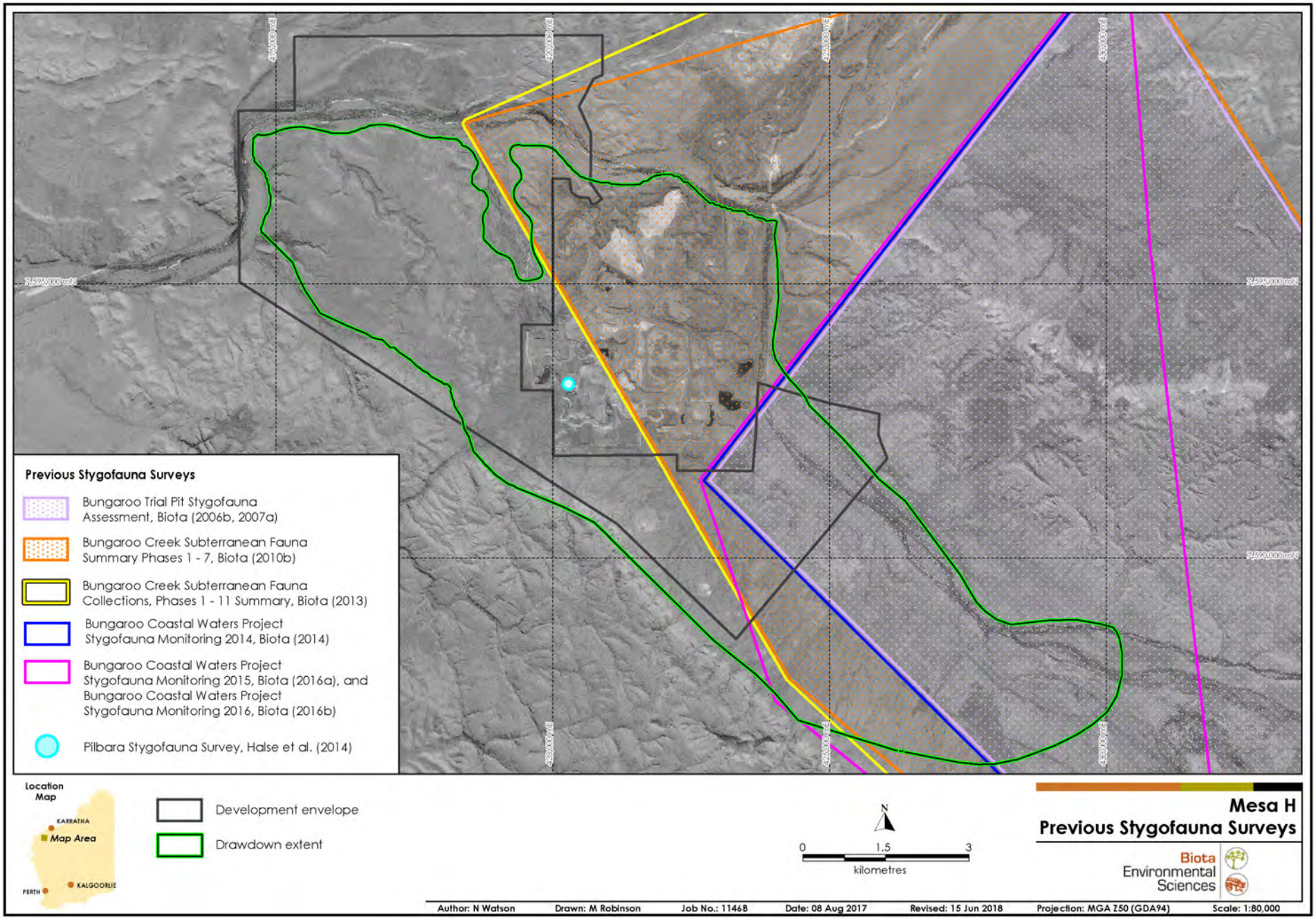

Figure 4.4: Previous stygofauna surveys within 15 km of the Mesa H development envelope.

4.4 Desktop Review Results

4.4.1 Stygofauna

A total of 15 orders were represented amongst the past stygofauna specimens recorded from within the desktop review area, the majority of which were recorded during stygofauna surveys at Bungaroo (Table 4.4; Figure 4.5).

Excluding indeterminate specimens, a total of 22 species-level taxa have been recorded during previous surveys occur within the Mesa H drawdown extent. This included three stygofauna species of conservation significance:

- Blind Cave Eel, *Ophisternon candidum* – Vulnerable; Schedule 3 (see Section 4.4.1.1);
- the amphipod species *Nedsia hurlberti* – Schedule 3; and
- the amphipod species *Nedsia sculptilis* – Schedule 3 (Table 4.4; Figure 4.5).

Five of the remaining 19 taxa are considered to represent potential SRE species (Neoniphargidae sp. 'B02', *Parastenocaris* sp. 'B28', *Haptolana* sp. 'B01', Candoninae sp. 'BOS541' and Hydrobiidae sp. 2; Table 4.4). These taxa have been included in the assessment of taxa recorded from within the drawdown extent in Table 6.1 (see Section 6.2).

4.4.1.1 Blind Cave Eel

The Blind Cave Eel (*Ophisternon candidum*) is a de-pigmented, subterranean fish growing up to 40 cm in length, with a long slender body, no eyes, and a thin rayless membrane around the tip of the tail (DSEWPaC 2008). The Blind Cave Eel is the world's longest cave fish and one of only three vertebrate animals known from Australia that are restricted to subterranean waters (Humphreys 2001b). The species is specially protected under legislation at both State (Schedule 3) and Commonwealth (Vulnerable) levels.

The Blind Cave Eel inhabits groundwater systems in subterranean caves, transmissive geological formations, fissures and wells (Humphreys 2001b). On Cape Range, the Blind Cave Eel is known to utilise cave floor pool sediments characteristic of crustacean-rich cave habitats. It also occurs within the karst aquifers of Barrow Island, though it remains to be confirmed if this record represents the same species as present on Cape Range (Humphreys et al. 2013).

The Blind Cave Eel has also been previously collected from three sites in the Jimawurrada-Bungaroo Creek system, within the current study area. The first specimen was recorded in 2009 at Bungaroo Creek from borehole BC186, 5.6 km southeast of the development envelope and just outside of the current desktop review boundary (Figure 2.1) (Biota 2010e), with subsequent records coming from JW023 (1 km southeast of the development envelope) (Biota 2016b) and the immediately adjacent JW024 in 2017 (C. O'Neill, Rio Tinto, pers. comm. 2017). Tissue from the Bungaroo specimens has been sequenced at both the CO1 mitochondrial DNA and 16S ribosomal RNA markers, showing that the Bungaroo records are less than 1% divergent from the Cape Range specimens, indicating that they are the same species (Foster and Humphreys 2011).

The species is considered likely to be associated with the regional aquifer of the Robe River (Biota and Helix 2014) and it is probable that it occurs within at least the southeast portion of the development envelope in association with the alluvial aquifer of Jimawurrada Creek. Environmental DNA sampling was undertaken as part of the current study in an attempt to better understand the distribution of the species in the locality (Section 3.4).

4.4.2 Troglofauna

Eleven orders were represented amongst the troglofauna taxa previously been recorded within the desktop review area (Table 4.4; Figure 4.6; Figure 4.7; Figure 4.8). One species is of conservation significance; the schizomid species *Paradraculoides kryptus* (Schedule 3). This species is restricted to Mesa K and is very unlikely to occur at Mesa H.

Excluding indeterminate records, four taxa have been recorded from sites within the Mesa H development envelope and two of these are true troglobites considered to represent potential SRE fauna: the isopod species *Troglarmadillo* sp. 1 and the schizomid species *Paradraculoides* sp. nov. 'Mesa H' (Table 4.4; Figure 4.6).

Table 4.4: Stygofauna taxa and abundance (n) recorded from the desktop review (records highlighted in bold were recorded within the drawdown extent).

Order	Family	Species	n	Sites	Record Location	Conservation Significance
Oligochaeta	Naididae	*Antipodrilus* sp. nov.	2	JW023	Bungaroo	N/A
	Phreodrilidae	Phreodrilidae sp. dissimilar ventral chaetae	3	JW023	Bungaroo	Not SRE
	Tubificidae	Tubificidae sp. group B	27	JW011A, JW023	Mesa J, Bungaroo	Not SRE
Turbellaria	-	Platyhelminthes sp. indet.	1	JW024	Bungaroo	N/A
	-	Turbellaria sp. indet.	1	JW021	Bungaroo	N/A
Nematoda	-	Nematoda sp. indet.	4	Hyporheic04	Bungaroo	N/A
Gastropoda	Hydrobiidae	Hydrobiidae sp. 2	4	JW023	Jimmawurrada	Potential SRE
Acari	-	Sarcoptiformes group 1 (PSW)	2	Hyporheic04	Bungaroo	N/A
Ostracoda	Candonidae	*Humphreyscandona fovea*	5	JW011A, JW021	Mesa J, Jimmawurrada	Not SRE
		Humphreyscandona waldockae	1	JW011A	Mesa J	Not SRE
		Humphreyscandona sp. 2	2	JW011A	Bungaroo	Not SRE
		Pierrecandona sp. indet.	1	JW021	Bungaroo	N/A
		Areacandona brookanthana	1	JW023	Jimmawurrada	Not SRE
		Areacandona triangulum	4	JW011A	Mesa J	Not SRE
		Areacandona lepte	4	JW011A	Mesa J	Not SRE
		Pilbaracandona rosa	10	JW011A	Mesa J	Not SRE
		Candoninae sp. 'BOS541'	1	JW024	Jimmawurrada	Potential SRE
Copepoda: Calanoida	Ridgewayiidae	*Stygoridgewayia trispinosa*	132	JIMDR094, JW011A, JW021, JW024	Mesa J, Bungaroo, Jimmawurrada	Not SRE
Copepoda: Cyclopoida	Cyclopidae	*Diacyclops cockingi*	3	JIMDD080, JW021	Jimmawurrada	Not SRE
		Diacyclops humphreysi humphreysi	6	J154, JW023, PZ10BUN004	Bungaroo	Not SRE
		Diacyclops sp. indet	1	JW024	Bungaroo	N/A
		Halicyclops calm	4	JW011A	Mesa J	Not SRE
		Halicyclops rochai	66	JW023	Jimmawurrada	Not SRE
Copepoda: Harpacticoida	Parastenocarididae	*Parastenocaris* sp. 'B28'	1	JW023	Jimmawurrada	Potential SRE
Thermosbaenacea	Halosbaenidae	*Halosbaena tulki*	251	JW021, JW024	Jimmawurrada	Not SRE
Bathynellacea	Bathynellidae	Bathynellidae sp. indet.	1	Unknown	Mesa H	N/A
Isopoda	Cirolanidae	*Haptolana* sp. 'B01'	1	JW024	Jimmawurrada	Potential SRE
		Kagalana tonde	8	JW021, JW023, JW024	Jimmawurrada	Not SRE
	Tainisopidae	*Pygolabis* sp. indet.	1	JW023	Bungaroo	N/A
Amphipoda	Bogidiellidae	Bogidiellidae sp. indet.	13	JW021, JW024	Jimmawurrada	N/A
	Melititdae	Melitidae sp. 1 (PSS)	3	JW023	Jimmawurrada	Not SRE
		Melitidae sp. 1 nr norcarpensis	1	JW021	Jimmawurrada	Not SRE
		Nedsia hurlberti	134	JIMDD080, JIMDR094, JW011A, JW021, JW023, JW024	Mesa J, Bungaroo	Conservation Significant - Schedule 3
		Nedsia sculptilis	86	JIMDR094, JW011A, JW021	Mesa J, Bungaroo	Conservation Significant - Schedule 3
		Nedsia sp. indet.	4	J154, JW023, JW024	Bungaroo	N/A

Order	Family	Species	n	Sites	Record Location	Conservation Significance
	Neoniphargidae	Neoniphargidae sp. 'B02'	3	JW021	Bungaroo	Potential SRE
	Paramelitidae	Paramelitidae Genus 2 sp.	1	JW024	Jimmawurrada	N/A
		Paramelitidae sp. indet.	2	JIMDR094	Bungaroo	N/A
		Amphipoda sp. indet.	42	BUNUNK01, J154, JW023, JW024	Bungaroo	N/A
Synbranchiformes	Synbranchidae	*Ophisternon candidum*	2	JW023, JW024	Jimmawurrada	Conservation Significant – Vulnerable; Schedule 3

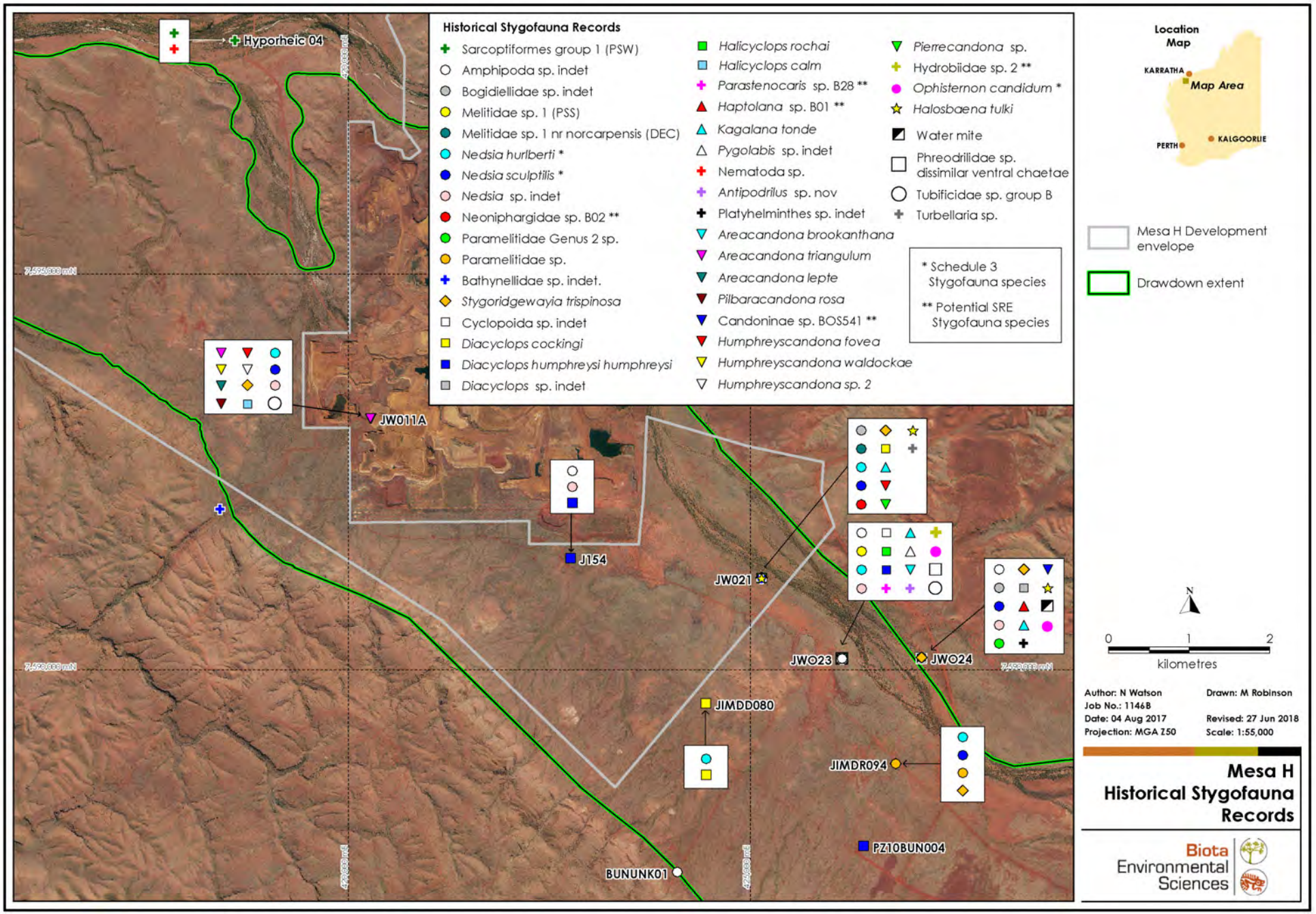

Figure 4.5: Stygofauna records from the desktop review.

Table 4.5: Troglofauna taxa and abundance (n) recorded during the desktop review (Taxa highlighted in bold were recorded within the Mesa H development envelope).

Order	Family	Species	n	Sites	Location	Conservation Significance
Araneae	Micropholcommatidae	*Eperiella* 'ARA050'	1	MEK1685A	Mesa K	Potential SRE
Blattodea		Blattodea sp. indet.	1	K1318	Mesa K	N/A
Chilopoda	Scolopendridae	Scolopendridae sp. 'CHI025'	1	DD14MEL0001	Mesa L	Potential SRE
		Cryptops sp. 1	1	MEK1570	Mesa K	Potential SRE
		Cryptops sp. indet.	1	Unknown	Mesa K	N/A
Coleoptera	Curculionidae	Curculionidae sp. 'CCU007'	5	MEK1478, MEK1718	Mesa K	Potential SRE
	Ptiliidae	Ptiliidae sp. 'CPT003'	11	K0968, MEK1721	Mesa K	Potential SRE
		Coleoptera sp. indet	76	K1303, MEK1701, MEK1731, MEK1735, MEK1694, MEK1478, MEK1728, K0503, K0607	Mesa K	N/A
Diplura	-	*Heterojapyx* sp. indet.	1	MEK1478	Mesa K	N/A
Isopoda	Armidillidae	*Barrowdillo* sp. 1	11	MEHRDO752, MEHRD0776	Mesa H	Not troglobitic, Not an SRE
		Troglarmadillo sp. 1	1	MEHDC0865	Mesa H	Potential SRE
	Oniscidae	*Haloniscus* sp. 1	1	MEK1337	Mesa K	Potential SRE
		Hanoniscus sp. 'Mesa K1'	1	Unknown	Mesa K	Potential SRE
		Hanoniscus sp.	1	Unknown	Mesa K	Potential SRE
	Philosciidae	Philosciidae sp. 'ISP050'	2	K0989, MEK1735A	Mesa K	Potential SRE
		nr *Andricophiloscia* sp. 'B19'	1	Unknown	Mesa K	Potential SRE
	-	Isopoda sp. indet.	3	K0989, K1318, MEHDC0865	Mesa K, Mesa H	N/A
Polydesmida	Polydesmidae	Polydesmida sp. indet.	9	K0741, K0949, K1315, MEK1712, K0502, MEK1685	Mesa K,	N/A
Polyxenida	Lophoproctidae	Lophoproctidae sp. indet.	8	MEK1478, MEK1712, MEK1718, MEK1731,	Mesa K	Not an SRE
		Polyxenida sp. indet.	12	MEK1551, MEK1552, MEK1556, MEK1337, MEK1685A, MEK1712, MEHRC0955	Mesa K, Mesa H	Not troglobitic, Not an SRE
Pseudoscorpiones	Syarinidae	*Ideoblothrus* sp. 'Mesa K'	1	MEK1685A	Mesa K	Potential SRE
		Ideoblothrus sp. nov	1	MEK1721	Mesa K	Potential SRE
	Hyidae	Hyiidae sp. 'PH019'	1	K0996	Mesa K	Potential SRE
		Indohya sp. Mesa K	1	K0741	Mesa K	Potential SRE
		Indohya sp. nov	1	MEK1696	Mesa K	Potential SRE
		Indohya sp. indet.	1	BC314, K0607, K0502	Mesa K	Potential SRE
	Chthoniidae	Chthoniidae sp. 'PCH009'	1	DD14MEL0001	Mesa L	Potential SRE
		Chthoniidae sp. 'PCH048'	2	MEK1731	Mesa K	Potential SRE
		Chthoniidae sp. 'PCH051'	1	MEK1721	Mesa K	Potential SRE

Order	Family	Species	n	Sites	Location	Conservation Significance
		Lagynochthonius sp. 'Mesa K'	2	MEK1685, MEK1735	Mesa K	Potential SRE
		Lagynochthonius sp. nov	1	MEK1689	Mesa K	Potential SRE
		Lagynochthonius sp. indet.	1	MEK1731	Mesa K	Potential SRE
	Olpiidae	Olpiidae sp. indet.	1	K0502	Mesa K	Potential SRE
	Atemnidae	Paratemnoides sp. indet.	1	K0607	Mesa K	Potential SRE
		Anatemnus 'PSE081'	1	K1074	Mesa K	Potential SRE
		Oratemnus 'PSE081'	1	Unknown	Mesa K	Potential SRE
	-	Pseudoscorpion sp. indet.	2	MEK1685, MEK1689	Mesa K	Potential SRE
Schizomida	Hubbardiidae	*Paradraculoides kryptus*	36	K0607, K0948, K0989, MEK0672, MEK0739, MEK1337, MEK1478, MEK1685, MEK1685A, MEK1689A, MEK1696, MEK1702, MEK1718, MEK1732, MEK1735A	Mesa K	Conservation Significant - Schedule 3
		Paradraculoides sp. indet. (Juvenile or female individuals, likely to be *P. kryptus*)	166	K0557, K0607, K0608, K0672 K0673, K0740, K0989, K0996, K1066, K1068, K1074, K1075, K1328, K1337, K1598, MEK1456, MEK1458, MEK1475, MEK1478, MEK1482, MEK1524, MEK1529, MEK1551, MEK1553 MEK1556, MEK1558, MEK1570, MEK1609, MEK1685, MEK1685A, MEK1689, MEK1689A, MEK1694, MEK1696, MEK1697, MEK1703 MEK1712, MEK1718, MEK1721, MEK1724, MEK1728, MEK1731, MEK1732, MEK1735, MEK1735A, MEK1757, OPK02	Mesa K	Conservation Significant - Schedule 3 (if *P. kryptus*)
		Paradraculoides sp. 'SCH004/004a'	1	DD14MEL0001	Mesa L	Potential SRE
		Paradraculoides sp. nov. "Mesa H"	8	MEHRC0724, MEHRC0870, MEHRC0894	Mesa H	Potential SRE
		Schizomida sp. indet.	2	DD14MEL0001	Mesa L	N/A
Zygentoma	-	Zygentoma sp. indet.	1	MEK1731	Mesa K	N/A

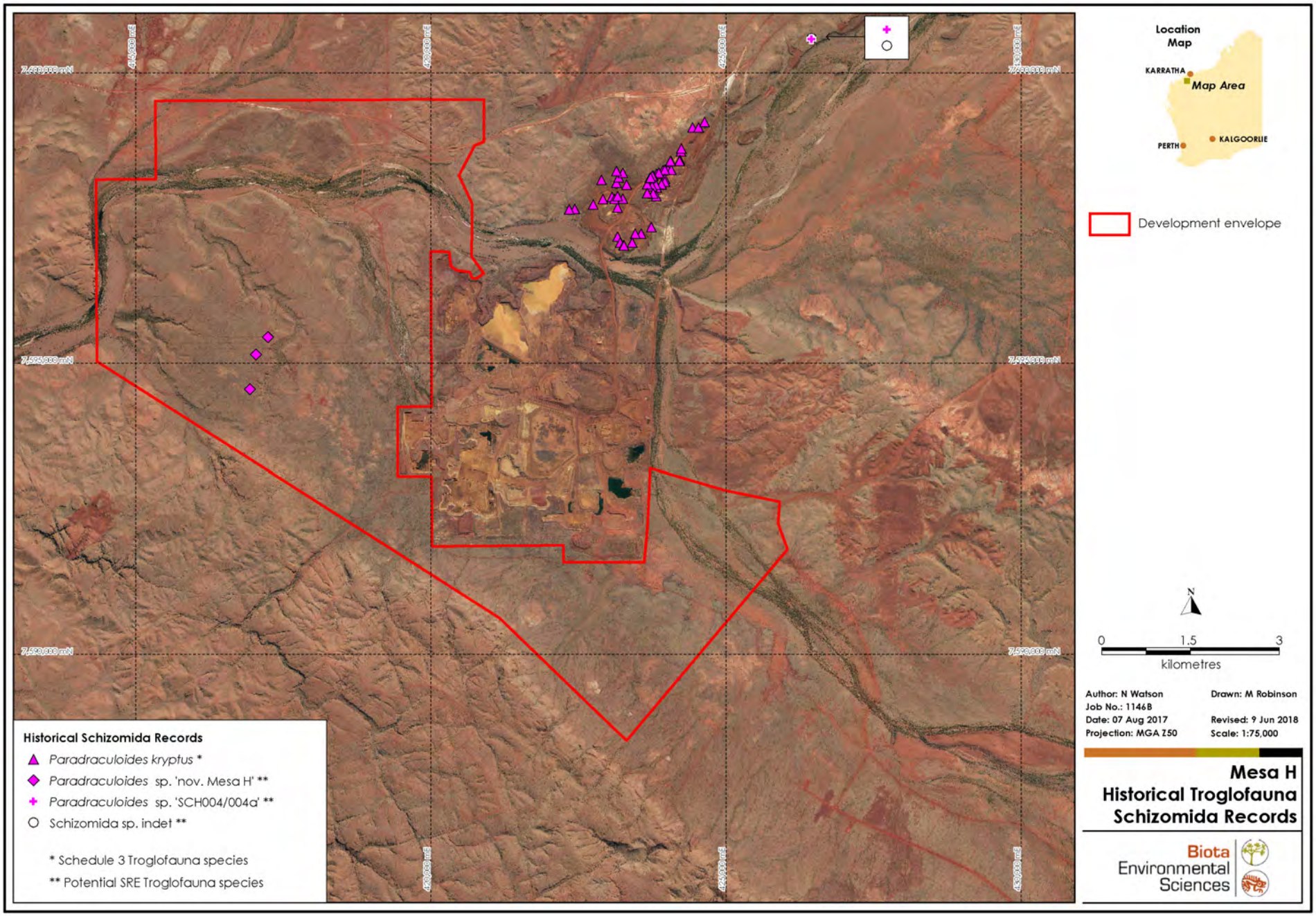

Figure 4.6: Schizomid records from the desktop review.

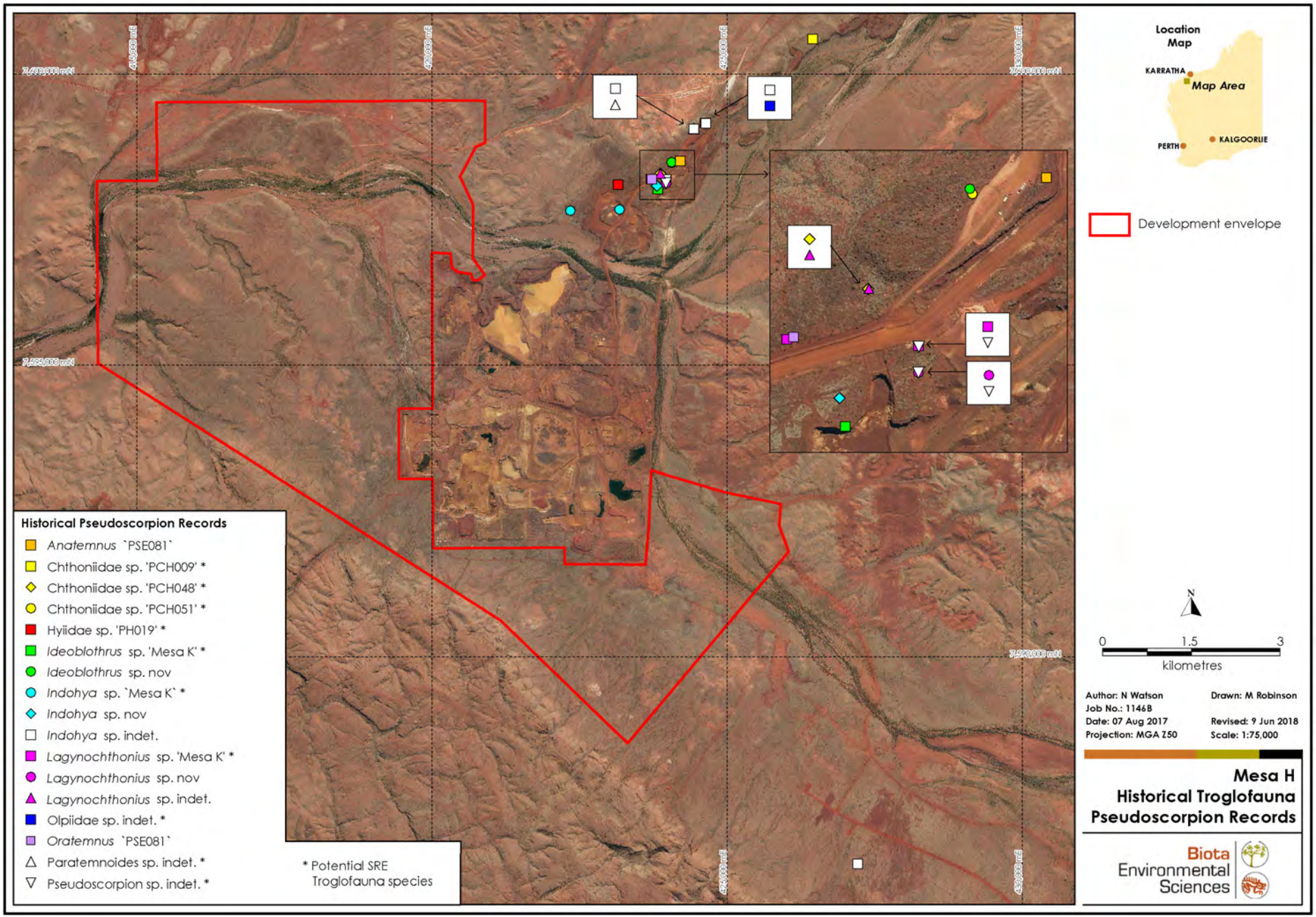

Figure 4.7: Pseudoscorpion records from the desktop review.

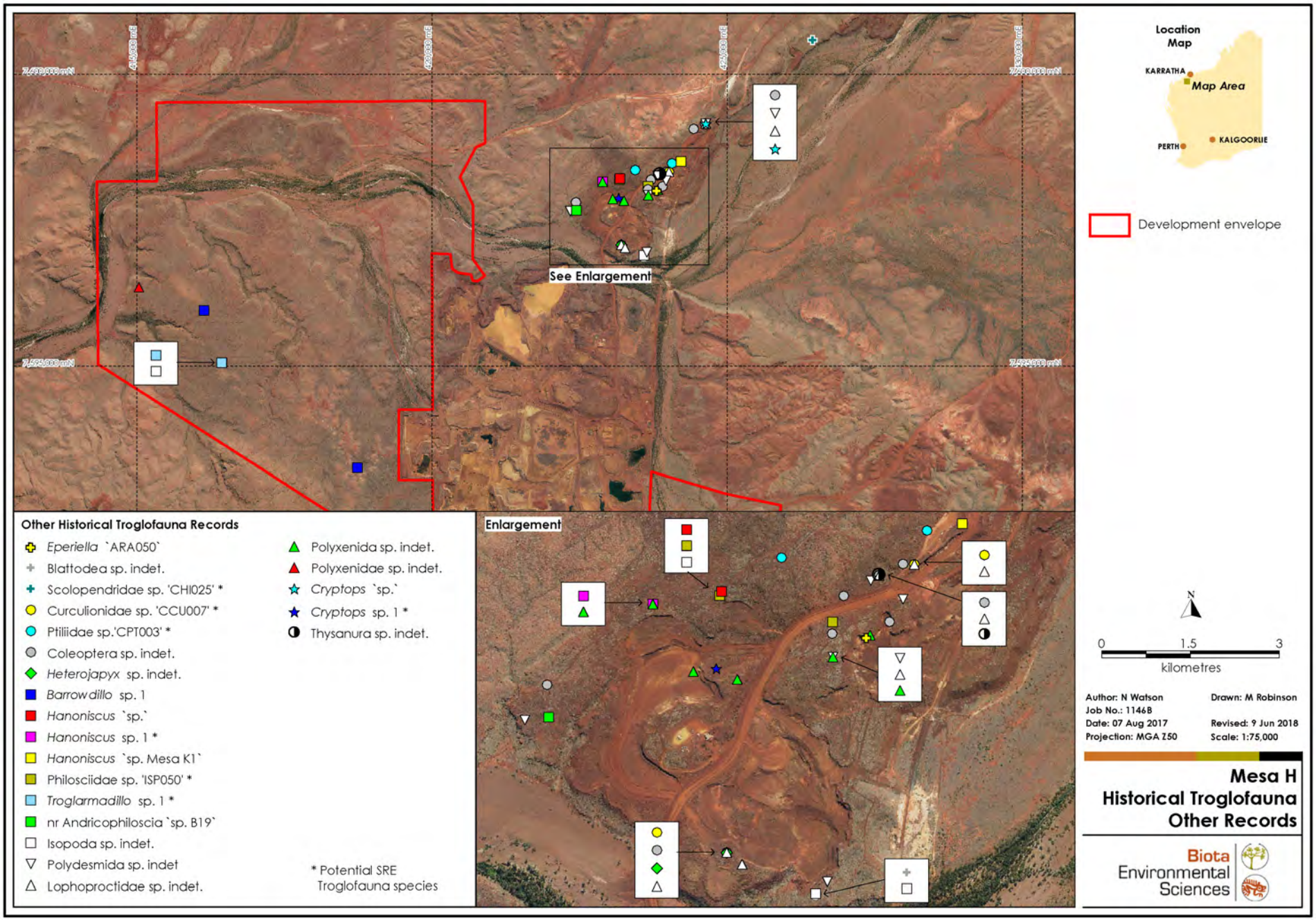

Figure 4.8: Other troglofauna records from the desktop review.

5.0 Survey Results

5.1 Stygofauna

A total of 855 stygofauna specimens were recorded over five phases of sampling, comprising at least 43 species-level taxa (excluding indeterminate specimens that could not be resolved to species level). The fauna was dominated by the Crustacea, which was represented by seven orders, with the Maxillopoda (copepods) and Amphipoda (amphipods) accounting for the most specimens (48% and 37% of total specimens respectively; Table 5.1). The least commonly recorded groups were the oligochaete and nematode worms (n=1 and 2 respectively), isopods (n=4), water mites (order Tombidiformes; n=4) and snails (order Hypsogastropoda; n=2) (Table 5.1).

Table 5.1: Summary of stygofauna recorded during the current survey (n= number of specimens).

Taxonomy				n	Number of Sites
Phylum	Subphylum	Class	Order		
Annelida	-	Oligochaeta	Tubificida	1	1
Platyhelminthes	-	-	-	9	2
Nematoda	-	-	-	2	2
Mollusca	-	Gastropoda	Hypsogastropoda	2	1
Arthropoda	Chelicerata	Arachnida	Trombidiformes	4	3
	Crustacea	Ostracoda	Podocopida	83	9
		Maxillopoda	Calanoida	236	20
			Cyclopoida	138	17
			Harpacticoida	36	3
		Malacostraca	Thermosbaenacea	20	3
			Isopoda	4	2
			Amphipoda	320	24
			Total	855	

A detailed account of the fauna recorded, including the results of genetic analysis, follows in Sections 5.1.10 to 5.1.3. Record locations for the lower abundance groups are shown in Figure 5.1, with the numerically dominant Maxillopoda in Figure 5.2 and Amphipoda in Figure 5.3.

5.1.1 Class Oligochaeta (Earthworms)

A single oligochaete was recorded from site BC186, on the margin of the drawdown extent (Figure 5.1). The specimen was identified as *Enchytraeus* sp. 'AP PSS1', which has previously been recorded during the Pilbara Biodiversity Survey from approximately 39 km to the west (Halse et al. 2014).

5.1.2 Phylum Platyhelminthes (Flatworms)

A total of nine platyhelminth specimens were recorded from sites 31 and 32, both of which were outside of the drawdown extent (Figure 5.1). These specimens are unable to be identified below phylum level due to a lack of taxonomic framework for this group.

5.1.3 Phylum Nematoda (Nematode Worms)

Two nematode specimens were recorded from two sites within the drawdown extent during the survey (DD13MEH0007 and RC12JIM0019; Figure 5.1). These specimens are unable to be identified below phylum level due to a lack of taxonomic framework for this group.

5.1.4 Class Gastropoda (Aquatic Snails)

Eight specimens of hydrobiid snails were recorded from site MB17MEH0007 to the north of the drawdown extent during the Phase 5 sampling (Figure 5.1). The specimens were identified to morphotype level as Hydrobiidae sp. 'B09', which appears to be distinct from other hydrobiid snail forms collected previously from the adjacent Bungaroo valley (Biota 2015a).

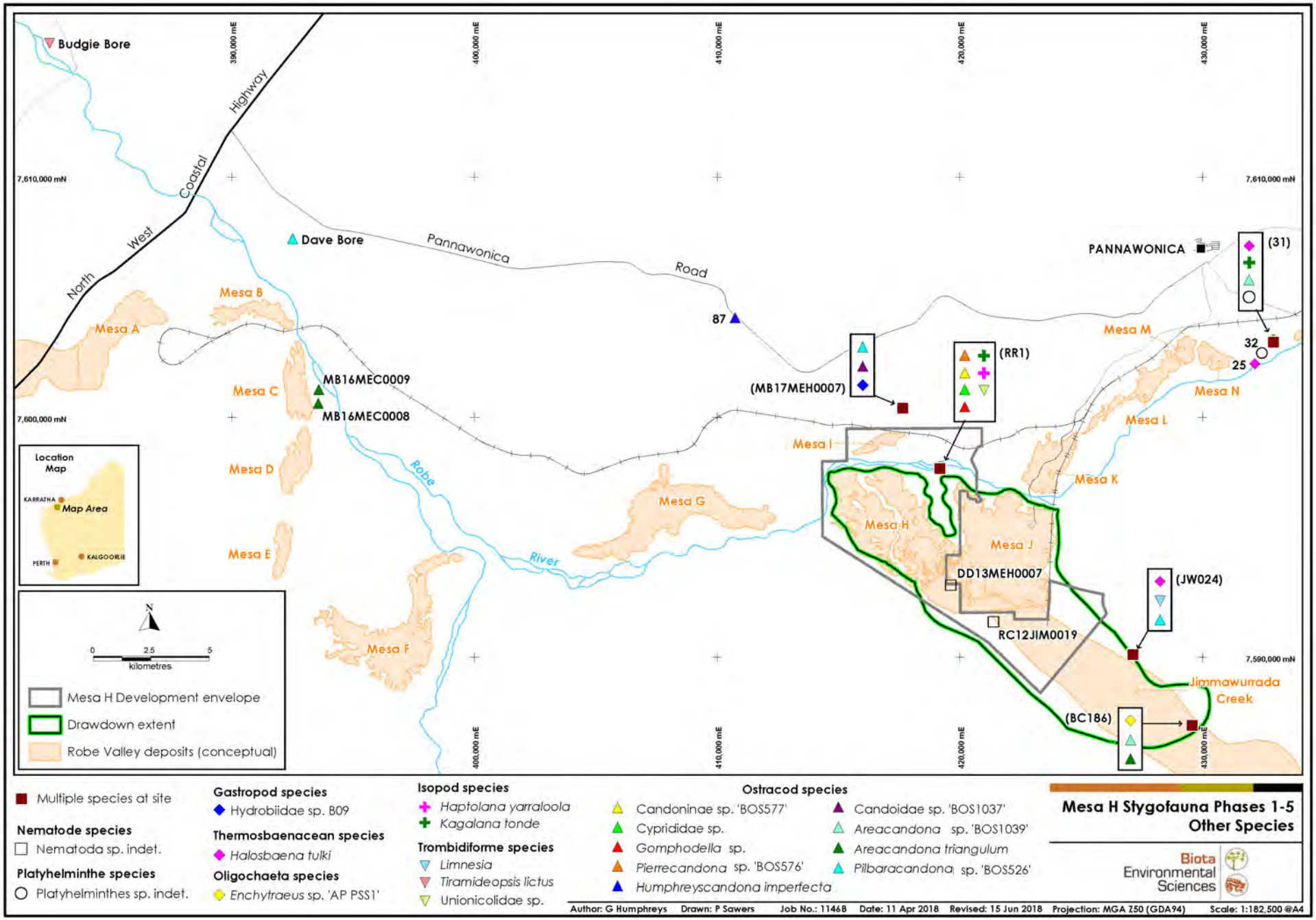

Figure 5.1: Lower abundance stygofauna taxa recorded from Mesa H during the current survey.

5.1.5 Order Trombidiformes (Water Mites)

Three water mite taxa were recorded during the survey, all during the Phase 5 sampling (Appendix 5; Table 5.2). Two of the taxa, Unionicolidae sp. indet and *Tiramideopsis lictus*, were recorded from sites outside of the drawdown extent (Figure 5.1).

Table 5.2: Summary of water mite taxa recorded from the current survey (*denotes sites outside of the drawdown extent).

Family	Species	Site	Number
Limnesiidae	*Limnesia* sp. indet.	JW024	1
Mideopsidae	*Tiramideopsis lictus*	Budgie Bore*	2
Unionicolidae	Unionicolidae sp. indet.	RR1*	1
		Total	4

5.1.6 Order Ostracoda (Ostracods)

Eighty-three ostracod specimens were recorded during the Mesa H survey (Table 5.3; Figure 5.1), with one specimen from site RR1 unable to be resolved below family level (Cyprididae sp.). Two taxa represented were previously known species (*Humphreyscandona imperfecta* and *Areacandona triangulum*) were recorded (Table 5.3), which are both originally described from elsewhere in the Pilbara (Karanovic 2005).

Gomphodella sp. from site RR1 was the sole representative of the Limnocytheridae (Table 5.3), and all of the five remaining ostracod taxa belong to the family Candonidae and are currently undescribed. Two of these, *Pilbaracandona* sp. 'BOS526' and *Pierrecandona* sp. 'BOS576', have been recorded previously from Warramboo (Biota 2017) and Bungaroo (Biota 2016b), respectively. None of the ostracod taxa are known only from the drawdown extent (Table 5.3).

Table 5.3: Summary of ostracod taxa recorded from the current survey (*denotes sites outside of the drawdown extent).

Family	Species	Site	Number
Cyprididae	Cyprididae sp.	RR1*	1
Limnocytheridae	*Gomphodella* sp.	RR1*	3
Candonidae	Candoninae sp. 'BOS577'	RR1*	3
	Humphreyscandona imperfecta	87*	3
	Pierrecandona sp. 'BOS576'	RR1*	2
	Pilbaracandona sp. 'BOS526'	Dave Bore*, MB17MEH0007*, JW024	10
	Areacandona sp. 'BOS1039'	BC186, 31*	9
	Areacandona triangulum	MB16MEC0008*, MB16MEC0009*, BC186	27
	Candonidae sp. 'BOS1037'	MB17MEH0007*	25
		Total	83

5.1.7 Subclass Copepoda (Copepods)

Nine species of copepod were identified from amongst the 410 specimens collected during the survey, representing four families (Figure 5.2; Table 5.4). Seventeen juvenile specimens could only be morphologically determined to genus level (*Diacyclops* sp.; Table 5.4). All of the described species recorded are widespread and previously known from outside the survey area (Biota 2016b).

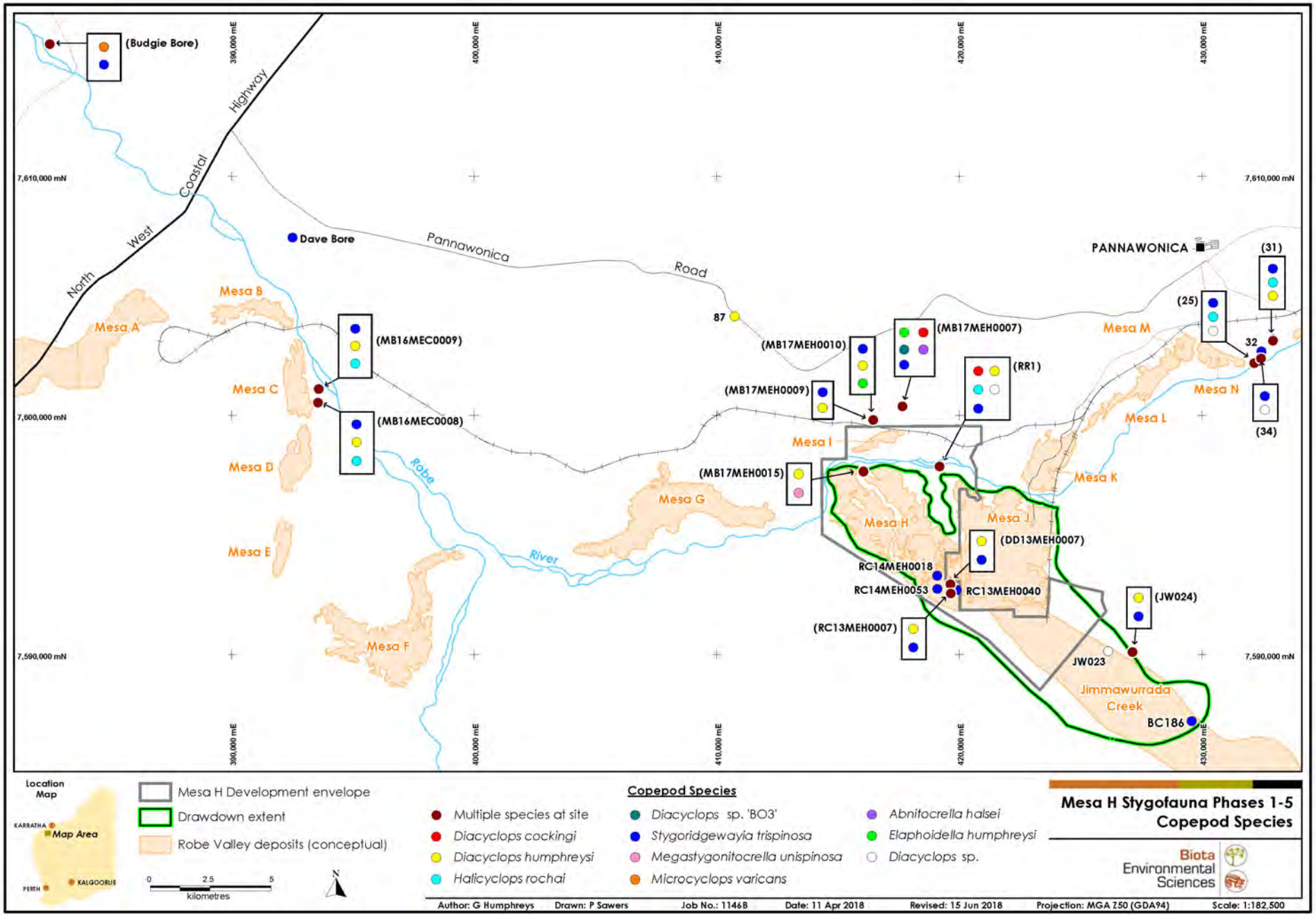

Figure 5.2: Copepod taxa recorded from Mesa H during the current survey.

Table 5.4: Summary of copepod taxa recorded from the current survey (*denotes sites outside of the drawdown extent).

Family	Species	Site	Number
Ridgewayiidae	*Stygoridgewayia trispinosa*	25*, 31*, 32*, 34*, Dave Bore*, Budgie Bore*, RR1*, MB16MEC0008*, MB16MEC0009*, MB17MEH0007*, MB17MEH0009*, MB17MEH0010*, BC186, DD13MEH0007, JW024, RC13MEH0007, RC13MEH0040, RC14MEH0018, RC14MMEH0053	236
Cyclopidae	*Diacyclops cockingi*	RR1*, MB17MEH0007*	24
	Diacyclops humphreysi humphreysi	31*, 87*, JW024*, RR1*, MB16MEC0008*, MB16MEC0009*, MB17MEH0007*, MB17MEH0009*, MB17MEH0010*, DD13MEH0007, RC13MEH0007, MB17MEH0015	68
	Diacyclops sp. 'BO3'	MB17MEH0007*	1
	Halicyclops rochai	25*, 31*, RR1*, MB16MEC0008*, MB16MEC0009*, Budgie Bore*	20
	Microcyclops varicans	Budgie Bore*	8
	Diacyclops. sp.	25*, 34*, RR1*, JW023	17
Ameiridae	*Abnitocrella halsei*	MB17MEH0007*	1
	Megastygonitocrella unispinosa	MB17MEH0015	2
Canthocamptidae	*Elaphoidella humphreysi*	MB17MEH0007*	33
		Total	410

5.1.8 Order Thermosbaenacea (Thermosbaenaceans)

Twenty specimens of *Halosbeana tulki* were recorded from three sites; JW024, 25 and 31, the latter two of which are outside of the drawdown extent (Table 5.5; Figure 5.1). *H. tulki* is widespread and has been collected commonly from the Bungaroo Valley (Biota 2016b) as well as from locations around Cape Range, Barrow Island and Warramboo (Humphreys 1989, Humphreys et al. 2013, Biota 2017). Recent molecular work has indicated that this taxon may actually represent a species complex containing at least five separate species that reflect local geography (Page et al. 2016). Records of *H. tulki* from the Robe River would belong to the Pilbara high elevation species.

Table 5.5: Summary of thermosbaenaceans recorded from the current survey (*denotes sites outside of the drawdown extent).

Family	Species	Site	Number
Thermosbaenacidae	*Halosbaena tulki*	25*, 31*, JW024	20

5.1.9 Order Isopoda (Isopods)

Four stygal isopods belonging to two described species were recorded from site 31 and RR1, both of which are outside the drawdown extent (Table 5.6; Figure 5.1). *Haptolana yarraloola* was originally described from records from Yarraloola station (Bruce 2008) and has also been recorded from the Warramboo area (Biota 2017). *Kagalana tonde* is widespread in the west Pilbara (Biota 2010c) and has been recorded adjacent to the Mesa H survey area from Bungaroo (Biota 2016b).

Table 5.6: Summary of stygal isopod taxa recorded from the current survey (*denotes sites outside of the drawdown extent).

Family	Species	Site	Number
Cirolanidae	*Haptolana yarraloola*	RR1*	1
	Kagalana tonde	RR1*, 31*	3
		Total	4

5.1.10 Order Amphipoda (Amphipods)

A total of 320 amphipod specimens were recorded, comprising 19 taxa from three families (Table 5.7; Figure 5.3). Eighty-four specimens that were unable to be identified to species level remained as Amphipoda sp. indet (Table 5.7). These specimens were unable to be determined due to either a failure to sequence or where large numbers of specimens of the same morphotype were recorded from the same site (only a subsample of the specimens from such sites were sequenced; Section 3.7).

A total of 148 specimens recorded across 16 sites were assigned to lineage AMM001 (Table 5.7). This lineage was placed into a well-supported group which has been assigned the putative species name of *Nedsia* sp. 'AMM001' (family Eriopisidae), which is part of a species complex containing multiple other closely-related (<5% mean sequence divergence) lineages from the locality (Helix 2017a). This species complex has been recorded at multiple locations throughout the Robe River valley including from Warramboo, Budgie Bore and Camp Bore (Biota 2017, Helix 2017a) (Appendix 3).

An additional taxon belonging to family Eriopisidae, *Nedsia* sp. 'AMM031' was also recorded from a single site outside of the drawdown extent (Dave Bore; Table 5.7; Figure 5.3). This lineage was originally included within the *Nedsia* sp. 'AMM001' species complex but discussion with genetic and taxonomic specialists at Helix, WAM and the South Australian Museum have conservatively determined that *Nedsia* sp. 'AMM031' is likely to be a distinct species, though additional specimens and further analysis would be needed to more fully confirm this. This species has also been recorded from Dave Bore, Budgie Bore and Mesa A (Biota 2017, Helix 2017a) (Table 5.7).

Six other taxa from the family Eriopisidae, *Nedsia* sp. 'AMM004', sp. 'AMM06', sp. 'AMM022', sp. 'AMM031', sp. 'AMM032' and sp. 'AMM033', were also recorded during the survey, but none of these were detected within the drawdown extent (Table 5.7; Figure 5.3). Three of these taxa, *Nedsia* sp. 'AMM004', sp. 'AMM032' and sp. 'AMM033', represent new species not previously recorded in the Pilbara (Helix 2017a) (Appendix 3). The final erioposid taxon, Nedsia sp. 'AMM026' was recorded from within the drawdown extent, but also occurs outside (at site 31; Table 5.7; Figure 5.3).

Five species of Neoniphargidae amphipods were recorded from the survey area (Table 5.7), consisting of one species that has been recorded elsewhere in the Robe River valley; Neoniphargidae sp. 'AMN008' (Biota 2017), and three new species that had not previously been recorded in the region: Neoniphargidae sp. 'AMN002', sp. 'AMN003' and *Wesniphargus* sp. 'AMN004' (Helix 2017a) (Appendix 3). Additional sequencing of historical survey specimens by the WAM found that records of both Neoniphargidae sp. 'AMN003' and *Wesniphargus* sp. 'AMN004', had previously gone unrecognised as such from sampling at Bungaroo (Cullen and Harvey 2017). *Wesniphargus* sp. 'AMN004' was the only neoniphargid taxa to be recorded from the drawdown extent, but was also recorded from reference site 25 (Table 5.7), in addition to the earlier Bungaroo record. The fifth species, Neoniphargidae sp. 'B02', was recorded from site 32 on the basis of morphology. This species has also been recorded from a site within the Mesa H development envelope during a previous survey at Bungaroo (Biota 2013) (see Section 4.4.1).

The final family, Paramelitidae, was represented by six species, with three recorded from within the drawdown extent: Paramelitidae sp. 'AMP003' sp., 'AMP035' (Plate 5.1) and 'AMP037', two of which were collected as singletons (Table 5.7), and appear to represent new taxa not previously detected in the region (Helix 2017a) (Appendix 3).

Plate 5.1: Paramelitidae sp. 'AMP035' from drillhole RC13MEH0007.

Table 5.7: Summary of amphipod taxa recorded from the current survey (*denotes sites outside of the drawdown extent).

Family	Lineage	Species	Site	Number
Eriopisidae	AMM001	*Nedsia* sp. 'AMM001'	25*, 31*, 32*, 34*, Budgie Bore*, DD13MEH0007, JW024, RC12JIM0019, RC13MEH0040, RC13MEH0041, RC13MEH0097, RC14MEH0018, RC14MEH0053, RC16JIM0019, RR1	148
	AMM004	*Nedsia* sp. 'AMM004'	87*, Dave Bore*, MB16MEC0009*	16
	AMM006	*Nedsia* sp. 'AMM006'	MB16MEC0008*, MB16MEC0009*	2
	AMM022	*Nedsia* sp. 'AMM022'	MB17MEH0007*	1
	AMM026	*Nedsia* sp. 'AMM026'	31*, RC13MEH0097	6
	AMM031	*Nedsia* sp. 'AMM031'	Dave Bore*	3
	AMM032	*Nedsia* sp. 'AMM032'	31*	1
	AMM033	*Nedsia* sp. 'AMM033'	MB17MEH0007*, MB17MEH0009*, MB17MEH0010*	27
Neoniphargidae	AMN002	Neoniphargidae sp. 'AMN002'	RR1*	1
	AMN003	Neoniphargidae sp. 'AMN003'	32*	1
	AMN004	*Wesniphargus* sp. 'AMN004'	25*, JW024	4
	AMN008	Neoniphargidae sp. 'AMN008'	Dave Bore*, Budgie Bore*	11
	-	Neoniphargidae sp. 'B02'	32*	1
Paramelitidae	AMP003	Paramelitidae sp. 'AMP003'	RC13MEH0041	1
	AMP009	Paramelitidae sp. 'AMP009'	Budgie Bore*	1
	AMP035	Paramelitidae sp. 'AMP035'	RR1*, RC13MEH0007	8
	AMP036	*Chydaekata* sp. 'AMP036'	RR1*	1
	AMP037	Paramelitidae sp. 'AMP037'	BC186	1
	AMP038	Paramelitidae sp. 'AMP038'	25*, RR1*	2
Indeterminate	Failed to sequence or not sequenced	Amphipoda sp. indet.	31*, 34*, 87*, MB17MEH0010*, RR1*, BC186, DD13MEH0007, JW024, RC12JIM0019, RC16JIM0019, RC13MEH0007	84
			Total	320

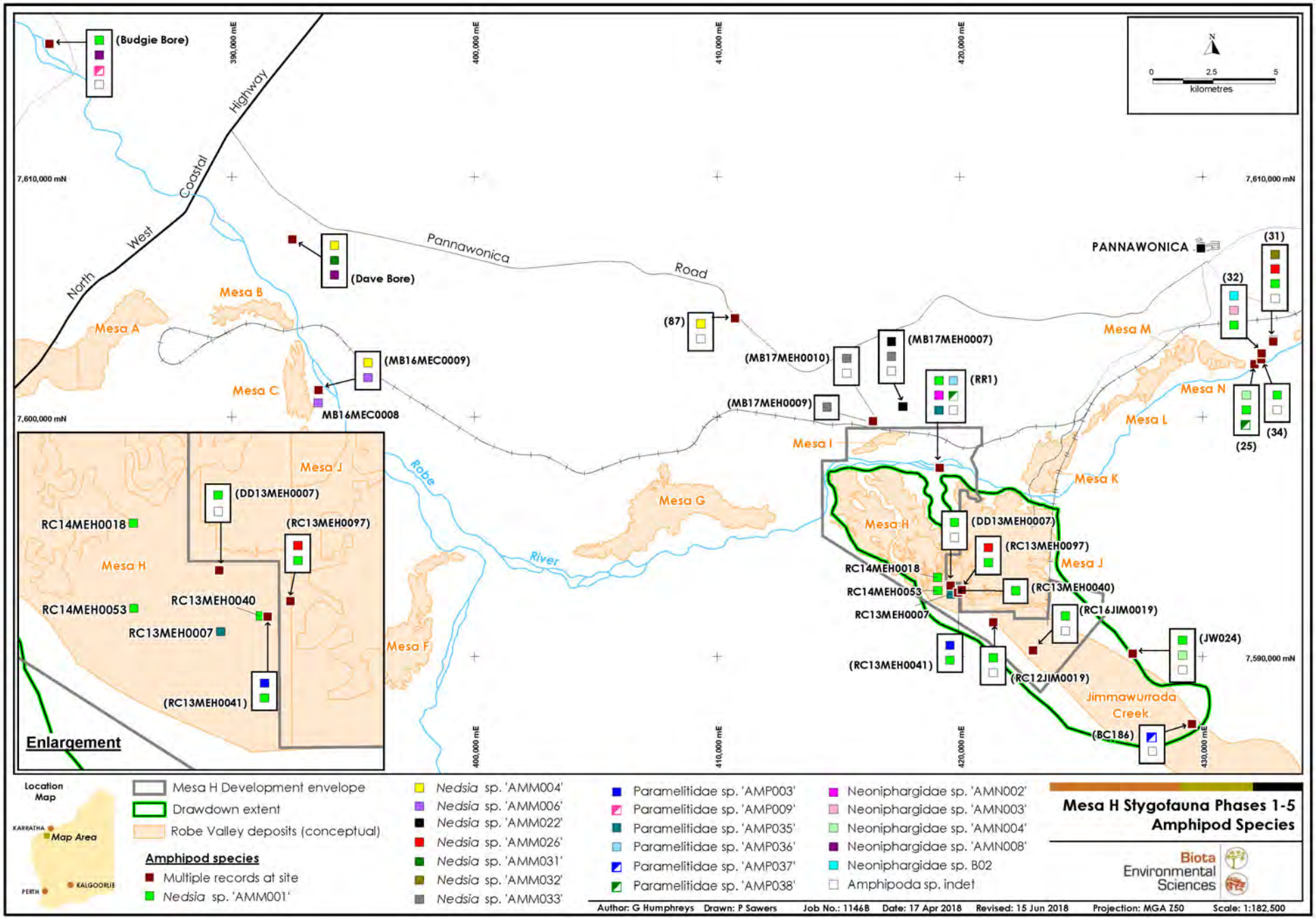

Figure 5.3: Amphipoda taxa recorded from Mesa H during the current survey.

5.2 eDNA

Replicated samples from the 16 sites where groundwater was sampled for eDNA were analysed by two different molecular methods in an attempt to detect residual DNA from the Blind Cave Eel (*Ophisternon candidum*) (Section 3.4).

Six of the 16 eDNA sampling sites yielded positive results for *Ophisternon* DNA by at least one method (Figure 5.4; Table 5.8), with the results from sites 25, MB17MEH0015 and the Control site having an even higher degree of confidence being independently detected by both laboratories (Table 5.8). An additional site, JW021, which was previously sampled for groundwater as part of previous work (Figure 5.4; Table 5.8), also yielded a positive detection during the preliminary metabarcoding analysis undertaken by Curtin University (Appendix 4).

Table 5.8: Results of eDNA analysis of environmental samples ('Y' = positive detection of *Ophisternon* DNA; *denotes sites outside of the drawdown extent; †denotes detection only after refinement of metabarcoding methods (latter section of Appendix 4)).

			Ophisternon DNA Detected?		
Site	Easting (m E)	Northing (m N)	Helix qPCR Assay	Curtin Metabarcoding	Notes
Control*	424478	7597147	Y	Y	Surface pool site
25*	432152	7602229	Y	Y	
MB17MEH0015	416041	7597690	Y	Y†	
RR1*	419176	7597904	-	Y	
31*	432929	7603179	-	-	
Dave Bore*	392512	7607436	-	-	
BC186	429578	7587212	-	Y†	Confirmed eel site
BC401*	443563	7574126	-	-	
Budgie Bore*	382495	7615587	-	-	
JW023	426138	7590140	-	-	Confirmed eel site
JW024	427126	7590154	-	Y†	Confirmed eel site
MB16MEC0008*	393565	7600580	-	-	
MB16MEC0009*	393590	7601145	-	-	
MB17MEH0007*	417664	7600421	-	-	
MB17MEH0008*	417120	7600417	-	-	
MB17MEH0009*	416436	7599848	-	-	
MB17MEH0010*	416440	7599848	-	-	
JW021	424138	7589754	Not sampled	Y	Sampled previously

The qPCR assay is a targeted molecular method that will only identify the presence of target DNA in an environmental sample when both the species-specific primer and the specific-specific probe match the DNA present in the sample (Biota and Helix 2014). This means the positive results from the qPCR assay from sites 25, MB17MEH0015 and the Control sample can all be regarded with confidence as containing *Ophisternon candidum* DNA (Table 5.8) (Helix 2018).

The metabarcoding approach uses a high throughput approach to amplify DNA and in the case of this study the 16S gene was specifically targeted during amplification to compare against reference sequence data. The findings from the preliminary Curtin University analysis were that possible *Ophisternon* DNA was detected from site 25 and RR1, as well as site JW021 (Table 5.8; Figure 5.4). The sequences from the JW021 site were a 100% match for the known *O. candidum* sequences from JW024, and those from sites 25 and RR1 were a 97% match. Subsequent additional work using an assay specifically developed for *Ophisternon* resulted in further detections at three other sites, including MB17MEH0015; where the qPCR assay had independently detected eDNA belonging to the species (Table 5.8).

In addition to the desktop review records, a specimen was recently recorded from the phreatic zone of the Robe River during aquatic fauna sampling in a surface pool in the river (Biota 2018) (site RRD2; Figure 5.4). Considered in total then, the eDNA positive sites and specimen collection locations to date comprise five sites within the drawdown extent and four sites outside (Figure 5.4).

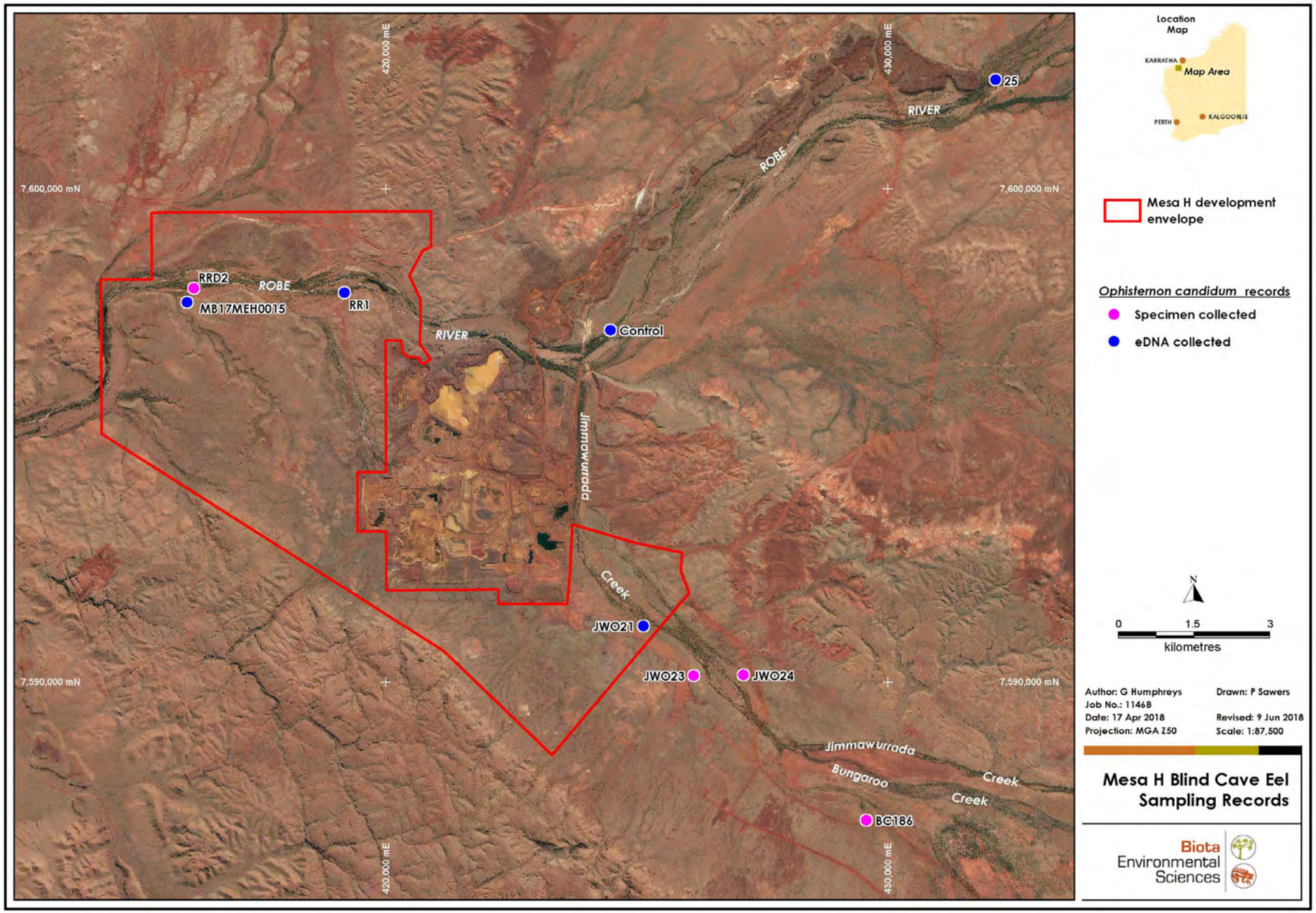

Figure 5.4: Locations where positive eDNA results were recorded for *Ophisternon* DNA detection, in context with confirmed *Ophisternon* specimen collection locations.

5.3 Troglofauna

A total of 150 troglobitic specimens were collected across the six phases of sampling of the Mesa H survey area (Table 5.9). The specimens represented five classes and nine orders and 32 taxa (Appendix 5). A total of 150 troglobitic specimens were collected across the six phases of sampling of the Mesa H survey area (Table 5.9). The specimens represented five classes and nine orders and 32 taxa (Appendix 5). The orders Coleoptera and Schizomida were the greatest contributors to faunal composition, accounting for 33% and 25% of the specimens, respectively.

Table 5.9: Summary of troglobitic fauna recorded from Mesa H during the current survey (n= number of specimens collected).

Taxonomy				n	Number of Sites
Phylum	Subphylum	Class	Order		
Arthropoda	Chelicerata	Arachnida	Araneae (Spiders)	2	2
			Pseudoscorpiones (Pseudoscorpions)	14	12
			Schizomida (Schizomids)	37	22
	Hexapoda	Entognatha	Diplura (Bristletails)	12	11
		Insecta	Blattodea (Cockroaches)	2	2
			Coleoptera (Beetles)	50	5
			Zygentoma (Silverfish)	2	2
	Crustacea	Malacostraca	Isopoda (Slaters)	30	4
	Myriapoda	Chilopoda	Scolopendromorpha (Centipedes)	1	1
			Total	150	

As is common during troglofauna surveys, a large number of edaphobitic (deep soil adapted fauna) and epigean (surface) specimens were also collected. These specimens are not troglobitic and are therefore not discussed further in this report.

A detailed account of the troglobitic fauna recorded, including discussion of the results of genetic analysis, follows in Sections 5.3.1 to 5.3.6. Record locations are presented in Figure 5.16.

5.3.1 Order Diplura (Diplurans)

Twelve dipluran specimens were recorded and assigned to nine lineages based on molecular analysis (Helix 2017b) (Table 5.10; Figure 5.16). Two specimens failed to sequence and were therefore indeterminate (Diplura sp. indet.), while three lineages were closely related (3.5 % sequence divergence) and were combined into one species; Projapygidae sp. 'DPR008/009/011'. The remaining six lineages identified correspond to six new species (Helix 2017b) (Figure 5.5).

Table 5.10: Summary of dipluran taxa recorded from the current survey.

Family	Lineage	Species	Site	Number
Parajapygidae	DPA001	Parajapygidae sp. 'DPA001' (Plate 5.2).	RC14MEH0308	1
	DPA009	Parajapygidae sp. 'DPA009'	MEHRD0758	1
Projapygidae	DPR008	Projapygidae sp. 'DPR008/DPR009/DPR011'	RC15MEH0166, RC15MEH0175, RC15MEH0261, RC16JIM0005	4
	DPR009			
	DPR011			
	DPR010	Projapygidae sp. 'DPR010'	RC16JIM0005	1
Japygidae	DJA003	Japygidae sp. 'DJA003'	RC14MEH0388	1
	DJA011	Japygidae sp. 'DJA011'	DD13MEH0007	1
Campodeidae	DCA005	Campodeidae sp. 'DCA005'	GR15MEH0032	1
Indeterminate	Failed to sequence	Diplura sp. indet.	RC15MEH0114, RC16MEH0264	2
			Total	12

Plate 5.2: Parajapygidae sp. 'DPA001' from drillhole RC14MEH0308.

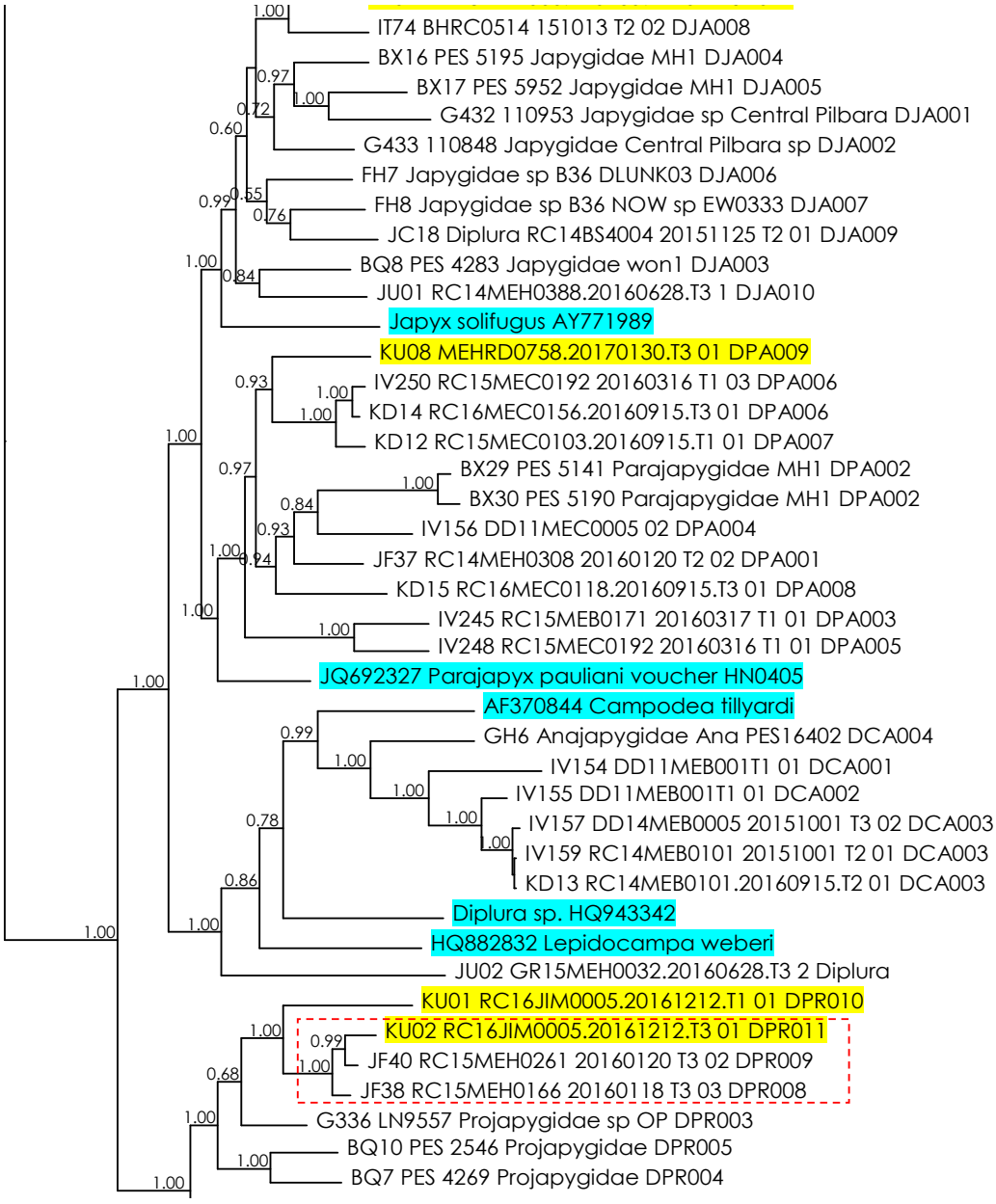

Figure 5.5: Bayesian analysis of CO1 haplotypes of Diplura recorded from the Mesa H survey area. (Numbers on major nodes correspond to posterior probabilities; values <50% are not shown. Specimens from the current study are highlighted in yellow; GenBank specimens are highlighted in turquoise. Red boxes enclose species with high confidence. Red boxes with dashed lines indicate lineages combined to form single species for the purposes of this assessment.

5.3.2 Order Isopoda (Slaters)

A total of 30 troglomorphic isopod specimens were recorded from the survey area, 27 of which were sequenced. Ten of these specimens failed to yield a sequence and therefore remained indeterminate as Isopoda sp. indet., along with three specimens that were not sequenced as large numbers of specimens of the same morphotype were recorded from the same site (Table 5.11). The remaining 17 specimens were assigned to four lineages belonging to two families; Philosciidae and Armadillidae (Table 5.11; Figure 5.16).

All four collected lineages are new, however the two philosciid lineages (Philosciidae. sp. 'ISP047' and 'ISP055') are closely related (5.1 % sequence divergence) (Figure 5.6) and may represent the same species, but confirming this requires further investigation using morphological analysis of adult specimens or sequencing of additional genes (Helix 2017b). In the interests of a conservative assessment, the two taxa are maintained as distinct species in the current report (Table 5.11).

Of the two armadillid lineages, Lineage ISA046 was assigned to the species *Troglarmadillo* sp. 'ISA046' and differed by 18.5% to its mostly closely related lineage (ISA054 from Mesa C) (Figure 5.7). The second armadillid Lineage, ISA057, was closely related (4.5 % sequence divergence) to a lineage previously recorded from Mesa C (lineage 'ISA056') (Figure 5.8) (Helix 2017b), and the two lineages were grouped to form a single putative species, Armadillidae sp. 'ISA056/ISA057' (Table 5.11).

Table 5.11: Summary of isopod taxa recorded from the current survey.

Family	Lineage	Species	Site	Number
Philosciidae	ISP047	Philosciidae sp. 'ISP047'	RC15MEH0382	6
	ISP055	Philosciidae sp. 'ISP055'	RC15MEH0427	1
Armadillidae	ISA046	*Troglarmadillo* sp. 'ISA046'	RC15MEH0382	1
	ISA057	Armadillidae sp. 'ISA056/ISA057'	MEHRD0577, MEHRD0834	9
Indeterminate	Failed to sequence	Isopoda sp. indet.	MEHRD0577, MEHRD0834	13
			Total	30

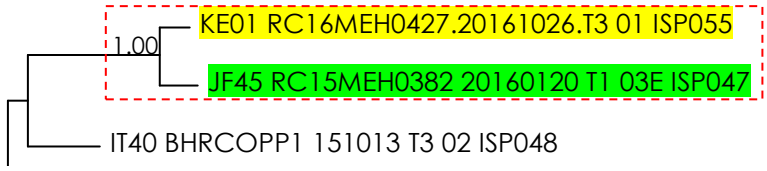

Figure 5.6: Excerpt of bayesian analysis of CO1 haplotypes of Philosciidae recorded from the Mesa H survey area (see Appendix 3 for complete phylogenetic tree).

(Numbers on major nodes correspond to posterior probabilities; values <50% are not shown. Specimens from the current study are highlighted in yellow (Phase 1 – 3) and green (Phase 4 - 6. Red boxes enclose species with high confidence. Red boxes with dashed lines indicate lineages grouped into a single species for the purposes of this assessment.

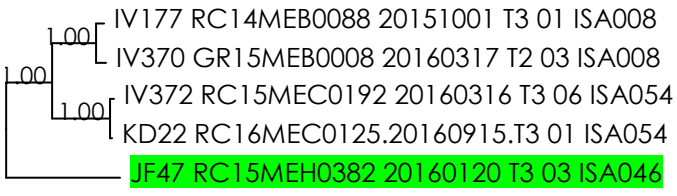

Figure 5.7: Excerpt of Bayesian analysis of CO1 haplotypes of Armadillidae recorded from the Mesa H survey area (see Appendix 3 for complete phylogenetic tree).

(Numbers on major nodes correspond to posterior probabilities; values <50% are not shown. Specimens from the current study are highlighted in green.

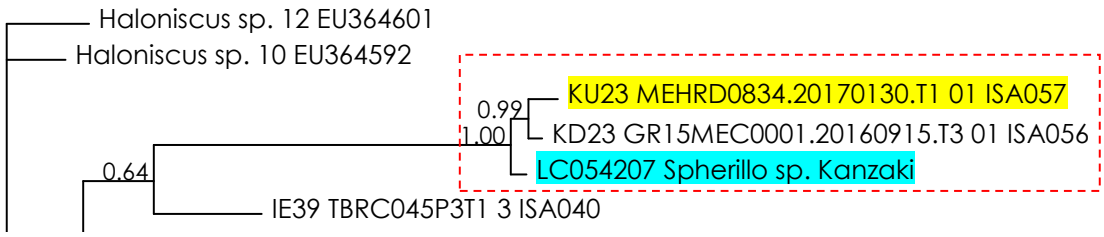

Figure 5.8: Excerpt of bayesian analysis of CO1 haplotypes of Armadillidae recorded from the Mesa H survey area, showing Lineage ISA057 in context with Lineage ISA056 from Mesa C (see Appendix 3 for complete phylogenetic tree).

(Numbers on major nodes correspond to posterior probabilities; values <50% are not shown. Specimens from the current study are highlighted in yellow; GenBank specimens are highlighted in turquoise. Red boxes enclose species with high confidence. Red boxes with dashed lines indicate groups requiring further investigation.

5.3.3 Order Pseudoscorpiones (Pseudoscorpions)

Fourteen pseudoscorpion specimens were recorded from the survey area. Molecular analysis placed the specimens into 10 lineages, which correspond to eight species across three families (Helix 2017b) (Table 5.12; Figure 5.9 to Figure 5.11; Figure 5.16).

Representative photographs of four of the taxa are presented in Plate 5.3 to Plate 5.6. Two specimens failed to sequence and remained indeterminate as Pseudoscorpion sp. indet.. None of the eight species recorded have been previously detected in the Pilbara (Helix 2017b).

Table 5.12: Summary of pseudoscorpion taxa recorded from the current survey.

Family	Lineage	Species	Site	Number
Hyidae	PH017, PH027	Hyidae sp.'PH017/PH027'	RC14MEH0252, RC16MEH0264	2
	PH026	Hyidae sp. 'PH026'	RC16MEH0436	1
Olpiidae	PO008	Olpiidae sp. 'PO008'	RC15MEH0302	1
	PO014	*Beierolpium* sp. 'PO014'	RC16JIM0026	1
	PO015	*Beierolpium* sp. 'PO015'	RC16MEH0433	1
Atemnidae	PA004	Atemnidae sp. 'PA004'	RC15MEH0329	1
Chthoniidae	PC014, PC015	Chthoniidae sp. 'PC014/PC015'	GR15MEH0015, RC15MEH0315, RC15MEH0335	4
	PC055	Chthoniidae sp. 'PC055'	MEHRD0834	1
Indeterminate	Failed to sequence	Pseudoscorpion sp. indet.	RC12MEH0120	2
			Total	14

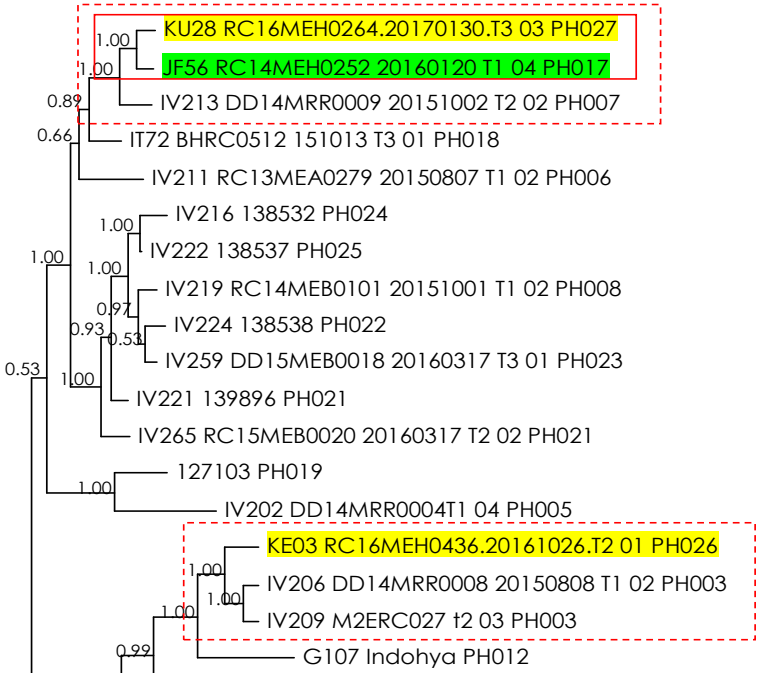

Figure 5.9: Excerpt of bayesian analysis of CO1 haplotypes of Hyiidae recorded from survey area. (Numbers on major nodes are posterior probabilities; values <50% not shown. Specimens from the current survey highlighted in yellow (Phase 1 – 3) and green (Phase 4 – 6). Red boxes enclose species with high confidence. Boxes with dashed lines denote groups requiring further investigation).

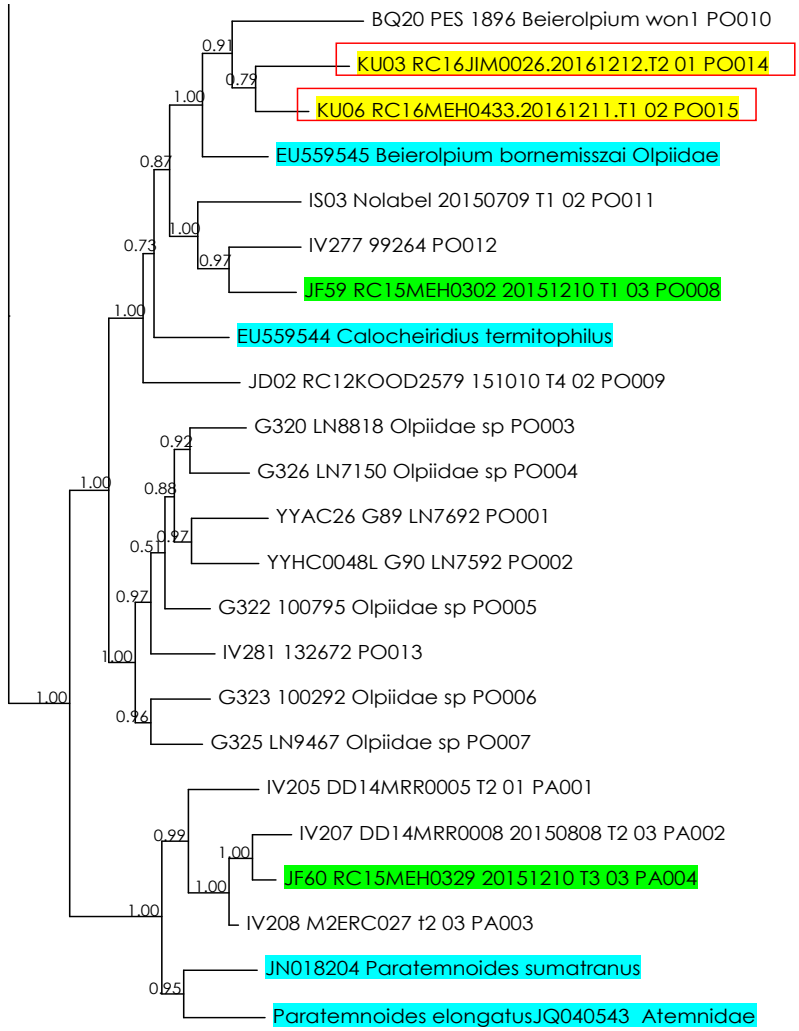

Figure 5.10: Excerpt of bayesian analysis of CO1 haplotypes of Olpiidae and Atemnidae from the survey area. (Numbers on major nodes are posterior probabilities; values <50% not shown. Specimens from the current survey highlighted in yellow (Phase 1 – 3) and green (Phase 4 – 6). Red boxes enclose species with high confidence. Boxes with dashed lines denote groups requiring further investigation).

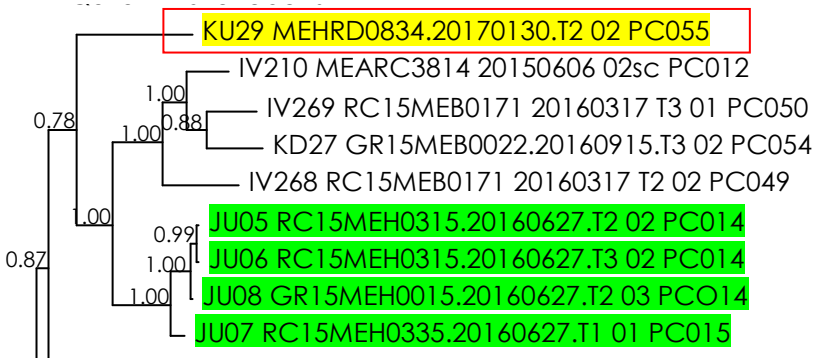

Figure 5.11: Excerpt of bayesian analysis of CO1 haplotypes of Chthoniidae recorded from the Mesa H survey area (see Appendix 3 for complete phylogenetic tree).

(Numbers on major nodes correspond to posterior probabilities; values <50% are not shown. Specimens from the current study are highlighted in yellow (Phase 1 – 3) and green (Phase 4 – 6). Red boxes enclose species with high confidence. Red boxes with dashed lines indicate groups requiring further investigation.

Plate 5.3: *Beierolpium* sp. 'PO014' from drillhole RC16JIM0026.

Plate 5.4: Hyidae sp. 'PH017/PH027' from drillhole RC14MRH0252.

Plate 5.5: Olpiidae sp. 'PO008' from drillhole RC15MEH0302.

Plate 5.6: Atemnidae sp. 'PA004' from drillhole RC15MEH0329.

5.3.4 Order Schizomida (Schizomids)

A total of 45 schizomid specimens were sequenced as part of the Mesa H assessment. Fourteen were collected during the current survey (Table 5.13), 23 were collected during a previous survey at Mesa J (Biota 2009), and WAM also separately sequenced, and morphologically identified, eight specimens from historically sampled sites at Mesa H previously identified as *Paradraculoides* sp. nov. 'Mesa H' (see Section 4.4.2) (Cullen and Harvey 2017). Five lineages corresponding to four species were identified, with six of the 45 specimens unable to be assigned to a lineage due to failure to sequence or missing historical specimens (Table 5.13; Figure 5.16).

Of the four species detected, Hubbardiidae sp. 'SCH011' was recorded within the Mesa H development envelope and also from several sites across Mesa J (Table 5.13). Two lineages recorded from Mesa H were found to be closely related (at 4.3% divergence) and were grouped together as a single species based on habitat proximity and geology (Helix 2017b) (Figure 5.12). This species, Hubbardiidae sp. 'SCH015/SCH016' (Plate 5.7 and Plate 5.8) has also been recorded previously, from approximately 6 km southwest of the development envelope (T. Finston, Helix, pers. comm. April 2017). The WAM analysis of historical material was consistent with the Helix analysis, indicating the presence of two distinct lineages corresponding to Hubbardiidae sp. 'SCH011' and Hubbardiidae sp. 'SCH015/SCH016' (Table 5.13) (Cullen and Harvey 2017). The remaining two lineages were each assigned to new species within the genus *Paradraculoides* (*P.* sp. 'SCH038' and *P.* sp.'SCH039'; Table 5.13). Both species are previously unrecorded outside the development envelope.

Table 5.13: Summary of schizomid taxa recorded from Mesa H during the current study. (Includes sequencing of specimens from (Biota 2009) and Cullen and Harvey (2017)).

Family	Lineage	Species	Site	Number
Hubbardiidae	SCH011	Hubbardiidae sp. 'SCH011'	J0866, J0867, J0928, MEJ0007, MEJ0048, MEJ0076, MEJ0085, J0866, MEJ5548alt, RC08MEJ0015, RC08MEJ0004, RC08MEJ0023, MEHRC0724	23
	SCH015	Hubbardiidae sp. 'SCH015/SCH016'	DD13MEH0007, RC12MEH0221, RC14MEH0252, RC15MEH0306, RC16JIM0026, RC16JIM0031, MEHRD0870	10
	SCH016			
	SCH038	*Paradraculoides* sp. 'SCH038'	MEHRC157, RC15MEH0329, RC16MEH0264, RC16MEH0433	5
	SCH039	*Paradraculoides* sp. 'SCH039'	RC15MEJ0019	1
	Failed to sequence	Schizomida sp. indet.	RC15MEH0329, MEH, MEJ0007, MEJ0076, J0866, MEHRC0894	6
			Total	45

Plate 5.7: Hubbardiidae sp. 'SCH015/SCH016' (lateral view) from drillhole RC12MEH0221.

Plate 5.8: Hubbardiidae sp. 'SCH015/SCH016' (dorsal view) from drillhole RC12MEH0221.

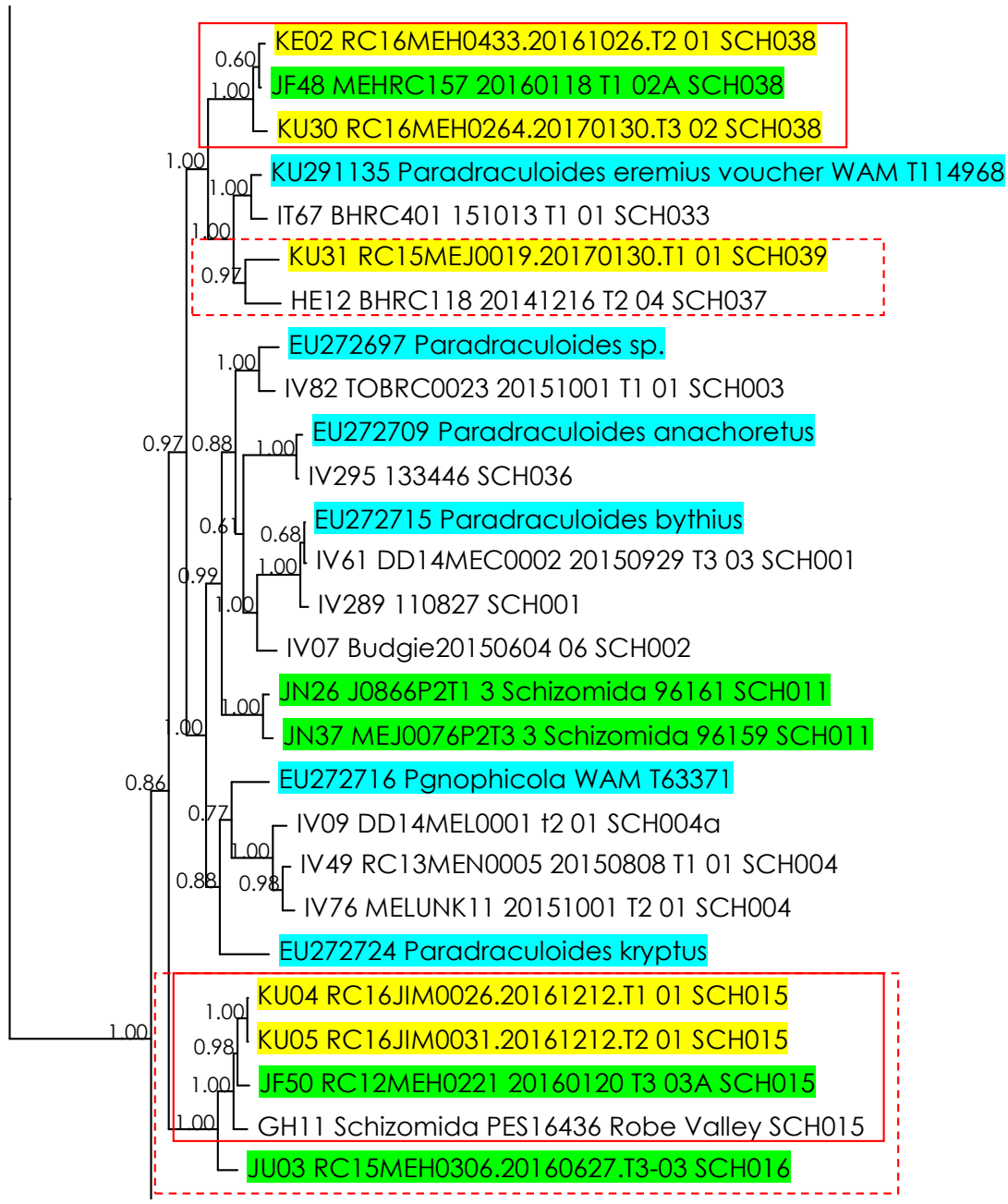

Figure 5.12: Excerpt of Bayesian analysis of CO1 haplotypes of Schizomida recorded from the Mesa H survey area (see Appendix 3 for complete phylogenetic tree).

(Numbers on major nodes correspond to posterior probabilities; values <50% are not shown. Specimens from the current study are highlighted in yellow (Phase 1 – 3) and green (Phase 4 - 6); GenBank specimens are highlighted in turquoise. Red boxes enclose species with high confidence. Red boxes with dashed lines indicate groups requiring further investigation.

5.3.5 Order Scolopendromorpha (Centipedes)

A single centipede specimen was sequenced and assigned to the family Cryptopidae (Table 5.14; Figure 5.16). This specimen differed from reference specimens by more than 15% and is a new species (Figure 5.13)(Helix 2016).

Table 5.14: Summary of centipede taxa recorded from the current survey.

Family	Lineage	Species	Site	Number
Cryptopidae	SC18	Cryptopidae sp. 'SC18'	RC14MEH0388	1

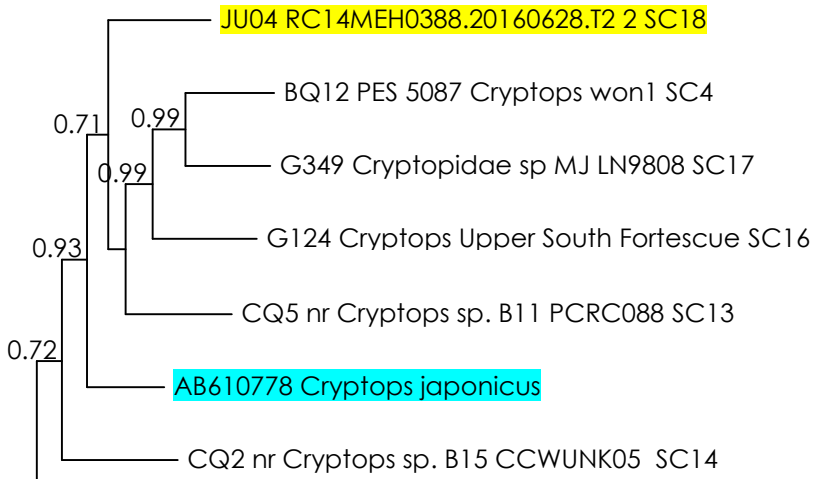

Figure 5.13: Excerpt of Bayesian analysis of CO1 haplotypes of Scolopendrida recorded from the Mesa H study area (see Appendix 3 for complete phylogenetic tree).

(Numbers on major nodes correspond to posterior probabilities; values <50% are not shown. Specimens from the current study are highlighted in yellow; GenBank specimens are highlighted in turquoise.

5.3.6 Order Araneae (Spiders)

Two troglobitic spider specimens were recorded from Mesa H (Table 5.15; Figure 5.16).

After morphological examination by the WAM (Appendix 4), one adult male specimen from the family Oonopidae was assigned to a new species within the genus *Prethopalpus* (Table 5.15). No specimens from this genus have been previously collected from Mesa H and this species is considered likely to be an SRE species (Cullen et al. 2017).

The remaining specimen was a juvenile of the family Gnaphosidae and could not be identified to genus level. This specimen is considered to represent a potential SRE species (Cullen et al. 2017).

Table 5.15: Summary of spider taxa recorded from the current survey.

Family	Species	Site	Number
Oonopidae	*Prethopalpus* 'ARA052'	RC16JIM0019	1
Gnaphosidae	Genus indet. sp. 'Mesa H'	RC14MEH0270	1
		Total	2

5.3.7 Order Blattodea (Cockroaches)

Two troglobitic cockroach specimens were recorded from Mesa H (Table 5.16; Figure 5.16). Sequencing identified these as belonging to two separate lineages, which form part of a potential West Pilbara species complex: ?*Nocticola* sp. 'West Pilbara Complex' (family Nocticolidae; Table 5.16; Appendix 3). The two specimens from the current study differed from each other by 6.3%, which is greater than normally expected within a species, but the lineages within this potential species complex also show an equivalent average genetic distance of approximately 6% over a very large geographic range, including a record from Red Hill (some 60 km to the south) which varied from the RC16MEH0427 specimen from the current survey by only 4.2% (divergence more consistent with within-species variation; Appendix 3). The records have therefore been retained here as representatives of the ?*Nocticola* species complex until further work can clearly identify where any species boundaries should be ascribed within the complex.

Table 5.16: Summary of cockroach taxa recorded from the current survey.

Family	Species	Site	Number
Nocticolidae	?*Nocticola* sp. 'West Pilbara Complex'	RC12MEH0221	1
		RC16MEH0427	1
		Total	2

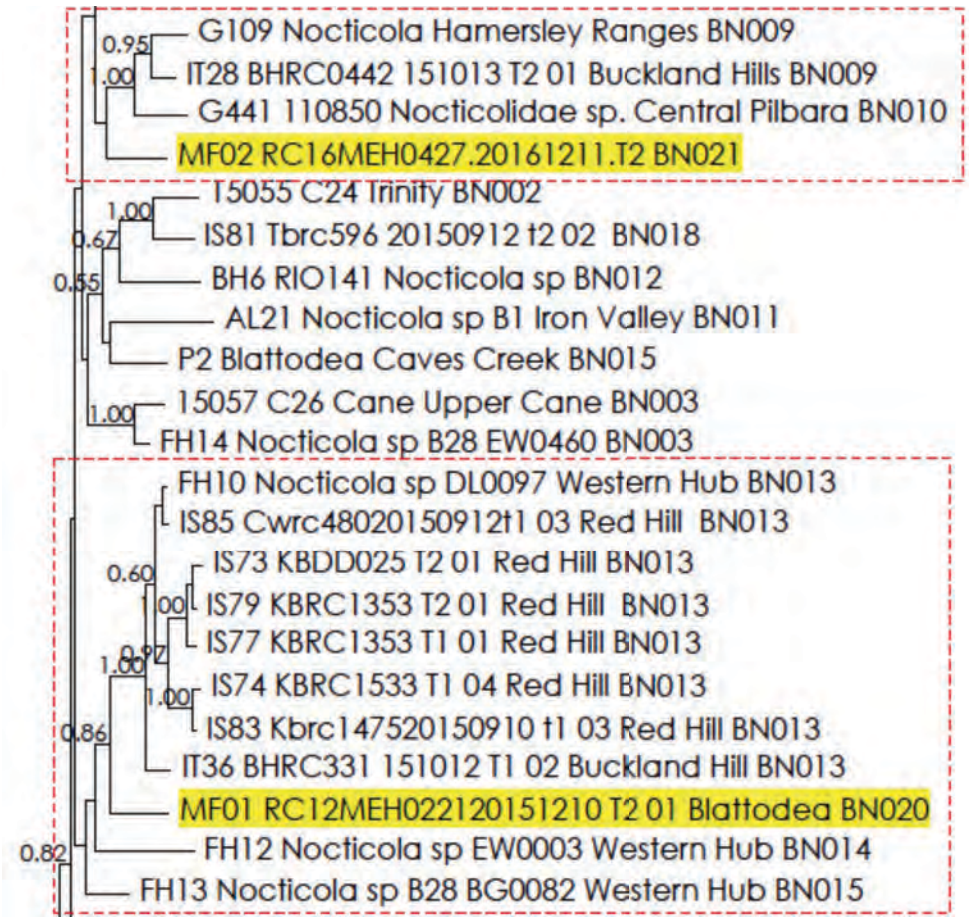

Figure 5.14: Excerpt of Bayesian analysis of CO1 haplotypes of Blattodea recorded from the Mesa H survey area (see Appendix 3 for complete phylogenetic tree).

(Numbers on major nodes correspond to posterior probabilities; values <50% are not shown. Specimens from the current study are highlighted in yellow. Red boxes with dashed lines indicate groups requiring further investigation.

5.3.8 Order Coleoptera (Beetles)

Eighteen specimens of Coleoptera from Mesa H were sequenced, with the specimens found to represent four phylogenetic lineages (Appendix 3). These correspond to three putative species, representing two families (Table 5.17). Two of the specimens could not be assigned to a lineage due to failure to sequence.

Curculionidae sp. 'CCU014' is a new species currently only known from the development envelope, but was recorded from three locations (Table 5.17). The remaining two beetle species are known from outside of the development envelope: Ptilidae sp. 'Robe Valley' was only recorded from the development envelope during the current survey, but it has previously been recorded elsewhere in the Robe Valley (lineage CP002 on Figure 5.15). Although the last taxon, Ptilidae sp. 'CP003' was recorded solely from site RC12MEH0221 within the development envelope, it is likely to represent the same species as Ptilidae sp. 1, as divergence from that taxon was only 4.4% (Figure 5.15). Ptilidae sp. 1 has been previously recognised by WAM from outside of the development envelope.

Table 5.17: Summary of beetle taxa recorded from the current survey.

Family	Species	Site	Number
Curculionidae	Curculionidae sp. 'CCU014'	RC12MEH0221	4
		RC14MEH0252	1
		RC15MEH0302	1
Ptilidae	Ptilidae sp. 1/ 'CP003'	RC12MEH0221, RC16MEH0264	34
	Ptilidae sp. 'Robe Valley'/'CP002'	RC14MEH0238	10
		Total	50

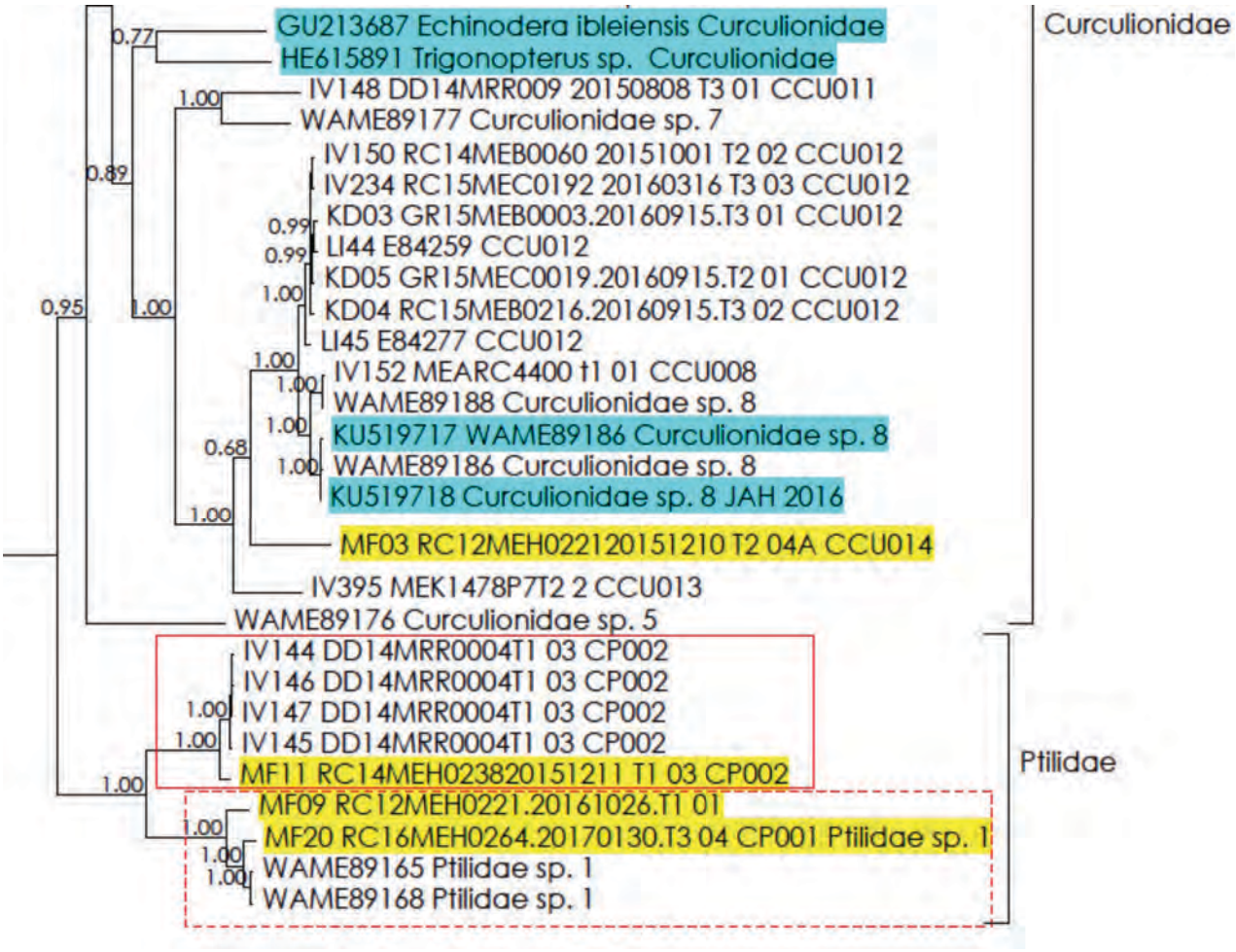

Figure 5.15: Excerpt of Bayesian analysis of CO1 haplotypes of Coleoptera recorded from the Mesa H survey area (see Appendix 3 for complete phylogenetic tree).

(Numbers on major nodes correspond to posterior probabilities; values <50% are not shown. Specimens from the current study are highlighted in yellow. GenBank specimens are highlighted in turquoise. Red boxes enclose species with high confidence. Red boxes with dashed lines indicate groups requiring further investigation.

5.3.9 Order Zygentoma (Silverfish)

Two troglobitic silverfish specimens, representing two different species, were recorded from Mesa H (Table 5.18). Both taxa were recorded from only within the development envelope (Figure 5.16).

Table 5.18: Summary of silverfish taxa recorded from the current survey.

Family	Species	Site	Number
Nicoletiinae	Nicoletiinae sp. 'TN019'	RC16JIM0006	1
	Nicoletiinae sp. 'TN020'	RC14MEH0252	1
		Total	2

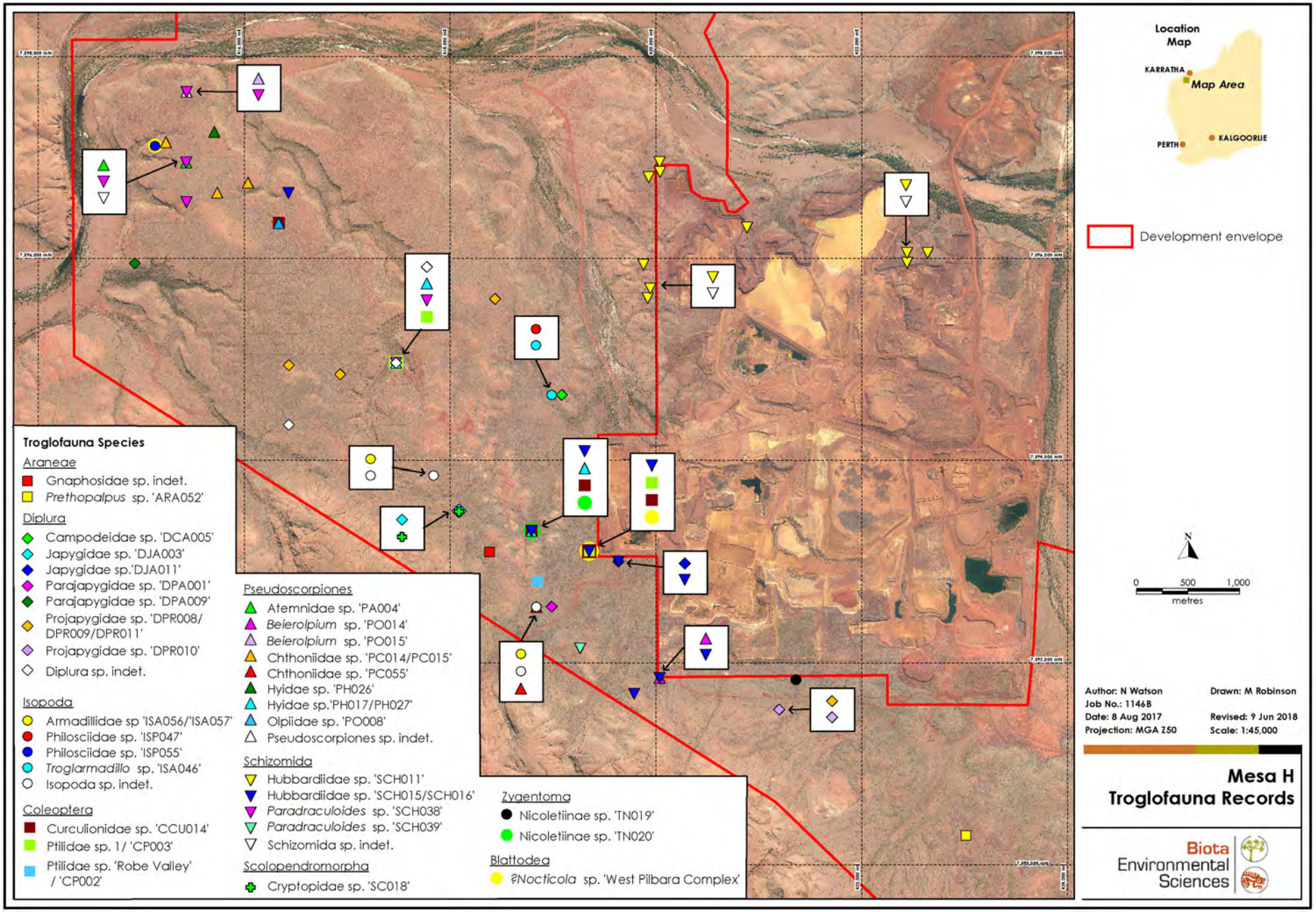

Figure 5.16: Troglofauna taxa recorded from Mesa H during the current survey.

6.0 Discussion

6.1 Known Subterranean Assemblage

6.1.1 Stygofauna

At least 43 species of stygofauna were recorded during the current survey (Section 5.1), with an additional 13 species-level taxa known from previous records (Section 4.4.1), bringing the total known assemblage of the survey area to 56 species (removing duplicated species in common to both the survey and the desktop review data set, and excluding indeterminate specimens).

Forty-six species occur in the immediate Mesa H locality (Rio Tinto 2019), and a subset of 32 of these species occurs within the drawdown extent: 14 recorded during the current survey plus an additional 18 from the desktop review (again, excluding indeterminate specimens and removing overlaps in the two data sets). The majority of these species (26 out of 32 taxa; 81%) are either widespread regionally or have records outside of the drawdown extent. The remaining seven taxa that are currently only known from the drawdown extent are not formally listed as being of conservation significance but are potential SRE taxa, the majority of which are represented by single specimens (see Section 6.3.1).

6.1.2 Troglofauna

Thirty-two troglobitic taxa were recorded from the Mesa H development envelope during the current survey, which, with one additional desktop taxon[1] (Section 4.4.2), brings the known total fauna of the development envelope to at least 33 troglobitic species.

Six of the 33 taxa have been recorded from outside of the development envelope and have demonstrated wider distributions, with the remaining 27 taxa currently only known from within the development envelope. Twenty of these latter were singleton taxa, making comment on their potential wider distributions difficult, but they have been retained as potential SRE taxa here to provide a precautionary assessment.

6.2 Conservation Significant Fauna

6.2.1 Stygofauna

No stygofauna specimens of conservation significance (i.e. listed as Priority, Schedule or Vulnerable at State or Federal levels) were collected during the current survey. Records of *Ophisternon candidum* were, however, obtained from eDNA analysis of environmental samples (Section 5.2).

Specimens of the Blind Cave Eel have now been collected from three sites in the Jimmawurruda and Bungaroo Creeks locality (BC186, JW023 and JW024; Figure 6.1), and a recent additional site on the Robe River immediately north of Mesa H (Biota 2018), in addition to occurring at Cape Range (Section 4.4.1.1).

Sampling targeting this species was conducted during this study using eDNA techniques (Section 3.4). This resulted in the detection of *Ophisternon* DNA at five additional locations, both along Jimmawurruda Creek and the Robe River, including at one site within the development envelope and two to the immediate southeast (Figure 6.1). This indicates that the species occurs more widely in the locality, having been recorded from nine locations in total, and it probably occurs in association with the major alluvial aquifers of the Bungaroo-Jimmawurruda-Robe system (Biota 2018).

[1] *Paradraculoides* sp. nov. 'Mesa H' was also identified from the Development Envelope during the desktop review in Section 4.4.2, but subsequent sequencing reassigned those historical specimens to other Schizomida taxa (Section 5.3.4), removing it from this final tally.

Two Amphipoda species of conservation significance have been recorded from multiple locations within the Mesa H drawdown extent during past surveys: *Nedsia hurlberti* and *Nedsia sculptilis*, both of which are Schedule 3 species collected during a survey at Bungaroo (Biota 2013) (Figure 6.1).

It is worth noting that theses two conservation significant amphipod species recorded from within the Mesa H development envelope have been described morphologically with no genetic analysis completed as part of their formal description (Bradbury and Williams 1996), whereas specimens from this survey were identified based on molecular analysis. Multiple studies in the Pilbara have indicated that amphipod species described solely on the basis of morphology may represent species complexes, or multiple species (Biota 2015b). Equally, past difficulties have arisen with resolving Amphipoda taxonomic boundaries based on morphology alone, where differences in characters has actually represented variation within a species rather than delineating separate species (Biota 2001). The large number of specimens that are juvenile and damaged, and are therefore not informative to morphological analysis, compounds these issues, reducing the power of morphological approaches and limiting determinations of species distribution based on this.

Given these considerations, genetic analysis is likely to be more effective and objective approach to assigning species, reviewing distributions, and thereby assessing conservation significance of putative species within this group. It is possible that taxa identified in this way on a molecular basis during the current study may represent either *Nedsia hurlberti* or *N. sculptilis* but a fuller taxonomic and phylogeographic review would be required to adequately resolve this.

6.2.2 Troglofauna

No troglofauna of conservation significance (i.e. those listed as Priority, Schedule or Vulnerable at State or Federal levels) were recorded during the survey at Mesa H.

One species of conservation significance was recorded from the desktop assessment, the schizomid *Paradraculoides kryptus* (Schedule 3), which to date has been recorded solely from Mesa K. It is unlikely that this species would occur at Mesa H.

6.3 Potential SRE Fauna

6.3.1 Stygofauna

Twenty-nine stygofauna species recorded from the Mesa H survey area are not formally listed as being of conservation significance but are considered to represent potential SRE fauna (Table 6.1). Eleven of these taxa are singletons, making comment on their true wider distribution difficult (Table 6.1). Specimens belonging to one higher rank taxon were unable to be identified to species level (*Gomphodella* sp. indet.) but were still retained as potential SRE stygofauna given distributional patterns in other members of this genus (Biota 2015c).

Thirteen of the 29 potential SRE taxa have been recorded within the drawdown extent (Figure 6.1), with seven of these either also recorded from sites outside of the drawdown extent or known to occur more widely in the region due to previous surveys (Table 6.1).

The remaining six potential SRE taxa are currently only known from the drawdown extent (Hydrobiidae sp. 2, Candoninae sp. 'BOS541', *Parastenocaris* sp. 'B28', *Haptolana* sp. 'B01', Paramelitidae sp. 'AMP003' and Paramelitidae sp. 'AMP037') (Figure 6.1; Table 6.1).

Table 6.1: Summary of conservation significant and potential SRE stygofauna species from the Mesa H survey area (combined desktop review and survey results; desktop records highlighted in grey shading; species in bold recorded from within the drawdown extent).

Species Name	Site Recorded with Drawdown Extent	Distribution (km^2)	Collection Representation (Total number sites)*	New Species	Singleton Record	SRE Sub-categories ^	Location of Records Outside Drawdown extent
CONSERVATION SIGNIFICANT FAUNA							
Amphipoda							
Nedsia hurlberti	JW021, JW011A	169.3	Good (Good)	-	-	-	Bungaroo, Barrow Island
Nedsia sculptilis	JW021, JW011A	19.1	Good (Good)	-	-	-	Bungaroo, Barrow Island
Vertebrata							
Ophisternon candidum Ψ	JW021, JW023, JW024, MB17MEH0015, BC186	108.3	Poor (Poor)	-	-	-	RR1, Robe River (site 25), RRD2, Cape Range
POTENTIAL SRE FAUNA							
Gastropoda							
Hydrobiidae sp. 2	JW023	-	Poor (Poor)	X	-	A. Data Deficient C. Morphology Indicators	-
Hydrobiidae sp. 'B09'	-	-	Poor (Poor)	X	-	A. Data Deficient C. Morphology Indicators	MB17MEH0007
Ostracoda							
Gomphodella sp.	-	-	Poor (Poor)	-	-	A. Data Deficient C. Morphology Indicators	RR1
Pierrecandona sp. 'BOS576'	-	-	Poor (Poor)	-	-	A. Data Deficient C. Morphology Indicators	RR1, Bungaroo, Waramboo
Pilbaracandona sp. 'BOS526'	JW024	90.2	Poor (Poor)	-	-	A. Data Deficient C. Morphology Indicators	Dave Bore, MB17MEH0007
Areacandona sp. 'BOS1039'	BC186	-	Poor (Poor)	X	-	A. Data Deficient C. Morphology Indicators	Robe River (site 31)
Candonidae sp. 'BOS577'	-	-	Poor (Poor)	-	-	A. Data Deficient C. Morphology Indicators	RR1
Candonidae sp. 'BOS1037'	-	-	Poor (Poor)	X	-	A. Data Deficient C. Morphology Indicators	MB17MEH0007
Candonidae sp. 'BOS541'	JW024	-	Poor (Poor)	X	X	A. Data Deficient C. Morphology Indicators	-
Copepoda							
Megastygonitocrella unispinosa	MB17MEH0015	5.2	Poor (Poor)	-	-	A. Data Deficient	Robe River valley
Parastenocaris sp. 'B28'	JW023	-	Poor (Poor)	X	X	A. Data Deficient	-
Isopoda							
Haptolana yarraloola	-	107.4	Poor (Poor)	-	-	A. Data Deficient	RR1, Yarraloola, Budgie Bore
Haptolana sp. 'B01'	JW024	-	Poor (Poor)	X	X	A. Data Deficient C. Morphology Indicators	-

Species Name	Site Recorded with Drawdown Extent	Distribution (km²)	Collection Representation (Total number sites)*	New Species	Singleton Record	SRE Sub-categories ^	Location of Records Outside Drawdown extent
Amphipoda							
Nedsia sp. 'AMM004'	-	-	Poor (Poor)	-	-	A. Data Deficient D. Molecular Evidence	87, Dave Bore, MB16MEC0009
Nedsia sp. 'AMM006'	-	-	Poor (Poor)	-	-	A. Data Deficient D. Molecular Evidence	MB16MEC0008, MB16MEC0009
Nedsia sp. 'AMM022'	-	-	Poor (Poor)	-	X	A. Data Deficient D. Molecular Evidence	MB17MEH0007
Nedsia sp. 'AMM026'	RC13MEH0097	-	Poor (Poor)	X		A. Data Deficient D. Molecular Evidence	Robe River (site 31)
Nedsia sp. 'AMM032'	-	-	Poor (Poor)	X	X	A. Data Deficient D. Molecular Evidence	Robe River (site 31)
Nedsia sp. 'AMM033'	-	-	Poor (Poor)	X	-	A. Data Deficient D. Molecular Evidence	MB17MEH0007, MB17MEH0009, MB17MEH0010
Neoniphargidae sp. 'AMN002'	-	-	Poor (Poor)	X	X	A. Data Deficient D. Molecular Evidence	RR1
Neoniphargidae sp. 'AMN003'	-	-	Poor (Poor)	X	X	A. Data Deficient D. Molecular Evidence	Robe River (site 32)
Neoniphargidae sp. 'AMN008'	-	-	Poor (Poor)	X	-	A. Data Deficient D. Molecular Evidence	Dave Bore, Budgie Bore
Wesniphargus sp. 'AMN004' Ψ	JW024	-	Poor (Poor)	-	-	A. Data Deficient D. Molecular Evidence	Robe River (site 25)
Neoniphargidae sp. 'B02' Ψ	JW021	-	Poor (Poor)	-	-	A. Data Deficient	Robe River (site 32)
Paramelitidae sp. 'AMP003'	RC13MEH0041	-	Poor (Poor)	X	X	A. Data Deficient D. Molecular Evidence	-
Paramelitidae sp. 'AMP035'	RC13MEH0007	-	Poor (Poor)	X	X	A. Data Deficient D. Molecular Evidence	RR1
Paramelitidae sp. 'AMP036'	-	-	Poor (Poor)	X	X	A. Data Deficient D. Molecular Evidence	RR1
Paramelitidae sp. 'AMP037'	BC186	-	Poor (Poor)	X	X	A. Data Deficient D. Molecular Evidence	-
Paramelitidae sp. 'AMP038'	-	-	Poor (Poor)	X	-	A. Data Deficient D. Molecular Evidence	RR1, Robe River (site 25)

Ψ Same taxa recorded during current survey and previous nearby surveys.

* Poor: <10 specimens/sites, Fair: 10 – 25, Good: >25 (estimated from available data).

^ A. Data Deficient, B. Habitat Indicators, C. Morphology indicators, D. Molecular Evidence, E. Research and Expertise (more detail in Appendix 4).

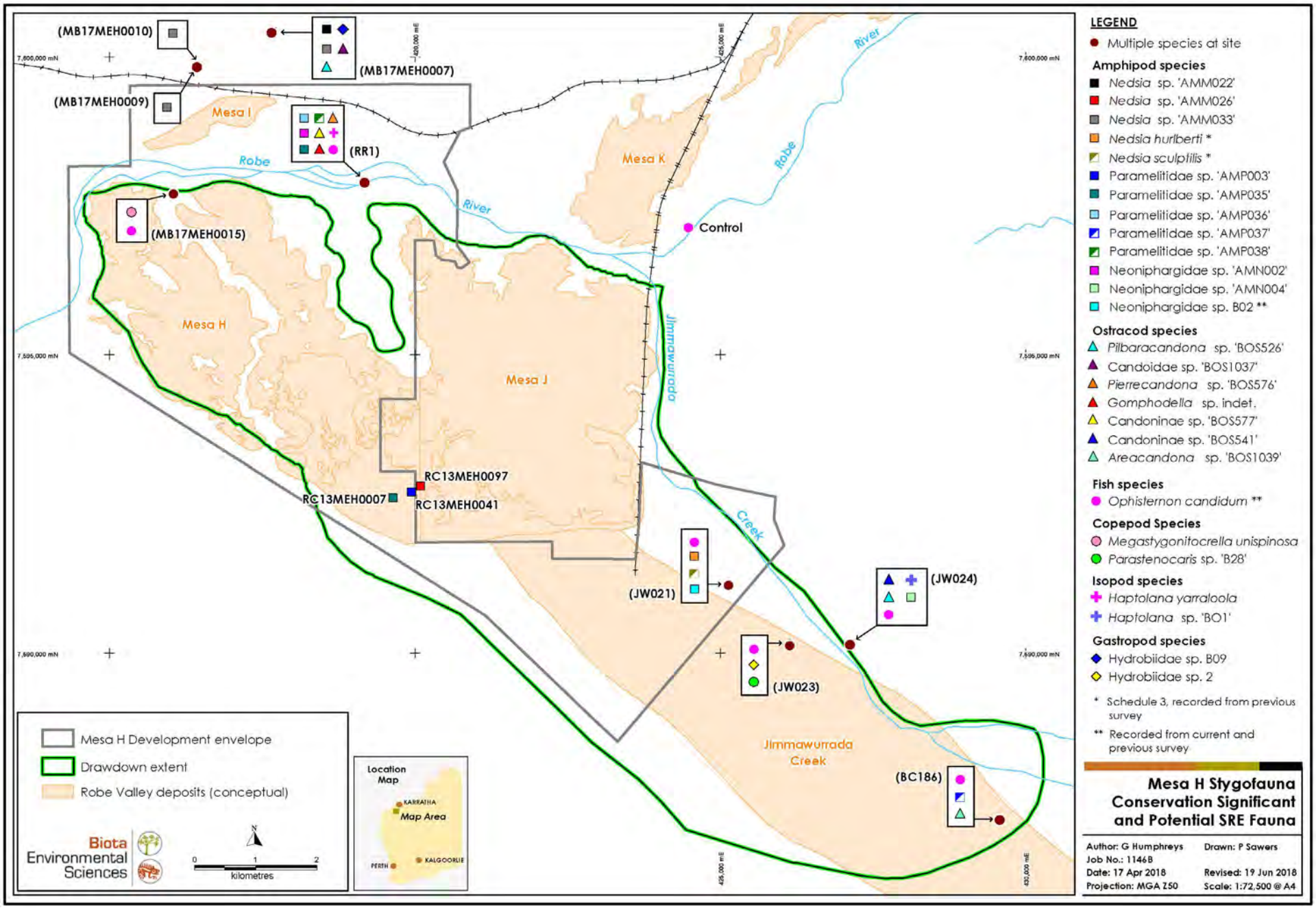

Figure 6.1: Distribution of conservation significant and potential SRE stygofauna relative to the Mesa H drawdown extent, including specimen and eDNA records of *Ophisternon candidum*, from both the current survey and past records.

6.3.2 Troglofauna

Specimens belonging to fiver higher rank troglobitic taxa could not be identified to species level (Diplura sp. indet., Pseudoscorpiones sp. indet., Isopoda sp. indet., Schizomida sp. indet. and Gnaphosidae sp. indet. (Section 4.4.2)). While it is highly likely that these specimens represent range-restricted species, it is not possible to reconcile whether they represent the same species as other records of their respective groups from within or outside the development envelope. The specimens still represent spatial records of potential SRE troglofauna (Figure 6.2), but most have not been recognised as distinct taxa in our conclusions (and are therefore not listed in Table 6.2). The only exception to this is the spider Gnaphosidae sp. indet. as this was the only specimen of its family and is clearly a discrete troglobitic taxon (Section 5.3.6) (Table 6.2).

Excluding indeterminate records, a total of 32 troglobitic taxa were recorded during the survey at Mesa H and all are regarded as potential SRE fauna (Figure 6.2; Table 6.2). Six of the potential SRE taxa have been recorded from both inside and outside of the development envelope: the schizomid species Hubbardiidae sp. 'SCH011' and Hubbardiidae sp. 'SCH015/SCH016', the isopod species Armadillidae sp. 'ISA056/ISA057', the blattodean ?*Nocticola* sp. 'West Pilbara Complex', and the beetles Ptilidae sp. 1/'CP003' and P. sp. 'Robe Valley'/'CP002' (Table 6.2).

The remaining 26 taxa recorded during the survey have been recorded solely from within the Mesa H development envelope based on current data (Figure 6.2; Table 6.2).

One additional potential SRE species recorded from previous surveys (Biota 2011c) occurs solely within the development envelope (Section 4.4.2); the isopod *Troglarmadillo* sp. 1, which is considered to represent a potential SRE species (Figure 6.2 and Table 6.2). It is probable that it represents the same species as other *Troglarmadillo* taxa recorded during the current survey.

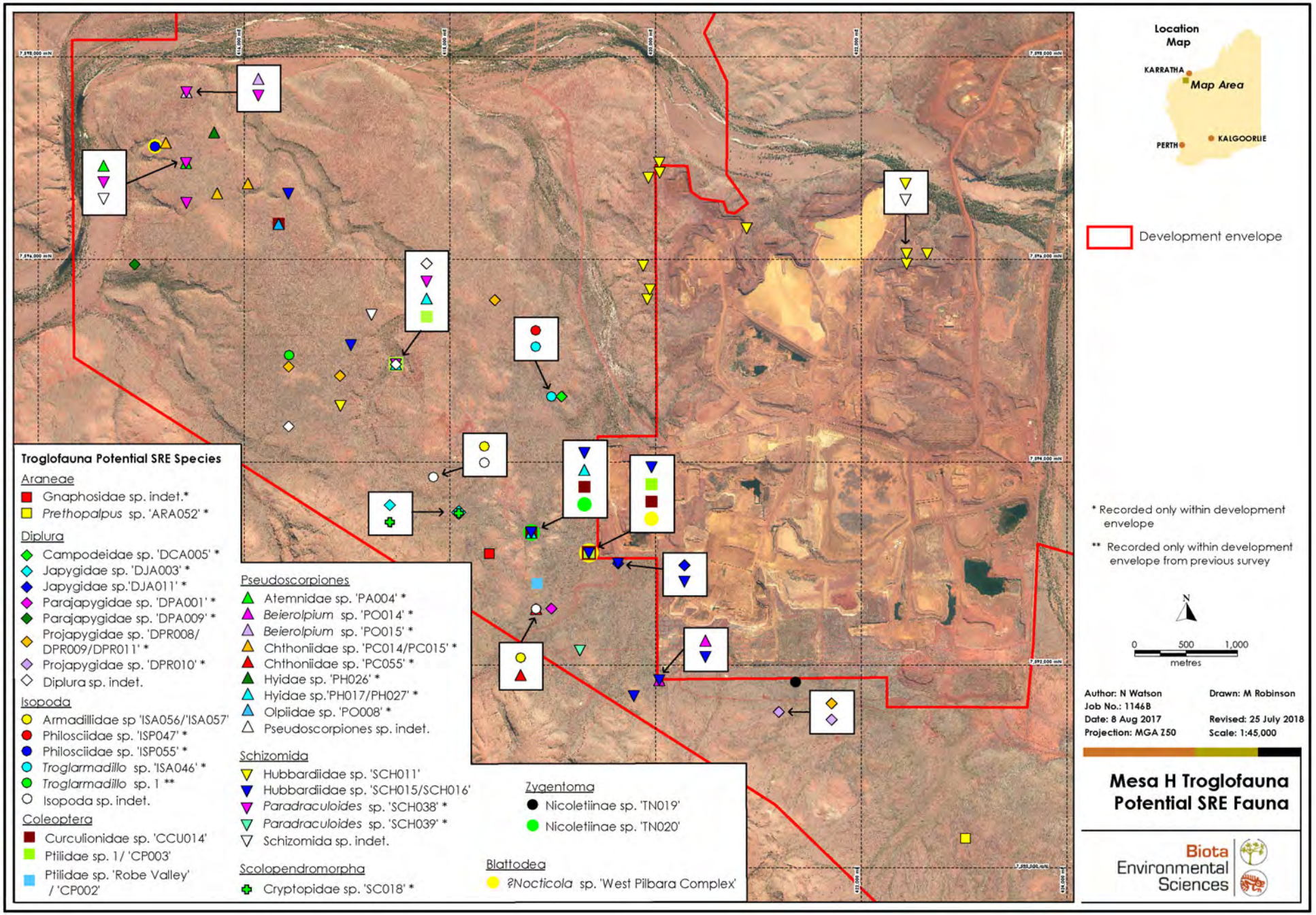

Figure 6.2: Potential SRE troglofauna recorded within the Mesa H development envelope (combined desktop review and survey results).

Table 6.2: Summary of potential SRE troglofauna species recorded within Mesa H development envelope (combined desktop review and survey results; desktop records highlighted in grey shading).

Species Name	Site Recorded	Distribution (km^2)	Collection Representation (Total number of sites) *	New Species	Singleton Record	SRE Sub-categories ^	Location of records outside Development Envelope
POTENTIAL SRE FAUNA							
Pseudoscorpiones							
Hyidae sp.'PH017/PH027'	RC14MEH0252, RC16MEH0264	-	Poor (Poor)	X	-	A. Data Deficient D. Molecular Evidence	-
Hyidae sp. 'PH026'	RC16MEH0436	-	Poor (Poor)	X	X	A. Data Deficient D. Molecular Evidence	-
Olpiidae sp. 'PO008'	RC15MEH0302	-	Poor (Poor)	X	X	A. Data Deficient D. Molecular Evidence	-
Beierolpium sp. 'PO014'	RC16JIM0026	-	Poor (Poor)	X	X	A. Data Deficient D. Molecular Evidence	-
Beierolpium sp. 'PO015'	RC16MEH0433	-	Poor (Poor)	X	X	A. Data Deficient D. Molecular Evidence	-
Atemnidae sp. 'PA004'	RC15MEH0329	-	Poor (Poor)	X	X	A. Data Deficient D. Molecular Evidence	-
Chthoniidae sp. 'PC014/PC015'	GR15MEH0015, RC15MEH0315, RC15MEH0335	0.1	Poor (Poor)	X	-	A. Data Deficient D. Molecular Evidence	-
Chthoniidae sp. 'PC055'	MEHRD0834	-	Poor (Poor)	X	X	A. Data Deficient D. Molecular Evidence	-
Schizomida							
Paradraculoides sp. 'SCH038'	MEHRC0957, RC15MEH0329, RC16MEH0264, RC16MEH0433	1.1	Poor (Poor)	X	-	A. Data Deficient D. Molecular Evidence	-
Paradraculoides sp. 'SCH039'	RC15MEJ0019	-	Poor (Poor)	X	X	A. Data Deficient D. Molecular Evidence	-
Hubbardiidae sp. 'SCH011'	J0866, J0867, J0928, MEJ0007, MEJ0048, MEJ0076, MEJ0085, J0866, MEJ5548alt, RC08MEJ0015, RC08MEJ0004, RC08MEJ0023, MEHRC0724	2.0	Fair (Fair)	-	-	A. Data Deficient D. Molecular Evidence	Mesa J
Hubbardiidae sp. 'SCH015/SCH016'	DD13MEH0007, RC12MEH0221, RC14MEH0252, RC15MEH0306, RC16JIM0026, RC16JIM0031, MEHRD0870	2.0	Poor (Poor)	-	-	A. Data Deficient D. Molecular Evidence	Redgate, 6 km SW
Myriapoda							
Cryptopidae sp. 'SC018'	RC14MEH0329	-	Poor (Poor)	X	X	A. Data Deficient D. Molecular Evidence	-
Diplura							
Parajapygidae sp. 'DPA001'	RC14MEH0308	-	Poor (Poor)	X	X	A. Data Deficient D. Molecular Evidence	-

Species Name	Site Recorded	Distribution (km²)	Collection Representation (Total number of sites) *	New Species	Singleton Record	SRE Sub-categories ^	Location of records outside Development Envelope
Parajapygidae sp. 'DPA009'	MEHRD0758	-	Poor (Poor)	X	X	A. Data Deficient D. Molecular Evidence	-
Projapygidae sp. 'DPR008/DPR009/DPR011'	RC15MEH0166, RC15MEH0175, RC15MEH0261, RC16JIM0005	5.0	Poor (Poor)	X	-	A. Data Deficient D. Molecular Evidence	-
Projapygidae sp. 'DPR010'	RC16JIM0005	-	Poor (Poor)	X	X	A. Data Deficient D. Molecular Evidence	-
Japygidae sp. 'DJA003'	RC14MEH0388	-	Poor (Poor)	X	X	A. Data Deficient D. Molecular Evidence	-
Japygidae sp. 'DJA011'	DD13MEH0007	-	Poor (Poor)	X	X	A. Data Deficient D. Molecular Evidence	-
Campodeidae sp. 'DCA005'	GR15MEH0032	-	Poor (Poor)	X	X	A. Data Deficient D. Molecular Evidence	-
Isopoda							
Philosciidae sp. 'ISP047'	RC15MEH0382	-	Poor (Poor)	X	X	A. Data Deficient D. Molecular Evidence	-
Philosciidae p. 'ISP055'	RC15MEH0427	-	Poor (Poor)	X	X	A. Data Deficient D. Molecular Evidence	-
Troglarmadillo sp. 1	MEHDC0865	-	Poor (Poor)	X	X	A. Data Deficient C. Morphological Evidence	-
Troglarmadillo sp. 'ISA046'	RC15MEH0382	-	Poor (Poor)	X	X	A. Data Deficient D. Molecular Evidence	-
Armadillidae sp. 'ISA056/ISA057'	MEHRD0577, MEHRD0834	-	Poor (Poor)	-	-	A. Data Deficient D. Molecular Evidence	Mesa C
Coleoptera							
Curculionidae sp. 'CCU014'	RC12MEH0221, RC14MEH0252, RC15MEH0302	0.7	Poor (Poor)	X	-	A. Data Deficient D. Molecular Evidence	-
Ptilidae sp. 1/'CP003'	RC16MEH0264, RC12MEH0221	17.1	Good (Poor)	-	- -	A. Data Deficient D. Molecular Evidence	Warramboo
Ptilidae sp. 'Robe Valley'/'CP002'	RC14MEH0238	19.3	Good (Poor)	-	-	A. Data Deficient D. Molecular Evidence	Robe Valley, Middle Robe
Zygentoma							
Nicoletiinae sp. 'TN019'	RC16JIM0006	-	Poor (Poor)	X	X	A. Data Deficient D. Molecular Evidence	-
Nicoletiinae sp. 'TN020'	RC14MEH0252	-	Poor (Poor)	X	X	A. Data Deficient D. Molecular Evidence	-
Araneae							
Prethopalpus 'ARA052'	RC16JIM0019	-	Poor (Poor)	X	X	E. Research and Expertise	-
Gnaphosidae sp. indet.	RC14MEH0270	-	Poor (Poor)	X	X	A. Data Deficient E. Research and Expertise	-

Species Name	Site Recorded	Distribution (km^2)	Collection Representation (Total number of sites) *	New Species	Singleton Record	SRE Sub-categories ^	Location of records outside Development Envelope
Blattodea							
?Nocticola sp. 'West Pilbara Complex'	RC12MEH0221, RC16MEH0427	114.9	Poor (Fair)	-	-	A. Data Deficient D. Molecular Evidence	Red Hill, 60 km S

* Poor: <10 specimens/sites, Fair: 10 – 25, Good: >25 (estimated from available data).

^ A. Data Deficient, B. Habitat Indicators, C. Morphology indicators, D. Molecular Evidence, E. Research and Expertise (more detail in Appendix 4).

7.0 Glossary

Conservation significance	Listed as Priority, Schedule or Vulnerable at State level.
Edaphobitic / Edaphobite	Soil-dwelling fauna that can often display troglomorphic characteristics. Edaphobites are unlikely to have limited distributions and are therefore unlikely to be classified as short-range endemics.
EPA	Environmental Protection Authority of Western Australia.
Interstices	An opening or space, especially a small or narrow one between mineral grains in a rock or within sediments or soil.
Karst	Soluble-rock landscape; terrain with distinctive hydrology and landforms arising from a combination of high rock solubility and well-developed secondary porosity (Wilkens et al. 2000).
Short-Range Endemic (SRE)	A species that has a naturally small distribution and is often characterised by having poor dispersal capabilities, confinement to disjunct habitats and low fecundity.
Stygobite / Stygofauna	Obligate groundwater fauna.
Taxonomy	Theory and practice of biological classification.
Troglobite / Troglofauna	Species living obligatory in caves; also blind, depigmented and often having an elongate body morphology.
Troglomorphic	Pertaining to morphological, behavioural and physiological characters that are convergent in subterranean populations (Christiansen 1962).
Troglophilic / Troglophile	Species able to live and reproduce underground as well as in the epigean environment (Wilkens et al. 2000).
Vug	A small cavity in a rock or vein, often with a mineral lining of different composition from that of the surrounding rock.

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Appendix 1

Licence to Take Fauna

DEPARTMENT OF PARKS AND WILDLIFE

Department of Parks and Wildlife

Enquiries: 17 DICK PERRY AVE, KENSINGTON, WESTERN AUSTRALIA
Telephone: 08 9219 9000
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JACINTA KING
ANDREW SHEPPARD
SCOTT WERNER

DATE OF ISSUE 24/09/2015
VALID FROM 30/09/2015
DATE OF EXPIRY 30/06/2016

LICENSING OFFICER

RESIDENTIAL ADDRESS: 22 HILLTOP PLACE
KELMSCOTT WA 6111

LICENSEE: MR CF COLE (CHRISTOPHER FITZPANE)
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DEPARTMENT OF PARKS AND WILDLIFE

Department of
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Facsimile: 08 9219 8242

Correspondence: **Locked Bag 30**
Bentley Delivery Centre WA 6983

PAGE NO. 1
SF010536
PERSON NO. 165096

RECEIPT NO. **AMOUNT**
$0.00

WILDLIFE CONSERVATION ACT 1950
REGULATION 17

LICENCE TO TAKE FAUNA FOR SCIENTIFIC PURPOSES

THE UNDERMENTIONED PERSON MAY TAKE FAUNA FOR RESEARCH OR OTHER SCIENTIFIC PURPOSES AND WHERE AUTHORISED, KEEP IT IN CAPTIVITY, SUBJECT TO THE FOLLOWING AND ATTACHED CONDITIONS, WHICH MAY BE ADDED TO, SUSPENDED OR OTHERWISE VARIED AS CONSIDERED FIT.

DIRECTOR GENERAL

CONDITIONS

1 The licensee shall comply with the provisions of the Wildlife Conservation Act 1950, Wildlife Conservation Regulations 1970 and any notices in force under this legislation.
2 Unless specifically authorised in the Conditions of this Licence or otherwise in writing by the Director General, species of fauna declared as likely to become extinct, rare or otherwise in need of special protection shall not be captured or otherwise taken.
3 No fauna shall be taken from any Nature Reserve, National Park, Marine Park, Marine Nature Reserve, Timber Reserve or State Forest without prior written approval of the Director General. No fauna shall be taken from any other public land without the written approval of the Government Authority managing that land.
4 No entry or collection of fauna to be undertaken on any private property or pastoral lease without the consent in writing of the owner or occupier, or from any Aboriginal lands without the written approval of the Department of Aboriginal Affairs.
5 No fauna or their progeny shall be released in any area where it does not naturally occur, nor be handed over to any other person or authority unless approved by the Director General, nor shall the remains of such fauna be disposed of in such manner as to confuse the natural or present day distribution of the species.
6 This licence and the written permission referred to at conditions 3 & 4 must be carried by the licensee or authorised agent at all times for the purpose of proving their authority to take fauna when questioned as to their right to do so by a Wildlife Officer, any other State or Local Government employee or any member of the public.
7 Any interaction involving Gazetted Threatened Fauna that may be harmful and/or invasive may require approval from the Department of the Environment ph 02 6274 1111. Interaction with such species is controlled by the Commonwealth Government's "Environment Protection and Biodiversity Conservation Act 1999" and "Environment Protection and Biodiversity Conservation Regulations 2000" as well as this Department's Wildlife Conservation Act 1950 and Wildlife Conservation Regulations 1970.
8 No bioprospecting involving the removal of sample aquatic and terrestrial organisms (both flora and fauna) for chemical extraction and bioactivity screening is permitted to be conducted without specific written approval by the Director General.
9 Further conditions (numbered 1 to 9) are attached.

PURPOSE SUBTERRANEAN FAUNA SURVEY, USING REINFORCED STYGOFAUNA HAUL NETS AND TROGLOFAUNA COLONISATION TRAPS PLUS SCRAPING OF PLANKTON HAUL NETS, IN ACCORDANCE WITH EPA GUIDANCE STATEMENT 54A, FOR ENVIRONMENTAL IMPACT ASSESSMENT AT RIO TINTO MESAS J AND H 18KMS SOUTH WEST OF PANNAWONICA.

WILDLIFE CONSERVATION REGULATIONS 1970

Regulation 17:- Licence to Take Fauna for Scientific Purposes

FURTHER CONDITIONS (OF LICENCE NUMBER SF010536)

1. The licensee shall take fauna only in the manner stated on the endorsed Regulation 17 licence application form and endorsed related correspondence.

2. Except in the case of approved lethal traps, the licensee shall ensure that measures are taken in the capture and handling of fauna to prevent injury or mortality resulting from that capture or handling. Where traps or other mechanical means or devices are used to capture fauna these shall be deployed so as to prevent exposure of trapped animals to ants and debilitating weather conditions and inspected at regular intervals throughout each day of their use. At the conclusion of research all markers etc and signs erected by the licensee and all traps shall be removed, all pitfalls shall be refilled or capped and the study area returned to the condition it was in prior to the research/capture program. During any break in research, cage traps should be removed and pitfalls either removed, capped or filled with sand.

3. No collecting is to be undertaken in areas where it would impinge on pre-existing scientific research programs.

4. Any form of colour marking of birds or bats shall only be undertaken in accordance with the requirements of the Australian Bird and Bat Banding Scheme.

5. Any inadvertently captured specimen of fauna which is declared as likely to become extinct, rare or otherwise in need of special protection is to be released immediately at the point of capture. Where such a specimen is injured or deceased, the licensee shall contact Department of Parks and Wildlife licensing staff at Kensington (08 9219 9831) for advice on disposal. Records are to be kept of any fauna so captured and details included in the report required under further condition 6 below.

6. Within one month of the expiration of this licence, the holder shall submit an electronic return detailing the locality, site, geocode, date and number of each species captured, sighted or vouchered during the currency of the licence, into the Department of Parks and Wildlife Fauna Survey Database (FSD). A copy of any paper, report or thesis resulting from the research shall on completion be lodged with the Director General. If a renewal of this licence is required, the licensee shall submit a written progress report for activities undertaken during this licence period prior to the expiry of this licence.

7. Not more than ten specimens of any one protected species shall be taken and removed from any location less than 20km apart. Where exceptional circumstances make it necessary to take large series in order to obtain adequate statistical data the collector will proceed with circumspection and justify their actions to the Director General in advance.

8. All holotypes and syntypes and a half share of paratypes of species or subspecies permitted to be permanently taken under this licence shall be donated to the Western Australian Museum. Duplicates (one pair in each case) of any species collected which represents a significant extension of geographic range shall be donated on request to the Western Australian Museum.

9. To prevent any unnecessary collecting in this State, all specimens and material collected under the authority of this license shall, on request, be loaned to the Western Australian Museum. Also, the unused portion or portions of any specimen collected under the authority of this license shall be offered for donation to the Western Australian Museum or made available to other scientific workers if so required.

DEPARTMENT OF PARKS AND WILDLIFE

Department of
Parks and Wildlife

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Bentley Delivery Centre WA 6983

SF010915

PERSON NO. 165096

AUTHORISED PERSONS

ROY TEALE
GARTH HUMPHREYS
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TIM SACHSE
JESSICA CAIRNES
PENNY BROOSHOOFT
DAVID KEIRLE
VICKIE CARTLEDGE
CHRIS COLE
NICOLA WATSON
SYLVIE SCHMIDT
STEWART FORD
JACINTA KING
ANDREW SHEPPARD
SCOTT WERNER

DATE OF ISSUE 11/07/2016
VALID FROM 22/07/2016
DATE OF EXPIRY 30/06/2017

LICENSING OFFICER

RESIDENTIAL ADDRESS: 22 HILLTOP PLACE
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LICENSEE: MR CF COLE (CHRISTOPHER FITZPANE)
ADDRESS C/- BIOTA ENVIRONMENTAL
PO BOX 155
LEEDERVILLE WA 6903

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DEPARTMENT OF PARKS AND WILDLIFE

Department of
Parks and Wildlife

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Bentley Delivery Centre WA 6983

NO. SF010915

PERSON NO. 165096

RECEIPT NO. **AMOUNT** $0.00

WILDLIFE CONSERVATION ACT 1950
REGULATION 17

LICENCE TO TAKE FAUNA FOR SCIENTIFIC PURPOSES

THE UNDERMENTIONED PERSON MAY TAKE FAUNA FOR RESEARCH OR OTHER SCIENTIFIC PURPOSES AND WHERE AUTHORISED, KEEP IT IN CAPTIVITY, SUBJECT TO THE FOLLOWING AND ATTACHED CONDITIONS, WHICH MAY BE ADDED TO, SUSPENDED OR OTHERWISE VARIED AS CONSIDERED FIT.

DIRECTOR GENERAL

CONDITIONS

1 The licensee shall comply with the provisions of the Wildlife Conservation Act 1950, Wildlife Conservation Regulations 1970 and any notices in force under this legislation.

2 Unless specifically authorised in the Conditions of this Licence or otherwise in writing by the Director General, species of fauna declared as likely to become extinct, rare or otherwise in need of special protection shall not be captured or otherwise taken.

3 No fauna shall be taken from any Nature Reserve, National Park, Marine Park, Marine Nature Reserve, Timber Reserve or State Forest without prior written approval of the Director General. No fauna shall be taken from any other public land without the written approval of the Government Authority managing that land.

4 No entry or collection of fauna to be undertaken on any private property or pastoral lease without the consent in writing of the owner or occupier, or from any Aboriginal lands without the written approval of the Department of Aboriginal Affairs.

5 No fauna or their progeny shall be released in any area where it does not naturally occur, nor be handed over to any other person or authority unless approved by the Director General, nor shall the remains of such fauna be disposed of in such manner as to confuse the natural or present day distribution of the species.

6 This licence and the written permission referred to at conditions 3 & 4 must be carried by the licensee or authorised agent at all times for the purpose of proving their authority to take fauna when questioned as to their right to do so by a Wildlife Officer, any other State or Local Government employee or any member of the public.

7 Any interaction involving Gazetted Threatened Fauna that may be harmful and/or invasive may require approval from the Department of the Environment ph 02 6274 1111. Interaction with such species is controlled by the Commonwealth Government's "Environment Protection and Biodiversity Conservation Act 1999" and "Environment Protection and Biodiversity Conservation Regulations 2000" as well as this Department's Wildlife Conservation Act 1950 and Wildlife Conservation Regulations 1970.

8 No bioprospecting involving the removal of sample aquatic and terrestrial organisms (both flora and fauna) for chemical extraction and bioactivity screening is permitted to be conducted without specific written approval by the Director General.

9 Further conditions (numbered 1 to 9) are attached.

PURPOSE SUBTERRANEAN FAUNA SURVEY, USING REINFORCED STYGOFAUNA HAUL NETS AND TROGLOFAUNA COLONISATION TRAPS PLUS SCRAPING OF PLANKTON HAUL NETS, IN ACCORDANCE WITH EPA GUIDANCE STATEMENT 54A, FOR ENVIRONMENTAL IMPACT ASSESSMENT AT RIO TINTO MESAS J AND H 18KMS SOUTH WEST OF PANNAWONICA.

WILDLIFE CONSERVATION REGULATIONS 1970

Regulation 17:- Licence to Take Fauna for Scientific Purposes

FURTHER CONDITIONS (OF LICENCE NUMBER SF 010915)

1. The licensee shall take fauna only in the manner stated on the endorsed Regulation 17 licence application form and endorsed related correspondence.

2. Except in the case of approved lethal traps, the licensee shall ensure that measures are taken in the capture and handling of fauna to prevent injury or mortality resulting from that capture or handling. Where traps or other mechanical means or devices are used to capture fauna these shall be deployed so as to prevent exposure of trapped animals to ants and debilitating weather conditions and inspected at regular intervals throughout each day of their use. At the conclusion of research all markers etc and signs erected by the licensee and all traps shall be removed, all pitfalls shall be refilled or capped and the study area returned to the condition it was in prior to the research/capture program. During any break in research, cage traps should be removed and pitfalls either removed, capped or filled with sand.

3. No collecting is to be undertaken in areas where it would impinge on pre-existing scientific research programs.

4. Any form of colour marking of birds or bats shall only be undertaken in accordance with the requirements of the Australian Bird and Bat Banding Scheme.

5. Any inadvertently captured specimen of fauna which is declared as likely to become extinct, rare or otherwise in need of special protection is to be released immediately at the point of capture. Where such a specimen is injured or deceased, the licensee shall contact Department of Parks and Wildlife licensing staff at Kensington (08 9219 9831) for advice on disposal. Records are to be kept of any fauna so captured and details included in the report required under further condition 6 below.

6. Within one month of the expiration of this licence, the holder shall submit an electronic return detailing the locality, site, geocode, date and number of each species captured, sighted or vouchered during the currency of the licence, into the Department of Parks and Wildlife Fauna Survey Database (FSD). A copy of any paper, report or thesis resulting from the research shall on completion be lodged with the Director General. If a renewal of this licence is required, the licensee shall submit a written progress report for activities undertaken during this licence period prior to the expiry of this licence.

7. Not more than ten specimens of any one protected species shall be taken and removed from any location less than 20km apart. Where exceptional circumstances make it necessary to take large series in order to obtain adequate statistical data the collector will proceed with circumspection and justify their actions to the Director General in advance.

8. All holotypes and syntypes and a half share of paratypes of species or subspecies permitted to be permanently taken under this licence shall be donated to the Western Australian Museum. Duplicates (one pair in each case) of any species collected which represents a significant extension of geographic range shall be donated on request to the Western Australian Museum.

9. To prevent any unnecessary collecting in this State, all specimens and material collected under the authority of this license shall, on request, be loaned to the Western Australian Museum. Also, the unused portion or portions of any specimen collected under the authority of this license shall be offered for donation to the Western Australian Museum or made available to other scientific workers if so required.

Appendix 2

Morphological Identifications by Bennelongia Environmental Consultants

Phase	Site	Date	Class	Subclass	Order	Suborder	Superfamily	Family	LowestID	n	IDBy	Sex	LifeStage	Comments
1	RC13MEH0007	24-Oct-15	Maxillopoda	Copepoda	Cyclopoida			Cyclopidae	*Diacyclops humphreysi humphreysi*	19	JMM			
1	RC14MMEH0053	24-Oct-15	Maxillopoda	Copepoda	Calanoida			Ridgewayiidae	*Stygoridgewayia trispinosa*	3	JMM			
1	DD13MEH0007	24-Oct-15	Maxillopoda	Copepoda	Cyclopoida			Cyclopidae	*Diacyclops humphreysi humphreysi*	1	JMM	Male	Adult	
1	DD13MEH0007	24-Oct-15	Maxillopoda	Copepoda	Calanoida			Ridgewayiidae	*Stygoridgewayia trispinosa*	16	JMM			
2	RC14MEH0018	19-Jan-16	Maxillopoda	Copepoda	Calanoida			Ridgewayiidae	*Stygoridgewayia trispinosa*	1	JMM			
1	RC13MEH0007	24-Oct-15	Maxillopoda	Copepoda	Calanoida			Ridgewayiidae	*Stygoridgewayia trispinosa*	14	JMM			
3	200	05-May-16	Ostracoda	Popocopa	Popocopida	Cypridocopina	Cypridoidea	Candonidae	*Pilbaracandona* sp. BOS526	1	SAH			BOS575
3	RR1	05-May-16	Ostracoda	Popocopa	Popocopida	Cypridocopina	Cypridoidea	Candonidae	*Pierrecandona* sp. BOS576	1	SAH			BOS576
3	RR1	05-May-16	Malacostraca	Eumalacostraca	Isopoda			Cirolanidae	*Haptolana yarraloola*	1	JMM			
3	RR1	05-May-16	Malacostraca	Eumalacostraca	Isopoda			Cirolanidae	*Kagalana tonde*	1	JMM			
3	RR1	05-May-16	Maxillopoda	Copepoda	Calanoida			Ridgewayiidae	*Stygoridgewayia trispinosa*	10	JMM			
3	RR1	05-May-16	Maxillopoda	Copepoda	Cyclopoida			Cyclopidae	*Halicyclops roachi*	2	JMM			
3	RR1	05-May-16	Maxillopoda	Copepoda	Cyclopoida			Cyclopidae	*Diacyclops cockingi*	1	JMM			
3	RR1	05-May-16	Ostracoda	Popocopa	Popocopida	Cypridocopina	Cypridoidea	Candonidae	Candoninae n. gen sp. BOS577	3	SAH			BOS577
3	87	05-May-16	Ostracoda	Popocopa	Popocopida	Cypridocopina	Cypridoidea	Candonidae	*Humphreyscandona imperfecta*	1	SAH	Male	Adult	BOS578. male. species described from juvenile female at Mardie, fortescue River. prob same species
3	32	06-May-16	Malacostraca	Eumalacostraca	Amphipoda			Neoniphargidae	Neoniphargidae sp. B02 (nr Wesniphargus)	1	JMM	Male	Adult	also found at Bungaroo
3	31	07-May-16	Maxillopoda	Copepoda	Cyclopoida			Cyclopidae	*Halicyclops roachi*	2	JMM			
3	31	07-May-16	Maxillopoda	Copepoda	Calanoida			Ridgewayiidae	*Stygoridgewayia trispinosa*	4	JMM			
4	87	10-Sep-16	Ostracoda	Popocopa	Popocopida	Cypridocopina	Cypridoidea	Candonidae	*Humphreyscandona imperfecta*	2	SAH			BOS805. see note on earlier id
4	200	10-Sep-16	Ostracoda	Popocopa	Popocopida	Cypridocopina	Cypridoidea	Candonidae	*Pilbaracandona* sp. BOS526	1	SAH			BOS801
4	31	10-Sep-16	Maxillopoda	Copepoda	Calanoida			Ridgewayiidae	*Stygoridgewayia trispinosa*	18	JMM			
4	34	10-Sep-16	Maxillopoda	Copepoda	Cyclopoida			Cyclopidae	*Diacyclops* sp.	2	JMM		Juvenile	
4	34	10-Sep-16	Maxillopoda	Copepoda	Calanoida			Ridgewayiidae	*Stygoridgewayia trispinosa*	2	JMM			
4	25	10-Sep-16	Malacostraca	Eumalacostraca	Thermosbaenacea			Thermosbaenacidae	*Halosbaena tulki*	1	JMM			
4	DD13MEH0007	14-Sep-16	Maxillopoda	Copepoda	Calanoida			Ridgewayiidae	*Stygoridgewayia trispinosa*	7	JMM			
4	RC13MEH0040	14-Sep-16	Maxillopoda	Copepoda	Calanoida			Ridgewayiidae	*Stygoridgewayia trispinosa*	1	JMM			
4	RC13MEH0007	14-Sep-16	Maxillopoda	Copepoda	Calanoida			Ridgewayiidae	*Stygoridgewayia trispinosa*	27	JMM			
4	25	10-Sep-16	Maxillopoda	Copepoda	Calanoida			Ridgewayiidae	*Stygoridgewayia trispinosa*	1	JMM			
4	32	10-Sep-16	Maxillopoda	Copepoda	Calanoida			Ridgewayiidae	*Stygoridgewayia trispinosa*	5	JMM			
4	RR1	10-Sep-16	Ostracoda	Popocopa	Popocopida	Cypridocopina	Cypridoidea	Candonidae	*Pierrecandona* sp. BOS576	1	SAH			
4	RR1	10-Sep-16	Ostracoda	Popocopa	Popocopida	Cytherocopina	Cytheroidea	Limnocytheridae	*Gomphodella* sp.	3	SAH			dead, damaged BOS802, BOS803
4	RR1	10-Sep-16	Ostracoda	Popocopa	Popocopida	Cypridocopina	Cypridoidea	Cyprididae	*Cyprididae* sp.	1	SAH			dead, damaged BOS804
4	87	10-Sep-16	Maxillopoda	Copepoda	Cyclopoida			Cyclopidae	*Diacyclops humphreysi humphreysi*	2	JMM			

Appendix 3

Genetic Analyses by Helix Molecular Solutions

Helix
Molecular
Solutions

School of Animal Biology The University of Western Australia
Hackett Entrance No. 4 Hackett Drive Crawley WA 6009

PO Box 155
Leederville WA 6903

t: (08) 6488 4509 | f: (08) 6488 1029 | abn: 32 133 230 243 | w: www.helixsolutions.com.au

29 July, 2017

Nicola Watson
Biota Environmental Sciences
Level 1, 228 Carr Place
Leederville, WA 6007

Via email

Re. Report on the molecular systematics of Amphipoda from Mesa H – Phase 4

Dear Nicola,

Following is a summary of the results of the Amphipoda study we have completed from Mesa H phase 4 collections. Eight distinct genetic lineages from three families (Melitidae, Niphargidae, Paramelitidae) were detected in the phase 4 collections, four of which have been detected previously in the Pilbara, and four of which appear to be new, based on the material available for comparsion.

Thanks once again for collaborating on this project with Helix. We hope we can continue to provide you with useful information, and feel free to contact us if you have any questions or would like to discuss the results in detail.

Sincerely,

Dr. Terrie Finston, Yvette Hitchen and Dr. Oliver Berry
Helix Molecular Solutions

Background and Objective

Forty-two specimens of Amphipoda were collected from Mesa H during phase 4 and sequenced for variation at the mitochondrial COI gene. The molecular data were assessed in order to determine the number of species present in each group and compare the results to those obtained during previous surveys at Mesa H and throughout the Pilbara.

Executive summary

- Forty-two specimens of amphipods from Mesa H phase 4 were sequenced for variation at the COI gene.
- Eight distinct genetic lineages from three families (Melitidae, Niphargidae, Paramelitidae) were detected among the 38 specimens for which sequences were obtained.
- Four of the eight lineages have been detected previously in the Pilbara.

Methods

Forty-two specimens of Amphipoda from 14 drillholes at Mesa H were sequenced for variation at the mitochondrial cytochrome oxidase subunit I gene (COI) using primers LCOI/HCO2.

Sequences were edited using GENEIOUS software (Drummond *et al.* 2011). Alignment was performed with CLUSTAL W (Thompson *et al*. 1994) using default parameters. Genetic distances between unique genetic sequences (haplotypes) were measured using uncorrected p-distances (total percentage of nucleotide differences between sequences).

MODELTEST software (Posada and Crandall, 1998) was used to determine the model of sequence evolution that best fitted the data for each taxonomic group. Bayesian analysis was used to construct the phylogenetic trees, incorporating the model as identified in MODELTEST for each taxonomic group. The phylogeny, branch lengths and posterior probabilities were obtained by running two trees simultaneously, each running four simultaneous MCMC chains. The number of cycles needed was determined by the standard deviation of the split frequencies of the two trees. The analysis was paused after every 1 x 10^6 generations and when the standard deviation fell below 0.01, the analysis was stopped. A majority rule consensus tree was constructed after discarding the "burn-in" trees in both analyses. The burn-in value was determined by plotting the posterior probabilities obtained after every generation and identifying the point at which the values reach stationarity (= the asymptote). Trees produced prior to stationarity were discarded.

For the purposes of this report, lineages were defined as haplotypes or groups of haplotypes differing from other such groups by >3% sequence divergence. This cut-off was selected based on bar-coding data, which indicates that intra-specific variation rarely exceeds 3% (Hebert et al., 2003b).

Results

Preliminary analysis - Reference sequences and outgroups

Forty-two specimens of amphipods from phase 4 were sequenced for COI (Table 1; Appendix 1). In order to reduce analysis time and to simplify the presentation of results, a preliminary neighbour-joining (NJ) analysis was conducted on the 38 Robe Valley amphipods for which sequences were obtained, and haplotypes were selected from each genetic lineage to include in a model-based phylogenetic analysis.

The neighbour-joining analysis placed the 38 specimens of amphipods into eight lineages (Figure 1). Comparisons to the GenBank sequence database indicated that four lineages were most similar to sequences of Niphargidae and one was most similar to Paramelitidae, whereas three lineages were most similar to sequences of Melitidae. The Paramelitidae and Niphargidae lineages each contained single specimens, whereas the Melitidae lineages contained between one and 25 specimens (Figure 1). The three lineages of Melitidae differed from one another by between 5.8 and 9.8% mean sequence divergence and the four lineages of Niphargidae differed from one another by between 12.1 and 18.9% sequence divergence (Table 2).

Differentiation within lineages for all three families ranged from 0 to 0.5% mean sequence divergence (Table 3).

The Paramelitidae and Niphargidae were analysed in a single phylogenetic analysis. For the Paramelitidae, 32 reference sequences were included in the phylogenetic analysis, six GenBank vouchers of Paramelitidae, *Maarrka etheli* (Genbank accession #DQ838031), two *Maarrka weeliwollii* (Genbank accession # DQ838032 and # DQ838033), Paramelitidae sp. 3 (Genbank accession # EF558852) and two references of 'Yilgarus' sp. (Genbank accession # EF118232 and EF118194) as well as 26 specimens from previous surveys of the Robe Valley, Central Pilbara, Barrow Island, Lower Shaw River, Fortescue River, and Marillana Creek, including one representative from a previous survey at Mesa H. For the Niphargidae, eight reference sequences were included in the analysis, six specimens from previous surveys in the Robe Valley, including one representative from Mesa H, and two Genbank reference sequences of *Niphargus*: *N. fontanus* (Genbank accession number KC315635) and *N. glenniei* (Genbank accession number KC315646). Two sequences of Melitidae, *Nedsia* sp. 1 (Genbank accession #EU304458), and *Norcapensis mandibulis* (Genbank accession # JQ608487)

For the Melitidae, 43 reference sequences were included in the phylogenetic analysis, two GenBank vouchers of Melitidae, *Nedsia* sp. 1 (Genbank accession #EU304458), and *Norcapensis mandibulis* (Genbank accession # JQ608487) as well as 41 specimens from previous surveys of the Robe Valley, Central Pilbara, Barrow Island, Lower Shaw River, Fortescue River, and Marillana Creek, including five representatives from previous surveys at Mesa H. Two sequences of the amphipod genus *Niphargus* were used as outgroups as follows: *N. fontanus* (Genbank accession number KC315635) and *N. glenniei* (Genbank accession number KC315646).

Phylogenetic analysis- Paramelitidae and Niphargidae
The phylogenetic analysis, which included the one representative of Paramelitidae and the four representatives of Niphargidae from Mesa H phase 4, in addition to 32 and eight reference specimens, respectively, revealed the presence of two well-supported major clades, corresponding to the two families (Figure 2). The phase 4 Mesa H specimen of Paramelitidae was placed in a single distinct lineage, which did not contain any reference specimens and thus was assigned to the new lineage AMP035 (Figure 2). The Mesa H phase 4 Niphargidae specimens were placed in four distinct genetic lineages, one of which also contained reference specimens from previous surveys at Mesa H and the Robe Valley (Figure 2). Specifically, specimen KE07 from bore 200, was placed in a lineage containing specimens from previous surveys in the Robe Valley and Mesa H (Daves, Budgie and bore 200) and thus was assigned to the existing lineage AMN008 (Figure 2). The remaining three lineages of Niphargidae from Mesa H phase 4 (KE18, KE28 and KE33) did not contain any reference specimens and thus were assigned to the new lineages AMN002, AMN003 and AMN004, respectively (Figure 2). Lineage KE28/AMN003 formed a well-supported clade with reference specimen IV129 from the Robe Valley (Figure 2).

Differentiation between lineages – Paramelitidae and Niphargidae
The Robe Valley Paramelitidae lineage represented by specimen KE16/AMP035 differed from the nearest reference specimen GK62 by 17.4% sequence divergence (Table 4). The Mesa H Niphargidae lineage represented by specimen KE07/AMN008 differed from the nearest reference specimens KJ64, KD39, IV100 and JN08 (lineage AMN008) by between 0.0 and 0.6% sequence divergence (Table 4). Phase 4 specimen KE28/AMN003 differed from the nearest reference specimen (IV129) by 6.3% sequence divergence and the remaining two lineages of Niphargidae from phase 4, KE18/AMN002 and KE33/AMN004 differed from the nearest reference specimens by >12% sequence divergence (Table 4).

Phylogenetic analysis- Melitidae
The phylogenetic analysis, which included the three representatives of Melitidae from Mesa H phase 4, in addition to 43 reference specimens, placed the Mesa H specimens in three distinct genetic lineages, all of which also contained reference specimens from previous surveys in the Pilbara (Figure 3). Specifically, specimen KE31 was placed in a lineage containing reference

specimens KJ65, IV97, IV126, JN17, KD49, JF02 and rr3a and thus was assigned to the existing lineage AMM001, and specimen KE05 was placed in a lineage containing reference specimens KJ73, KD45 and KD55 and thus was assigned to the existing lineage AMM031 (Figure 3), Specimen KE10 was placed in a lineage with reference specimens IV128 and JN05, and thus was assigned to the existing lineage AMM004 (Figure 3).

Specimens KE05 and KE031 were placed in a larger clade containing eight closely related lineages from the Robe Valley (AMM001, AMM002, AMM024, AMM025, AMM027, AMM029, AMM030 and AMM031; Figure 3).

Differentiation between lineages - Melitidae
All three specimens representing the three lineages collected in phase 4 were assigned to existing lineages and differed from the nearest reference specimens by <2.5% (Table 5). Specifically, KE031/AMM001 differed from the nearest reference specimens IV97, IV126, JN17, KD49, KJ65, JF02 and rr3a by between 0.2 and 2.2% sequence divergence and KE05/AMM031 differed from the nearest reference specimens KJ73, KD45 and KD55 by between 2.2 and 3.5% sequence divergence (Table 5). KE10/AMM004 differed from the nearest reference specimens IV128 and JN05 by between 0.0 and 0.2% sequence divergence (Table 5).

The genetic distance between specimens in the large well-supported clade comprising the eight closely related lineages (enclosed by a dashed red box in Figure 3) ranged from 0 – 7.8% and the mean was 4.9% sequence divergence.

Conclusions
COI is widely considered to show suitable variation to distinguish species (Hebert et al., 2003a). In a comparison of COI sequences for over 13,000 pairs of taxa, Hebert et al (2003b) found a mean of 11.1% sequence divergence between distinct species. Nearly 80% of the comparisons showed that species pairs differed from one another by greater than 8% sequence divergence. However, a taxon by taxon approach, examining the amount of phylogenetic variation within and between species is the most widely accepted method of defining species.

Paramelitidae

One lineage of Paramelitidae (AMP035) was detected at Mesa H during phase 4. The lineage differed from the nearest reference specimens by 17% or greater, indicating that it represents a distinct lineage and species that has not been detected previously.

AMP035 = one species from RR1, so far not detected previously in the Pilbara, based on the material available for comparison.

Niphargidae

Four lineages of Niphargidae were detected at Mesa H during phase 4. One lineage, AMN008, has been detected previously at Mesa H and other sites in the Robe Valley, whereas two (AMN002 and AMN004) have not been detected previously, based on the high level of sequence divergence between them and the nearest reference specimens (>12%). The fourth lineage requires further consideration. Lineage AMN003 differed from the nearest reference specimen (IV129/AMN007 from Daves bore in the Robe Valley) by 6.3% sequence divergence. This level of genetic divergence, while moderately low, is more than would be expected to be observed between individuals of the same species and particularly from the same region. For example, lineage AMN008 shares a similar distribution, being detected at Mesa H and Daves and Budgie bores, however differentiation between specimens in lineage AMN008 is <1%. Nevertheless, lineages AMN003 and AMN007 are closely related. Because sample sizes are low and the specimens were collected at different deposits in the Robe Valley, further sampling at intermediate sites may help resolve the relationship among these lineages.

AMN008 = one species from bore 200, detected previously in the Robe Valley at Daves and Budgie bores.
AMN002 = new species

AMN003 = new species; closely related to AMN007 and further investigation may help resolve the relationship between the two lineages
AMN004 = new species

Melitidae

Three lineages of Melitidae were detected at Mesa H, differing from one another by between 5.8 and 9.8% mean sequence divergence, indicating that each is likely to represent a distinct species (however see following comments). All three of the lineages were assigned to existing lineages (AMM001, AMM004, and AMM031).

Two of the three lineages detected in phase 4 at Mesa H (AMM001 and AMM031) were placed in a well-supported clade containing a group of closely related specimens (enclosed by a dashed red box in Figure 3), which differed by <5% mean sequence divergence (range = 0 – 7.8%). Thus this group may represent several closely related species (as shown by solid red boxes in Figure 3), or may represent a single species showing genetic differentiation across its range. Further investigation may be required to resolve relationships among the lineages, but the most likely explanation would be to consider them a single species, owing to the fact that they have a relatively wide distribution (Robe Valley to Barrow Island) and the observed genetic variation may reflect geographic variation associated with a 'stepping stone' pattern of gene exchange – populations that are near-by would be expected to exchange genes, but those on the geographic extremes are not exchanging genes. This clade forms a larger clade with additional lineages, including the Genbank reference specimen of *Nedsia* sp. 1, allowing us to assign the lineages to the genus *Nedsia* with some confidence.

AMM001, AMM031 } AMM001 was detected in eight bores at Mesa H as well as previously at Dave's and Budgie bores in the Robe Valley. AMM031 was detected in bore 200 at Mesa H as well as Budgie bore. May correspond to one species of *Nedsia,* but relationships among the clade members requires further investigation.

AMM004 = one species from bores 87 and 200, detected previously in the Robe Valley.

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Table 1. Specimens of Amphipoda used in the present study and the lineage to which they were assigned, based on variation at the COI gene. *=new lineage

Tracking Number	Cap #	N	Helix ID	Lineage
RC16MEH0427.20161026.T3-01	56	1	KE01	AMM001
RC16MEH0433.20161026.T2-01	71	1	KE02	AMM001
RC16MEH0436.20161026.T2-01	85	1	KE03	AMM001
DD13MEH0007-20160914-01	22	1	KE04	AMM001
200-20160910-01	12	4	KE05	AMM031
200-20160910-01	12		KE06	AMM004
200-20160910-01	12		KE07	AMN008
200-20160910-01	12		KE08	AMM031
87-20160919-02	10	5	KE09	AMM004
87-20160919-02	10		KE10	AMM004
87-20160919-02	10		KE11	AMM004
87-20160919-02	10		KE12	AMM004
87-20160919-02	10		KE13	AMM004
RR1-20160910-01	7	5	KE14	AMM001
RR1-20160910-01	7		KE15	No data
RR1-20160910-01	7		KE16	AMP035*
RR1-20160910-01	7		KE17	AMM001
RR1-20160910-01	7		KE18	AMN002*
34-20160910-01	18	3	KE19	AMM001
34-20160910-01	18		KE20	No data
34-20160910-01	18		KE21	No data
31-20160910-04	17	5	KE22	AMM001
31-20160910-04	17		KE23	AMM001
31-20160910-04	17		KE24	AMM001
31-20160910-04	17		KE25	AMM001
31-20160910-04	17		KE26	AMM001
32-20160910-02	5	4	KE27	AMM001
32-20160910-02	5		KE28	AMN003*
32-20160910-02	5		KE29	AMM001
32-20160910-02	5		KE30	AMM001
25-20160910-01	1	3	KE31	AMM001
25-20160910-01	1		KE32	AMM001
25-20160910-01	1		KE33	AMN004*
RC16JIM0019.20160912-01	20	5	KE34	AMM001
RC16JIM0019.20160912-01	20		KE35	AMM001
RC16JIM0019.20160912-01	20		KE36	AMM001
RC16JIM0019.20160912-01	20		KE37	AMM001
RC16JIM0019.20160912-01	20		KE38	AMM001
DD13MEH0007-20160914-02	23	5	KE39	AMM001
DD13MEH0007-20160914-02	23		KE40	AMM001
DD13MEH0007-20160914-02	23		KE41	No data
DD13MEH0007-20160914-02	23		KE42	AMM001
DD13MEH0007-20160914-02	23		KE43	AMM001
RC13MEH0040.20160914-01	25	3	KE44	AMM001
RC13MEH0040.20160914-01	25		KE45	AMM001
RC13MEH0040.20160914-01	25		KE46	AMM001

Table 2. Mean genetic distance (p-distances) between lineages of amphipods as shown in Figure 1. Distances between lineages within families are highlighted in yellow. Para=Paramelitidae.

	Melitidae			**Para**	**Niphargidae**			
Lineage	1	2	3	4	5	6	7	8
Gp_1		0.009	0.010	0.018	0.016	0.017	0.016	0.016
Gp_2	0.058		0.011	0.017	0.016	0.017	0.016	0.017
Gp_3	0.098	0.098		0.016	0.016	0.016	0.016	0.017
Gp_4	0.330	0.322	0.331		0.013	0.014	0.014	0.014
Gp_5	0.308	0.306	0.312	0.231		0.015	0.014	0.013
Gp_6	0.305	0.300	0.303	0.228	0.184		0.012	0.013
Gp_7	0.307	0.307	0.322	0.243	0.189	0.156		0.012
Gp_8	0.305	0.300	0.310	0.246	0.183	0.156	0.121	

Table 3. Mean genetic distance (p-distances) and standard errors within lineages of amphipods as shown in Figure 1. N= number of specimens in the lineage and rep= specimen selected to represent the lineage in the model-based phylogenetic analysis.

Lineage	**D**	**s.e.**	**N**	**Rep**
Gp 1	0.005	0.001	25	KE31
Gp 2	0.000	0.000	2	KE05
Gp 3	0.001	0.001	6	KE10
Gp 4	n/c	n/c	1	KE16
Gp 5	n/c	n/c	1	KE18
Gp 6	n/c	n/c	1	KE28
Gp 7	n/c	n/c	1	KE07
Gp 8	n/c	n/c	1	KE33

Table 4 (attached). Genetic distances (below diagonal) and standard error (above diagonal, in blue) between specimens of Niphargidae and Paramelitidae (Amphipoda) detected at Robe Valley and the reference lineages as shown in Figure 2. Distances between the Robe Valley specimens and the reference specimens are highlighted in yellow.

Table 5 (attached). Genetic distances (below diagonal) and standard error (above diagonal, in blue) between specimens of Melitidae (Amphipoda) detected at Robe Valley and the reference lineages as shown in Figure 3. Distances between the Robe Valley specimens and the reference specimens are highlighted in yellow.

Appendix 1. All specimens, assigned to lineages, from phases 1-6. Lineages with name changes are highlighted in yellow.

Specimen ID	Taxon	Cap_No	Helix ID	phase	old lineage	new lineage
DD13MEH0007-20151024-01A	Amphipoda	11	JF01	1	A1	AMM001
DD13MEH0007-20151024-01B	Amphipoda	11	JF02	1	A1	AMM001
DD13MEH0007-20151024-01C	Amphipoda	11	JF03	1	A1	AMM001
DD13MEH0007-20151024-01D	Amphipoda	11	JF04	1	A1	AMM001
DD13MEH0007-20151024-01E	Amphipoda	11	JF05	1	A1	AMM001
DD13MEH0007-20160119-01A	Amphipoda	20	JF06	1	A1	AMM001
DD13MEH0007-20160119-01B	Amphipoda	20	JF07	1	A1	AMM001
DD13MEH0007-20160119-01C	Amphipoda	20	JF08	1	A1	AMM001
DD13MEH0007-20160119-01D	Amphipoda	20	JF09	1	A1	AMM001
DD13MEH0007-20160119-01E	Amphipoda	20	JF10	1	A1	AMM001
RC12JIM0019-20160119-01A	Amphipoda	14	JF11	1	A1	AMM001
RC12JIM0019-20160119-01B	Amphipoda	14	JF12	1	A1	AMM001
RC12JIM0019-20160119-01C	Amphipoda	14	JF13	1	No data	No data
RC12JIM0019-20160119-01D	Amphipoda	14	JF14	1	A1	AMM001
RC12JIM0019-20160119-01E	Amphipoda	14	JF15	1	A1	AMM001
RC13MEH00400-20160119-01A	Amphipoda	19	JF16	1	A1	AMM001
RC13MEH00400-20160119-01B	Amphipoda	19	JF17	1	A1	AMM001
RC13MEH0007-20151024-03	Amphipoda	3	JF18	1	A3	AMP003
RC13MEH0041-20160119-01	Amphipoda	13	JF19	1	A3	AMP003
RC13MEH0041-20151024-01	Amphipoda	5	JF20	1	A1	AMM001
RC13MEH0097-20151024-01A	Amphipoda	7	JF21	1	A2	AMM026
RC13MEH0097-20151024-01B	Amphipoda	7	JF22	1	A1	AMM001
RC13MEH0097-20151024-01C	Amphipoda	7	JF23	1	A1	AMM001
RC14MEH0018-20151025-01	Amphipoda	6	JF24	1	A1	AMM001
RC14MEH0018-20160119-01A	Amphipoda	16	JF25	1	A1	AMM001
RC14MEH0018-20160119-01B	Amphipoda	16	JF26	1	A1	AMM001
RC14MEH0018-20160119-01C	Amphipoda	16	JF27	1	A1	AMM001
RC14MEH0018-20160119-01D	Amphipoda	16	JF28	1	A1	AMM001
RC14MEH0018-20160119-01E	Amphipoda	16	JF29	1	A1	AMM001
RC14MEH0053-20151024-01A	Amphipoda	9	JF30	1	A1	AMM001
RC14MEH0053-20151024-01B	Amphipoda	9	JF31	1	A1	AMM001
RC14MEH0053-20160119-01A	Amphipoda	24	JF32	1	A1	AMM001
RC14MEH0053-20160119-01B	Amphipoda	24	JF33	1	A1	AMM001
RC14MEH0053-20160119-01C	Amphipoda	24	JF34	1	A1	AMM001
RC14MEH0053-20160119-01D	Amphipoda	24	JF35	1	A1	AMM001
RC14MEH0053-20160119-01E	Amphipoda	24	JF36	1	A1	AMM001
87-20160505-02A	Amphipoda	12A	JN01	2	A2(AMP004)	AMM004
87-20160505-02B	Amphipoda	12B	JN02	2	A2(AMP004)	AMM004
87-20160505-02C	Amphipoda	12C	JN03	2	A2(AMP004)	AMM004
87-20160505-02D	Amphipoda	12D	JN04	2	A2(AMP004)	AMM004
87-20160505-02E	Amphipoda	12E	JN05	2	A2(AMP004)	AMM004
200-20160505-02A	Amphipoda	15A	JN06	2	A2(AMP004)	AMM004

200-20160505-02B	Amphipoda	15B	JN07	2	A4(AMP008)	AMN008
200-20160505-02C	Amphipoda	15C	JN08	2	A4(AMP008)	AMN008
200-20160505-02D	Amphipoda	15D	JN09	2	A4(AMP008)	AMN008
200-20160505-02E	Amphipoda	15E	JN10	2	A2(AMP004)	AMM004
RR120160505-01A	Amphipoda	1A	JN11	2	A1(AMP001)	AMM001
RR120160505-01B	Amphipoda	1B	JN12	2	A1(AMP001)	AMM001
RR120160505-01C	Amphipoda	1C	JN13	2	A1(AMP001)	AMM001
RR120160505-01D	Amphipoda	1D	JN14	2	Failed PCR	Failed PCR
RR120160505-01E	Amphipoda	1E	JN15	2	Failed PCR	Failed PCR
34-20160506-01	Amphipoda	18	JN16	2	A1(AMP001)	AMM001
32-20160506-01A	Amphipoda	16A	JN17	2	A1(AMP001)	AMM001
32-20160506-01B	Amphipoda	16B	JN18	2	A1(AMP001)	AMM001
32-20160506-01C	Amphipoda	16C	JN19	2	A1(AMP001)	AMM001
32-20160506-01D	Amphipoda	16D	JN20	2	A1(AMP001)	AMM001
32-20160506-01E	Amphipoda	16E	JN21	2	A1(AMP001)	AMM001
3120160507-03A	Amphipoda	10A	JN22	2	A3(AMP010)	AMM026
3120160507-03B	Amphipoda	10B	JN23	2	A1(AMP001)	AMM001
3120160507-03C	Amphipoda	10C	JN24	2	A1(AMP001)	AMM001
3120160507-03D	Amphipoda	10D	JN25	2	A1(AMP001)	AMM001
200-20160910-01	Amphipoda	12	KE05	4	AMM031	AMM031
200-20160910-01	Amphipoda	12	KE06	4	AMM004	AMM004
200-20160910-01	Amphipoda	12	KE07	4	AMN008	AMN008
200-20160910-01	Amphipoda	12	KE08	4	AMM031	AMM031
87-20160919-02	Amphipoda	10	KE09	4	AMM004	AMM004
87-20160919-02	Amphipoda	10	KE10	4	AMM004	AMM004
87-20160919-02	Amphipoda	10	KE11	4	AMM004	AMM004
87-20160919-02	Amphipoda	10	KE12	4	AMM004	AMM004
87-20160919-02	Amphipoda	10	KE13	4	AMM004	AMM004
RR1-20160910-01	Amphipoda	7	KE14	4	AMM001	AMM001
RR1-20160910-01	Amphipoda	7	KE15	4	No data	No data
RR1-20160910-01	Amphipoda	7	KE16	4	AMP035*	AMP035*
RR1-20160910-01	Amphipoda	7	KE17	4	AMM001	AMM001
RR1-20160910-01	Amphipoda	7	KE18	4	AMN002*	AMN002*
34-20160910-01	Amphipoda	18	KE19	4	AMM001	AMM001
34-20160910-01	Amphipoda	18	KE20	4	No data	No data
34-20160910-01	Amphipoda	18	KE21	4	No data	No data
31-20160910-04	Amphipoda	17	KE22	4	AMM001	AMM001
31-20160910-04	Amphipoda	17	KE23	4	AMM001	AMM001
31-20160910-04	Amphipoda	17	KE24	4	AMM001	AMM001
31-20160910-04	Amphipoda	17	KE25	4	AMM001	AMM001
31-20160910-04	Amphipoda	17	KE26	4	AMM001	AMM001
32-20160910-02	Amphipoda	5	KE27	4	AMM001	AMM001
32-20160910-02	Amphipoda	5	KE28	4	AMN003*	AMN003*
32-20160910-02	Amphipoda	5	KE29	4	AMM001	AMM001
32-20160910-02	Amphipoda	5	KE30	4	AMM001	AMM001

25-20160910-01	Amphipoda	1	KE31	4	AMM001	AMM001
25-20160910-01	Amphipoda	1	KE32	4	AMM001	AMM001
25-20160910-01	Amphipoda	1	KE33	4	AMN004*	AMN004*
RC16JIM0019.20160912-01	Amphipoda	20	KE34	4	AMM001	AMM001
RC16JIM0019.20160912-01	Amphipoda	20	KE35	4	AMM001	AMM001
RC16JIM0019.20160912-01	Amphipoda	20	KE36	4	AMM001	AMM001
RC16JIM0019.20160912-01	Amphipoda	20	KE37	4	AMM001	AMM001
RC16JIM0019.20160912-01	Amphipoda	20	KE38	4	AMM001	AMM001
DD13MEH0007-20160914-02	Amphipoda	23	KE39	4	AMM001	AMM001
DD13MEH0007-20160914-02	Amphipoda	23	KE40	4	AMM001	AMM001
DD13MEH0007-20160914-02	Amphipoda	23	KE41	4	No data	No data
DD13MEH0007-20160914-02	Amphipoda	23	KE42	4	AMM001	AMM001
DD13MEH0007-20160914-02	Amphipoda	23	KE43	4	AMM001	AMM001
RC13MEH0040.20160914-01	Amphipoda	25	KE44	4	AMM001	AMM001
RC13MEH0040.20160914-01	Amphipoda	25	KE45	4	AMM001	AMM001
RC13MEH0040.20160914-01	Amphipoda	25	KE46	4	AMM001	AMM001

Figure 1. Neighbour-joining analysis of specimens of Amphipoda from the present study. Numbers on major nodes correspond to bootstrap support over 100 iterations; values <50% are not shown. Scale bar= genetic distance. The specimens used to represent each lineage in the model-based phylogenetic analysis are highlighted in yellow.

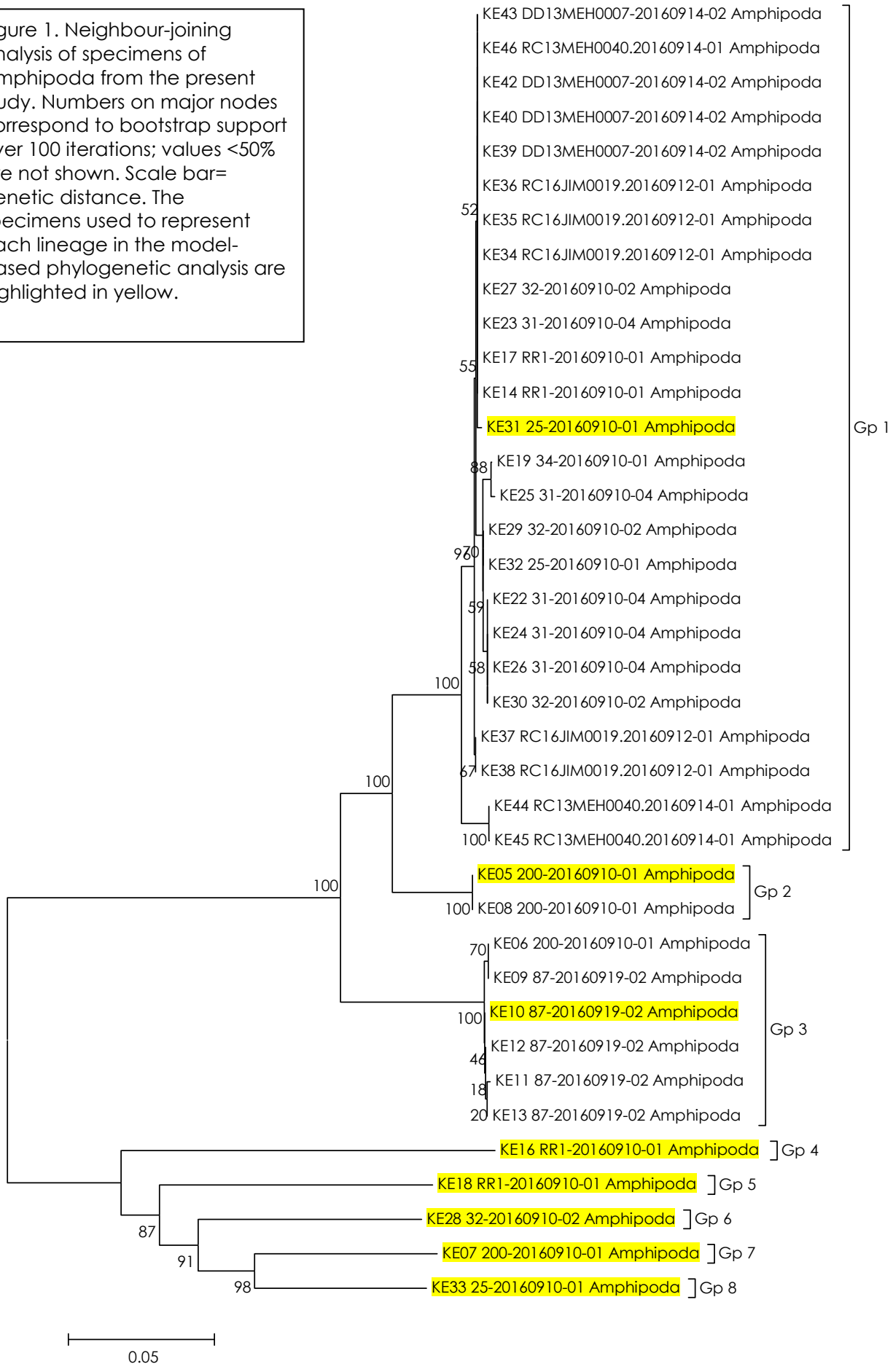


Figure 2. Bayesian analysis of COI haplotypes of Paramelitidae and Niphargidae (Amphipoda) from the present study and reference specimens from Genbank and previous surveys in the Pilbara. Numbers on major nodes correspond to posterior probabilities; values <50% are not shown. Specimens from the present study are highlighted in yellow; specimens from previous phases at Mesa H are highlighted in green; GenBank voucher specimens highlighted in turquoise. Scale bar= number of substitutions per site. Red boxes enclose species with high confidence.

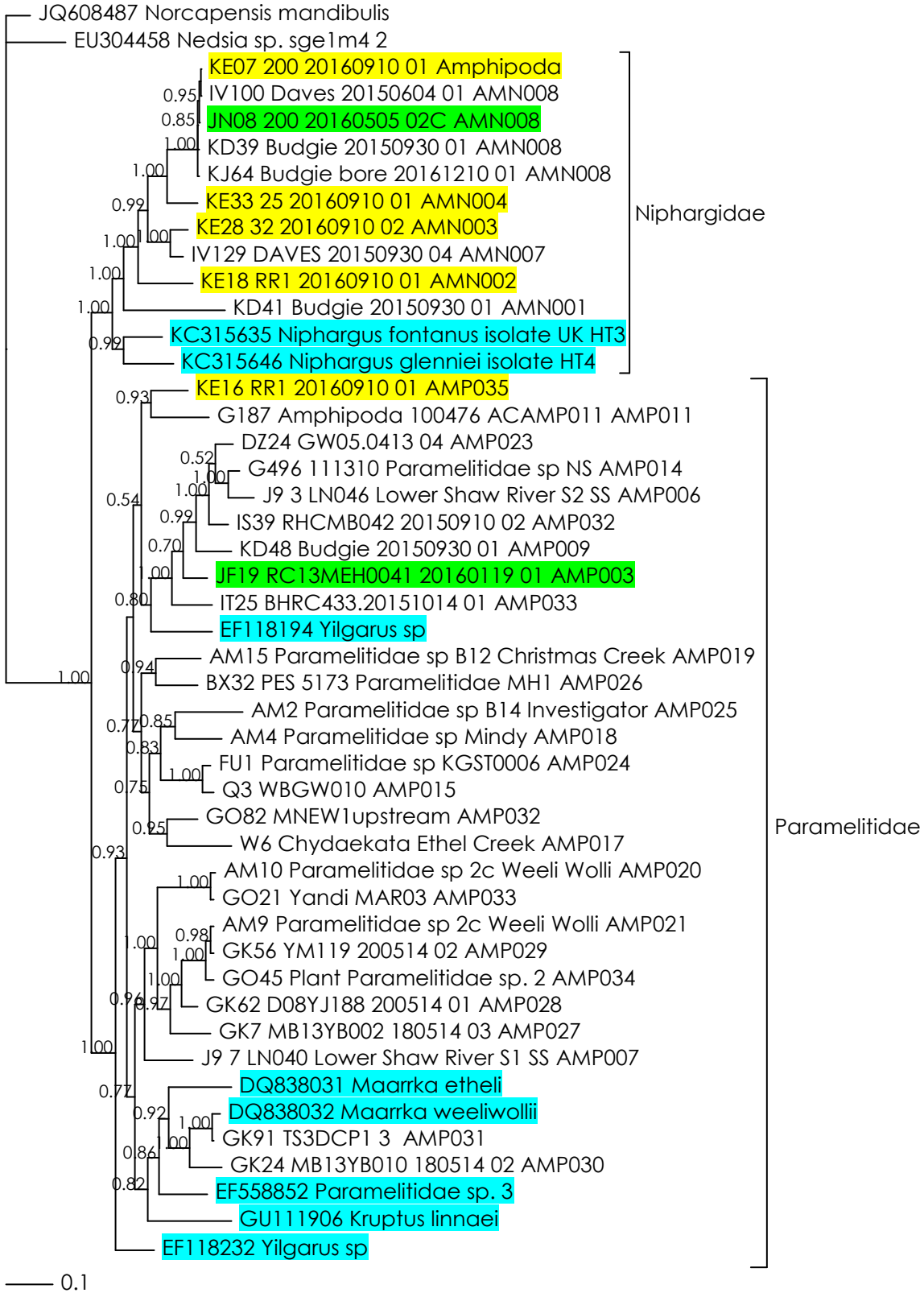
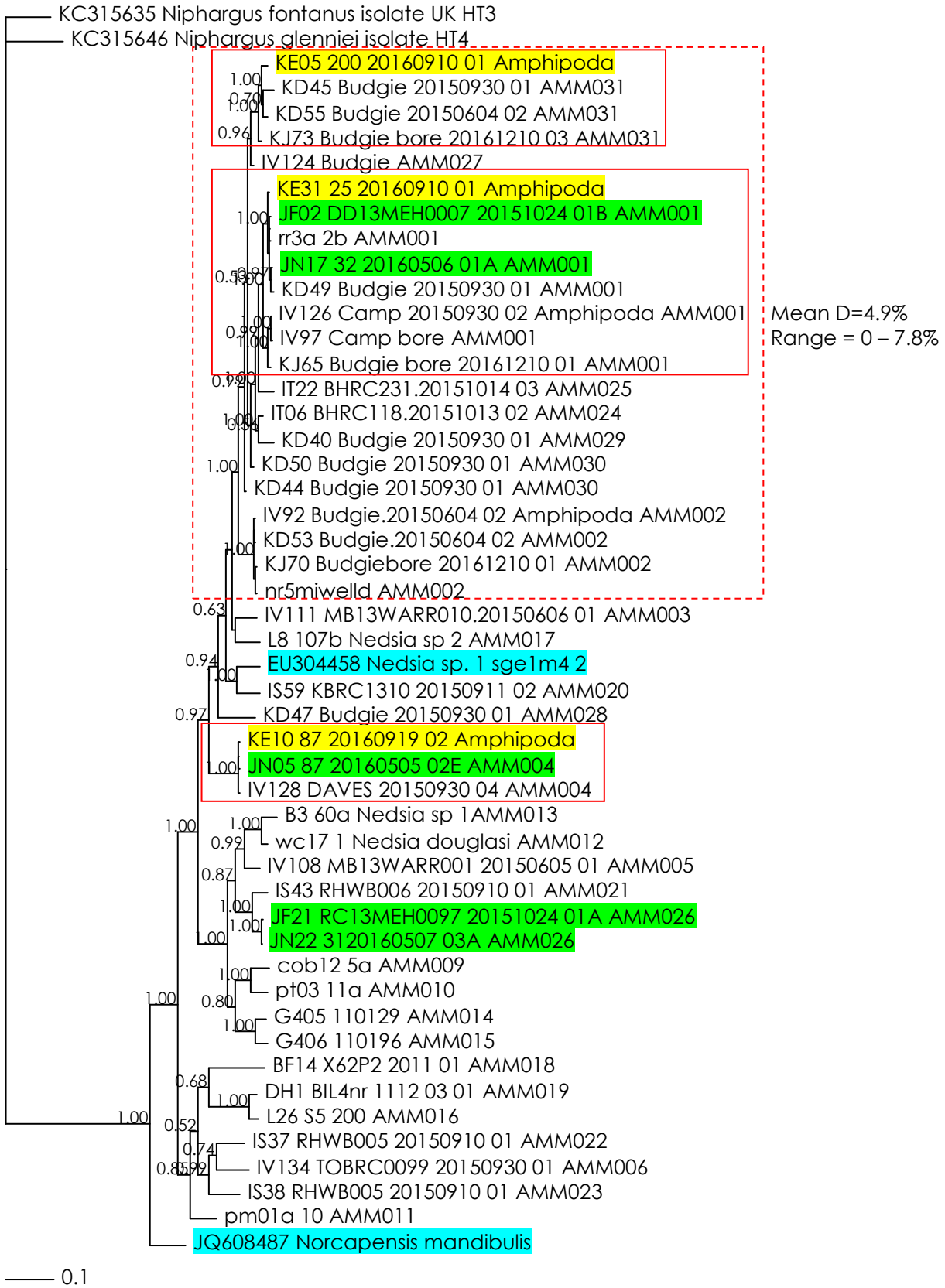


Figure 3. Bayesian analysis of COI haplotypes of Melitidae (Amphipoda) from the present study and reference specimens from Genbank and previous surveys in the Pilbara. Numbers on major nodes correspond to posterior probabilities; values <50% are not shown. Specimens from the present study are highlighted in yellow; specimens from previous phases at Robe Valley are highlighted in green; GenBank voucher specimens highlighted in turquoise. Scale bar= number of substitutions per site. Red boxes with dashed lines represent groups requiring further investigation.



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29 July, 2017

Nicola Watson
Biota Environmental Sciences
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Leederville, WA 6007

Via email

Re. Report on the molecular systematics of additional subfauna from the Mesa H – Phases 4 -6

Dear Nicola,

Following is a summary of the results of the subfauna study we have completed on four additional taxonomic groups (Diplura, Isopoda, Pseudoscorpiones, Schizomids) collected during Mesa H phases 4 - 6. Fourteen distinct genetic lineages were detected among the four groups. Two of the 14 lineages have been detected previously in the Pilbara, whereas the remaining 12 are new, based on the material available for comparison.

Thanks once again for collaborating on this project with Helix. We hope we can continue to provide you with useful information, and feel free to contact us if you have any questions or would like to discuss the results in detail.

Sincerely,

Dr. Terrie Finston, Yvette Hitchen and Dr. Oliver Berry
Helix Molecular Solutions

Background and Objective

Thirty-five specimens of subfauna belonging to four taxonomic groups (Diplura, Isopoda, Pseudoscorpiones, Schizomida) were collected from Mesa H, phases 4 - 6 and sequenced for variation at the mitochondrial COI gene. The molecular data were assessed in order to determine the number of species present in each group and compare the results to those obtained during previous surveys that have been undertaken for the these groups elsewhere in the Pilbara.

Executive summary

- Thirty-five specimens from Mesa H belonging to four taxonomic groups (Diplura, Isopoda, Pseudoscorpiones, Schizomida) were sequenced for variation at the COI gene.
- Fourteen lineages were detected among the four groups.
- Two of the lineages have been detected previously in the Pilbara, whereas the remaining 12 appear to be new, based on the material available for comparison.

Methods

Thirty-five specimens of subfauna from four taxonomic groups (Diplura, Isopoda, Pseudoscorpiones, Schizomida) collected from Mesa H, phases 4 - 6 were sequenced for variation at the mitochondrial cytochrome oxidase subunit I gene (COI) using multiple pairs of primers (LCOI/HCO2, LCOI-long/HCO2-long, NemF1/NemR1 and LCOI/CIN2341.

Sequences were edited using GENEIOUS software (Drummond *et al.* 2011). Alignment was performed with CLUSTAL W (Thompson *et al*. 1994) using default parameters. Genetic distances between unique genetic sequences (haplotypes) were measured using uncorrected p-distances (total percentage of nucleotide differences between sequences).

MODELTEST software (Posada and Crandall, 1998) was used to determine the model of sequence evolution that best fitted the data for each taxonomic group. Bayesian analysis was used to construct the phylogenetic trees, incorporating the model as identified in MODELTEST for each taxonomic group. The phylogeny, branch lengths and posterior probabilities were obtained by running two trees simultaneously, each running four simultaneous MCMC chains. The number of cycles needed was determined by the standard deviation of the split frequencies of the two trees. The analysis was paused after every 1 x 10^6 generations and when the standard deviation fell below 0.01, the analysis was stopped. A majority rule consensus tree was constructed after discarding the "burn-in" trees in both analyses. The burn-in value was determined by plotting the posterior probabilities obtained after every generation and identifying the point at which the values reach stationarity (= the asymptote). Trees produced prior to stationarity were discarded.

For the purposes of this report, lineages were defined as haplotypes or groups of haplotypes differing from other such groups by >3% sequence divergence. This cut-off was selected based on bar-coding data, which indicates that intra-specific variation rarely exceeds 3% (Hebert et al., 2003b).

We are currently developing a consistent and unique lineage and species naming system, so all lineages from previous phases will be consolidated in this report to aid in comparisons between phases.

Results

Isopoda

Preliminary analysis, reference specimens and outgroups

Twenty specimens of Isopoda were sequenced from Mesa H phases 4 - 6 (Table 1). Ten of the 20 specimens yielded a DNA sequence; the remainder could not be amplified, despite trying three different primer pairs. A preliminary neighbour-joining analysis of the ten specimens revealed the presence of two distinct genetic groups (Figure 1). One group contained nine specimens from phase 6 and the second group contained a single specimen from phase 4 (Figure 1). A search of similar sequences on Genbank and in the Helix database indicated that the specimens from the first group were most closely matched with Armadillidae and the specimen from the second

group to the Philosciidae. Hence two separate phylogenic analyses were conducted; the first contained the one representative from the phase 6 Mesa H Armadillidae and included two Genbank voucher specimens of Armadillidae: *Troglarmadillo* sp. 6 (Genbank accession # KX656276) and *Spherillo* sp. Kazaki , as well as 37 reference specimens of Armadillidae from previous surveys in the Pilbara. Two specimens of the isopod genus *Haloniscus, Haloniscus* sp. 10 (Genbank accession #EU364592) and *Halonsicus* sp. 12 (Genbank accession #EU364601) were used as outgroups.

The second analysis contained the single specimen of Philosciidae from phase 4 and included GenBank voucher specimens of *Halonsicus* sp. 21 (Genbank accession #EU364622), *Haloniscus* sp. 10 (Genbank accession #EU364592), *Halonsicus* sp. 12 (Genbank accession #EU364601), which are assigned by different authours to either the Philosciidae or the Onisceidae and *Laevophiloscia yalgoorensis* (Genbank accession #EU364629) from the family Philosciidae, as well as 19 specimens of Philosciidae from previous surveys in the Pilbara. Two specimens of Armadillidae, *Armadillidium nasatum* (Genbank accession # FN824099) and *Troglarmadillo* sp. 6 (Genbank accession # KX656276) were used as outgroups.

Phylogenetic analysis

The phylogenetic analysis of the Armadillidae, which included the representative specimen from Mesa H (KU23), in addition to 39 reference specimens, placed the Mesa H specimen in a single distinct lineage (Figure 2). The lineage did not contain any of the reference specimens, so was assigned to the new lineage ISA057, however, specimen KU23 did form a well-supported clade with reference specimen KD23 from the Robe Valley, and the Genbank voucher specimen of *Spherillo* from Japan (Figure 2).

The phylogenetic analysis of the Philosciidae, which included the specimen from Mesa H (KE01), in addition to 23 reference specimens, placed the Mesa H specimen in a single distinct genetic lineage (Figure 3). The lineage did not contain any of the reference specimens, so was assigned to the new lineage ISP055, however, specimen KE01 did form a well-supported clade with reference specimen JF45 from a previous survey at Mesa H (Figure 3).

Differentiation within and between lineages

Specimens within the Mesa H lineage of Armadillidae differed from one another by 0.1% mean sequence divergence (Table 2). Specimen KU23 differed from the nearest reference specimen, KD23, by 4.5% sequence divergence and from the Genbank specimen of *Spherillo* by 6.1% sequence divergence (Table 3). Specimen KU23 differed from the remaining reference specimens by >30% sequence divergence (Table 3).

The Mesa H lineage of Philosciidae differed from the nearest reference specimen, JF45 from a previous survey at Mesa H, by 5.1% sequence divergence and from the remaining reference specimens by >15% sequence divergence (Table 4).

Diplura

Reference specimens and outgroups

Five specimens of Diplura from Mesa H phases 4 – 6 were sequenced for COI (Table 5). The four specimens for which sequences were obtained were analysed with 36 specimens of Diplura from the Pilbara belonging to five families: Anajapygidae, Campodeiidae, Japygidae, Parajapygidae and Projapygidae, as well as five Genbank voucher specimens, Diplura sp. (Genbank accession #HQ943342), *Japyx solifugus* (Japygidae; Genbank accession #AY771989) *Campodea tillyardi* (Campodeidae; Genbank accession # AF370844), *Lepidocampa weberi* (Campodeidae: Genbank accession #HQ882832) and *Parajapyx pauliani* (Genbank accession # JQ692327). The planthopper *Lycorma delicatula* (Genbank accession # FJ456942) and a specimen of Fulgoridae (Hemiptera; Genbank accession #GU671563) were used as outgroups.

Phylogenetic analysis

The phylogenetic analysis, which included the four specimens of Diplura from Mesa H, in addition to 41 reference specimens, placed the Mesa H specimens in four distinct lineages

(Figure 4). The four lineages were placed in three well-supported clades containing Genbank and Pilbara reference specimens of Japygidae (one lineage), Projapygidae (two lineages) and Parajapygidae (three lineages; Figure 4). None of the four Mesa H specimens were placed in lineages containing reference specimens, and thus were assigned to the new lineages DJA011, DPR010, DPR011 and DPA009 for KE04, KU01, KU02 and KU08, respectively (Figure 4). However, one, DPR011, was placed in a well-supported clade that also contained reference specimen JF40 from a previous survey at Mesa H (Figure 4).

Differentiation within and between lineages

The four lineages of Diplura from Mesa H phases 4 - 6 differed from one another by between 16.4 and 27.0% sequence divergence (Table 6). The four lineages differed from the nearest reference specimens by between 3.6 and 15.5% sequence divergence (Table 6). Specifically, DPR011 (KU02) differed from specimens JF40 and JF38 from a previous survey at Mesa H by 3.6% and 5.1% sequence divergence, respectively (Table 6). In contrast, the remaining lineages detected at Mesa H (DPR010, DPA009 and DJA011) differed from the nearest reference specimens by >12% (Table 6).

Pseudoscorpions

Reference sequences and outgroups

Five pseudoscorpions from phases 4 – 6 were sequenced from Mesa H (Table 7). A search of similar sequences on Genbank and in the Helix database indicated that one of the specimens most closely matched reference specimens of Chthoniidae, two of the specimens most closely matched reference specimens of Olpiidae and two of the specimens most closely matched reference specimens of Hyiidae. Based on those results, three separate phylogenetic analyses were conducted, one for each family. In addition, specimens of Atemnidae were analysed with the Olipiidae, because Atemnidae were detected in a previous survey at Mesa H.

For the Hyiidae, one GenBank voucher sequence of Hyiidae, *Indohya* sp JM 2008 (Genbank accession # EU559564) and 27 specimens of Hyiidae from previous surveys in the Pilbara were included in the analysis.

For the Olpiidae and Atemnidae, two Genbank voucher specimens of Olpiidae, *Beierolpium bornemisszai* (Genbank accession # EU559545) and *Calocheiridius termitophilus* (Genbank accession #EU559544) and two Genbank vouchers of Atemnidae, *Paratemnoides sumatranus* (Genbank accession # JN018204) and *Paratemnoides elongates* (Genbank accession #JQ040543) as well as 13 and four specimens from the Pilbara, respectively were included in the analysis.

For the Chthoniidae, a reference dataset of 76 Genbank and Pilbara specimens was reduced to a more manageable and relevant dataset by selecting only the 40 reference specimens that occurred in the same clades as the phase 4 – 6 specimens, based on a preliminary neighbour joining analysis. Two Genbank voucher sequences of Chthoniidae were included in the analysis, *Paraliochthonius* sp JM 2008 (Genbank accession #EU5595505) and *Tyrannochthonius aridus* (GenBank accession # KJ659959 from Western Australia) and in addition, as local references, 38 specimens of Chthoniidae from previous surveys in the Pilbara. Sequences of the scorpion *Pandinus imperator* (Genbank accession # AY1565821) and harvestman spider *Siro rubens* (Genbank accession # DQ5131111) were used as outgroups.

Phylogenetic analyses

The phylogenetic analysis of the Hyiidae, which included one specimen from Mesa H phase 4 (KE03) and one from phase 6 (KU28), in addition to 28 reference specimens of Hyiidae, placed the Mesa H specimens in two distinct genetic lineages, neither of which contained reference specimens (Figure 5). KE03 therefore was assigned to the new lineage PH026 and KU28 was assigned to the new lineage PH027 (Figure 5). KE03/PH026 formed a well-supported clade with specimens IV206 and IV209 from the Robe Valley (lineage PH001) and KU28 formed a well-supported clade with specimen JF56 (lineage PH017) from a previous survey at Mesa H and IV213 (lineage PH007) from the Robe Valley (Figure 5).

The phylogenetic analysis of the Olpiidae, which included the two specimens from Mesa H phase 5 (KU03, KU06), in addition to 15 reference specimens, placed the Mesa H specimens in two distinct genetic lineages, neither of which contained reference specimens (Figure 6). KU03 therefore was assigned to the new lineage PO014 and KU06 was assigned to the new lineage PO015 (Figure 6). KU03/PO014 and KU06/PO015 formed a well-supported clade with one another and two specimen of *Beierolpium :* specimen BQ20 from Wonmunna and the Genbank voucher specimen of *Beierolpium bornemisszai* (Figure 6).

The phylogenetic analysis of the Chthoniidae, which included the one Chthoniidae specimen from Mesa H phase 6 (KU29), in addition to 40 reference specimens, placed the Mesa H specimen in a distinct genetic lineage that did not contain any reference specimens (Figure 7). KU29 was therefore assigned to the new lineage PC055 (Figure 7). However the lineage showed significant although distant relationships with some reference specimens (Figure 7). Specifically, specimen KU29/PC055 formed a well-supported clade with specimens JU05, JU06 and JU08 from a previous survey at Mesa H and specimens IV210, IV268, IV269 and KD27, from previous surveys at Mesas A and B in the Robe Valley (Figure 7).

Differentiation within and between lineages

The two specimens of Hyiidae from Mesa H (KE03 and KU28) differed from one another by 24.9% sequence divergence (Table 8). Specimen KE03 differed from the nearest reference specimens IV206 and IV209 by 7.3 sequence divergence (Table 8). Specimen KU28 differed from the nearest reference specimens JF56 from Mesa H and IV213 from the Robe Valley by 4.0 and 7.1% sequence divergence, respectively (Table 8).

The two specimen of Olpiidae from the Mesa H (KU03 and KU06) differed from one another by 17.0% sequence divergence and from the reference specimens of *Beierolpium* (*B. bornemisszai* and BQ20) by between 16.6 and 23.8% sequence divergence (Table 9).

The specimen of Chthoniidae from Mesa H (KU29) differed from the nearest references (three specimens from a previous survey at Mesa H, JU05, JU06, JU08 and four specimens from Mesa A and B in the Robe Valley, IV210, IV268, IV269, KD27) by more than 16% sequence divergence (Table 10).

Schizomida

Preliminary analysis - Reference sequences and outgroups
Five schizomids from phases 4 – 6 were sequenced from Mesa H (Table 11). The specimens were analysed with >700 reference sequences of schizomids from previous surveys in the Pilbara to compile a manageable and relevant reference data set. The reference sequences were selected based on the criteria that they showed ≤ 15% sequence divergence from at least one of the Mesa H lineages. A reference dataset of 28 reference specimens was selected, 20 from previous surveys in the Pilbara and eight Genbank voucher sequences as follows: *Paradraculoides anachoretus* (Genbank accession # EU272709), *Paradraculoides eremius* (Genbank accession # KU291135), *Paradraculoides* sp. (Genbank accession # EU272697), *Paradraculoides bythius* (Genbank accession # EU272715), *Paradraculoides gnophicola* (Genbank accession # EU272716), *Paradraculoides kryptus* (Genbank accession # EU272724), *Draculoides vinei* (Genbank accession # EU272694), *Draculoides julianneae* (Genbank accession # EU272696) A specimen of schizomid from the family Hubbardiidae, *Brignolozomus woodwardi* (GenBank accession # EU272675) was used as an outgroup.

Phylogenetic analysis
The phylogenetic analysis, which included the five Mesa H specimens, in addition to 28 selected reference specimens of schizomids, placed the Mesa H specimens in three distinct lineages, two of which also contained reference specimens from previous surveys at Mesa H and the Robe Valley (Figure 8). Thus two of the specimens (KE02, KU30) were assigned to the existing lineage SCH038 and two (KU04, KU05) were assigned to the existing lineage SCH015 (Figure 8). The last

specimen KU3, was placed in a lineage that did not contain any reference specimens and thus was assigned to the new lineage SCH039 (Figure 8). Lineages SCH038 and SCH039 were placed in a well-supported clade containing the six Genbank reference specimens of *Paradraculoides* (Figure 8). Lineage SCH015 was placed in a clade that was distinct from both the *Paradraculoides* and *Draculoides* clades (Figure 8).

Differentiation within and between lineages
The five specimen of schizomids detected at Mesa H differed from one another by between 0 and 13.0% sequence divergence (Table 12). The two specimens in lineage SCH038 (KE02, KU30) differed from one another by 2.4% sequence divergence and the two specimens in lineage SCH015 (KU04, KU05) were genetically identical (Table 12).

Two of the lineages differed from the closest reference specimens by <3% sequence divergence (Table 12). Specifically, specimens KE02 and KU30 (lineage SCH038) differed from reference specimen JF48 by 0.8% sequence divergence but from the next nearest reference specimens (IT67 and HE12) by >10% (Table 12). Specimens KU04 and KU05 differed from the nearest reference specimens JF50 and GH11 by 2.1% and 2.7%, respectively, and from JU03 by 4.3% sequence divergence (Table 12). Specimens KU04 and KU05 differed from the remaining reference specimens by >12% sequence divergence (Table 12).

Conclusions
COI is widely considered to show suitable variation to distinguish species (Hebert et al., 2003a). In a comparison of COI sequences for over 13,000 pairs of taxa, Hebert et al (2003b) found a mean of 11.1% sequence divergence between distinct species. Nearly 80% of the comparisons showed that species pairs differed from one another by greater than 8% sequence divergence. However, a taxon by taxon approach, examining the amount of phylogenetic variation within and between species is the most widely accepted method of defining species.

<u>Isopoda</u>
Two distinct genetic lineages of Isopoda were detected at Mesa H, one of which was most similar to reference specimens of Armadillidae, and one of which was most similar to reference specimens of Philosciidae. Both lineages were assigned to new lineages, ISA057 and ISP055, respectively, because they differed from the reference lineages by > 3%.

While each is a new lineage, the Mesa H lineages did show moderately close relationships to reference specimens, which require further consideration. The Mesa H Armadillidae lineage ISA057 differed from a reference specimen at Mesa C by 4.5% sequence divergence and from the *Spherillo* specimen from Japan by 6.1%. These values are greater than the intraspecific variation generally observed within Isopoda lineages (<1%; Hutchins, 2007; Finston et al., 2009), however, given the geographic distance between sites where this clade was detected, this could represent a pattern of genetic diversity associated with geographic distance. Sampling intermediate sites may help determine whether there is a sharp break between haplotypes (this might indicate the presence two different species) or if there is a gradual shift from one haplotype to the next over that geographical space (this would suggest connectivity among populations and imply that we are observing variation within a single species). It is worth nothing that lineage ISA057 (KU23) was highly divergent from the remaining reference specimens of Armadillidae, so it is only tentatively placed in that family, however, it was most closely related to Armadillidae in both the Helix and GenBank databases.

Mesa H Philosciidae lineage ISP055 differed from reference specimen JF45 from a previous survey at Mesa H by 5.1%. In contrast to the Armadillidae, this level of genetic variation is detected over a relatively short geographic distance – both samples were taken from Mesa H. This would suggest a lack of gene flow between populations despite being geographically close, and may indicate the presence of two recently-separated but distinct species. Again, sampling of intermediate areas may help resolve this relationship.

Armadillidae

ISA057 = new lineage; species likely to have been detected previously at Mesa C but requires further investigation.

Philosciidae
ISP055 = new lineage; species may be new but requires further investigation

Diplura
Four distinct genetic lineages of Diplura were detected at Mesa H, one of which was most similar to reference specimens of Japygidae, two of which were most similar to reference specimens of Projapygidae, and one of which was most similar to reference specimens of Parajapygidae. All four lineages were assigned to new lineages, DJA011, DPR010, DPR011 and DPA009, because they differed from the reference lineages by > 3%.

While each is a new lineage, one Mesa H lineage did show a moderately close relationship to a reference specimen, which requires further consideration. The Mesa H Projapygidae lineage DPR011 differed from reference specimen JF40 from a previous survey at Mesa H by 3.6% sequence divergence and from JF38 by 5.1% sequence divergence. These values are greater than the intraspecific variation normally observed within Diplura lineages (mean = 1.9% for species in the genus *Japyx*; Bu et al, 2012). This would suggest limited gene flow between populations in this clade despite being geographically close, although we may be observing a 'stepping-stone' pattern of genetic diversity, where nearby populations exchange genes, whereas those at the extreme ends of the continuum do not. Again, sampling of intermediate areas may help resolve this relationship.

Japygidae
DJA011= new lineage; new species

Parajapygidae
DPA009= new lineage, new species

Projapygidae
DPR010= new lineage, new species
DPR011= new lineage; species may have been detected previously at Mesa H, but requires further investigation

Pseudoscorpiones

Five distinct genetic lineages of pseudoscorpions were detected at Mesa H phases 4 - 6: one Chthoniidae, two Olpiidae and two Hyiidae.

The two lineages of Hyiidae detected at Mesa H (PH026 and PH027) differed from one another by 24.9% sequence divergence, indicating that they represent two distinct species. While both lineages were new, differing from the reference specimens by >3% sequence divergence, one, PH027, is likely to belong to a species that has been detected previously at Mesa H, differing from reference specimen JF56 (lineage PH017) by 4.0% sequence divergence. This level of genetic differentiation however, indicates that gene flow may be low between sampling sites, perhaps owing to the poor dispersal ability of the taxon or geographic barriers. Lineages PH027 and PH017 in turn form a well-supported clade with specimen IV213 (lineage PH007) from the Robe Valley. The three specimens differ from one another by between 6.9 and 7.1% sequence divergence. This suggests that while closely related, the Robe Valley lineage is likely to represent a distinct species from the Mesa H lineage, although sampling intermediate sites may help resolve relationships between these lineages.

The second lineage of Hyiidae, PH026, formed a relatively close relationship with lineage PH003 (specimens IV206 and IV209) from the Robe Valley, forming a well-supported clade, and differing by 7.3% sequence divergence. Distances between specimens assigned to the same species in previous studies in the Pilbara (i.e. PC047, PH002) differ by ≤ 2.0%, so the distance between PH026 and PH003 is higher than appears typical for the Pseudoscorpiones. This suggests that while closely related, the two lineages are likely to represent distinct species, although sampling intermediate sites may help resolve relationships between these lineages.

The two lineages of Olpiidae detected at Mesa H, PO014 and PO015, represent both new lineages and new species, as they differed from the nearest reference specimens by >16% sequence divergence. However, we can tentatively assign both lineages to the genus *Beierolpium*, as PO014 and PO015 were both placed in a clade containing reference specimens of that genus.

The lineage of Chthoniidae detected at Mesa H, PC055, represents both a new lineage and a new species, as it differed from the nearest reference specimens by >16% sequence divergence.

Hyiidae
PH026 = new lineage, new species
PH027 = new lineage, species detected previously at Mesa H

Olpiidae
PO014 = new lineage, new species of *Beierolpium*
PO015 = new lineage, new species of *Beierolpium*

Chthoniidae
PC055 = new lineage, new species

Schizomida
Previous analyses of genetic variation between morphologically distinct species of Schizomida can be used as a genetic 'yardstick' to interpret the current data set. The five described species of *Paradraculoides* (Harvey et al, 2008) differ from one another by between 8.4 to 12.1% sequence divergence (uncorrected p-distances; calculated by us from the Harvey et al., 2008 data). Similarly, the four described species of *Draculoides* differ from one another by between 4.5 to 13.7% sequence divergence (uncorrected p-distances calculated by us from Harvey et al., 2008).

Three lineages of Schizomida were detected at Mesa H, phases 4 – 6, two *Paradraculoides* (SCH038, SCH039), and one not assigned to a family (SCH015). Two of the lineages (SCH015, SCH038) have been detected previously at Mesa H and in the Robe Valley, whereas one (SCH039) is new.

One of the *Paradraculoides* lineages, SCH038, is a lineage and species that has been detected previously at Mesa H, however, the new lineage, SCH039, likely represents a new species, as it differs from the nearest reference specimen by >7%. However, this level of sequence divergence is only moderate, and the nearest reference specimen was collected in Buckland Hills, thus sampling intermediate sites may resolve the relationship between these two lineages.

The lineage that we could not assign to a family (SCH015) has been detected previously at Mesa H and a second site in the Robe Valley. It does not appear to belong to *Draculoides*, *Paradraculoides* or *Bamazomus* (*Bamazomus* not shown), as it was placed in a clade that was distinct from the clades of these families. A closely related lineage (SCH016) was detected during a previous survey at Mesa H. Lineages SCH015 and SCH016 differ from one another by 4.3% and are likely to represent the same species, however, this level of divergence is somewhat elevated, given that the two lineages were both collected at Mesa H. This suggests there may be a barrier to gene flow at Mesa H between RC16JIM and RC15MEH.

Paradraculoides
SCH038 = lineage and species detected previously at Mesa H
SCH039 = new lineage, new species

Unknown family
SCH015 lineage and species detected previously at Mesa H and the Robe Valley

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Table 1. Specimens of Isopoda used in the present study and the lineage to which they were assigned, based on variation at the COI gene. *=new lineage this study.

Specimen ID	Phase	Cap no.	New cap no.	Helix ID	Lineage
RC16MEH0427.20161026.T3-01	4	56	-	KE01	ISP055*
MEHRD0577.20170130.T1-02	6	13	13	KU09	No amp
MEHRD0577.20170130.T1-02	6		13c	KU10	No amp
MEHRD0577.20170130.T1-02	6		13b	KU11	No amp
MEHRD0577.20170130.T2-01	6	15	15	KU12	No amp
MEHRD0577.20170130.T2-01	6		15b	KU13	ISA057*
MEHRD0577.20170130.T2-01	6		-	KU14	ISA057*
MEHRD0577.20170130.T3-01	6	17	17	KU15	No amp
MEHRD0577.20170130.T3-01	6		17b	KU16	No amp
MEHRD0577.20170130.T3-01	6		17c	KU17	No amp
MEHRD0577.20170130.T3-01	6		-	KU18	No amp
MEHRD0577.20170130.T3-01	6		-	KU19	ISA057*
MEHRD0577.20170130.T3-01	6		-	KU20	ISA057*
MEHRD0577.20170130.T3-01	6		-	KU21	No amp
MEHRD0834.20170130.T1-01	6	21	21	KU22	ISA057*
MEHRD0834.20170130.T1-01	6		21b	KU23	ISA057*
MEHRD0834.20170130.T1-01	6		-	KU24	ISA057*
MEHRD0834.20170130.T1-01	6		-	KU25	ISA057*
MEHRD0834.20170130.T1-01	6		-	KU26	No amp
MEHRD0834.20170130.T2-01	6	23	23	KU27	ISA057*

Table 2. Mean genetic distance (D) and standard error (s.e.) within lineages of Isopoda as shown in Figure 1. N= number of specimens in the lineage; Rep= specimen used to represent the lineage in the model-based phylogenetic analysis. n/c= not calculated where the number of specimens in the lineage is 1.

Lineage	D	s.e.	N	Rep
1	0.001	0.001	9	KU23
2	n/c	n/c	1	KE01

Table 3 (attached). Genetic distances (below diagonal) and standard error (above diagonal, in blue) between specimens of Armadillidae (Isopoda) detected at Mesa H and the reference lineages as shown in Figure 2. Distances between the Mesa H specimens and the reference specimens are highlighted in yellow.

Table 4 (attached). Genetic distances (below diagonal) and standard error (above diagonal, in blue) between specimens of Philosciidae (Isopoda) detected at Mesa H and the reference lineages as shown in Figure 3. Distances between the Mesa H specimens and the reference specimens are highlighted in yellow.

Table 5. Specimens of Diplura used in the present study and the lineage to which they were assigned, based on variation at the COI gene. *=new lineage this study.

Specimen ID	Phase	Helix ID	Cap no.	New cap no.	Lineage
DD13MEH0007-20160914-01	4	KE04	22	22	DJA011*
RC16JIM0005.20161212.T1-01	5	KU1	48	48	DPR010*
RC16JIM0005.20161212.T3-01	5	KU2	50	50	DPR011*
RC16MEH0264.20170130.T3-01	6	KU7	3	3	No amp
MEHRD0758.20170130.T3-01	6	KU8	8	8	DPA009*

Table 6 (attached). Genetic distances (below diagonal) and standard error (above diagonal, in blue) between specimens of Diplura detected at Mesa H and the reference lineages as shown in Figure 4. Distances between the Mesa H specimens and the reference specimens are highlighted in yellow.

Table 7. Specimens of Pseudoscorpiones used in the present study and the lineage to which they were assigned, based on variation at the COI gene. *=new lineage this study.

Specimen ID	Phase	Cap no.	New cap no.	Helix ID	Lineage
RC16MEH0436.20161026.T2-01	4	85	1	KE03	PH026*
RC16JIM0026.20161212.T2-01	5	21	21	KU03	PO014*
RC16MEH0433.20161211.T1-02	5	47	47	KU06	PO015*
RC16MEH0264.20170130.T3-03	6	5	5	KU28	PH027*
MEHRD0834.20170130.T2-02	6	24	24	KU29	PC055*

Table 8 (attached). Genetic distances (below diagonal) and standard error (above diagonal, in blue) between specimens of Hyiidae detected at Mesa H and the reference lineages as shown in Figure 5. Distances between the Mesa H specimens and the reference specimens are highlighted in yellow.

Table 9 (attached). Genetic distances (below diagonal) and standard error (above diagonal, in blue) between specimens of Olpiidae detected at Mesa H and the reference lineages as shown in Figure 6. Distances between the Mesa H specimens and the reference specimens are highlighted in yellow.

Table 10 (attached). Genetic distances (below diagonal) and standard error (above diagonal, in blue) between specimens of Chthoniidae detected at Mesa H and the reference lineages as shown in Figure 7. Distances between the Mesa H specimens and the reference specimens are highlighted in yellow.

Table 11. Specimens of Schizomida used in the present study and the lineage to which they were assigned, based on variation at the COI gene. *=new lineage this study.

Specimen ID	Phase	Helix ID	Old cap no.	New cap no.	Lineage
RC16MEH0433.20161026.T2-01	4	KE02	71	71	SCH038
RC16JIM0026.20161212.T1-01	5	KU04	23	23	SCH015
RC16JIM0031.20161212.T2-01	5	KU05	16	16	SCH015
RC16MEH0264.20170130.T3-02	6	KU30	4	4	SCH038
RC15MEJ0019.20170130.T1-01	6	KU31	18	18	SCH039*

Table 12. (attached). Genetic distances (below diagonal) and standard error (above diagonal, in blue) between specimens of Schizomida detected at Mesa H and the reference lineages as shown in Figure 8. Distances between the Mesa H specimens and the reference specimens are highlighted in yellow.

Figure 1. Neighbour-joining analysis of specimens of Isopoda from the present study. Numbers on major nodes correspond to bootstrap support over 100 iterations; values <50% are not shown. Scale bar= genetic distance. The specimens used to represent each lineage in the model-based phylogenetic analysis are highlighted in yellow.

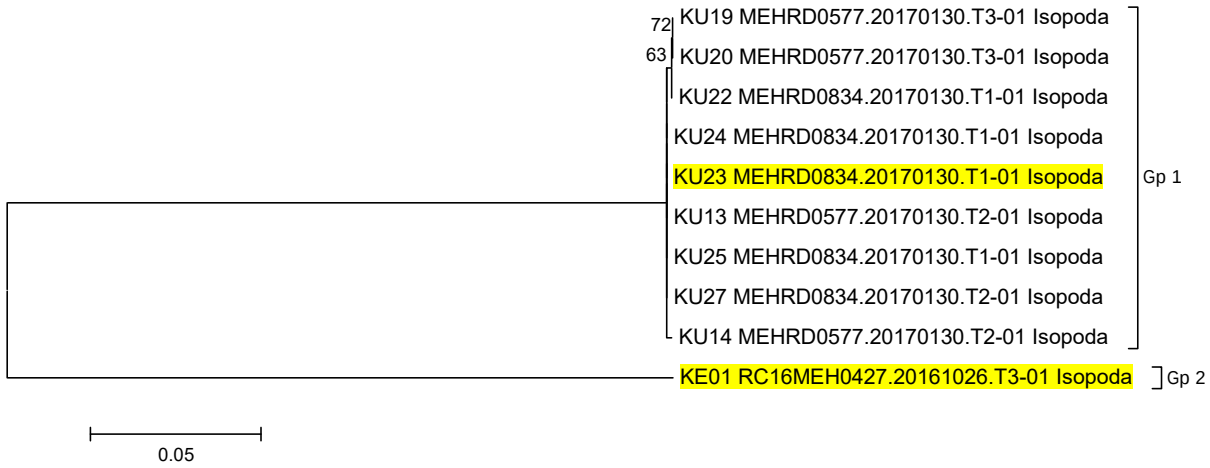


Figure 2. Bayesian analysis of COI haplotypes of Armadillidae from the present study and reference specimens from Genbank and previous surveys in the Pilbara. Numbers on major nodes correspond to posterior probabilities; values <50% are not shown. Specimens from the present study are highlighted in yellow; specimens from previous phases at Mesa H are highlighted in green; GenBank voucher specimens highlighted in turquoise. Scale bar= number of substitutions per site. Red boxes enclose species with high confidence; red boxes with dashed lines represent groups requiring further investigation.

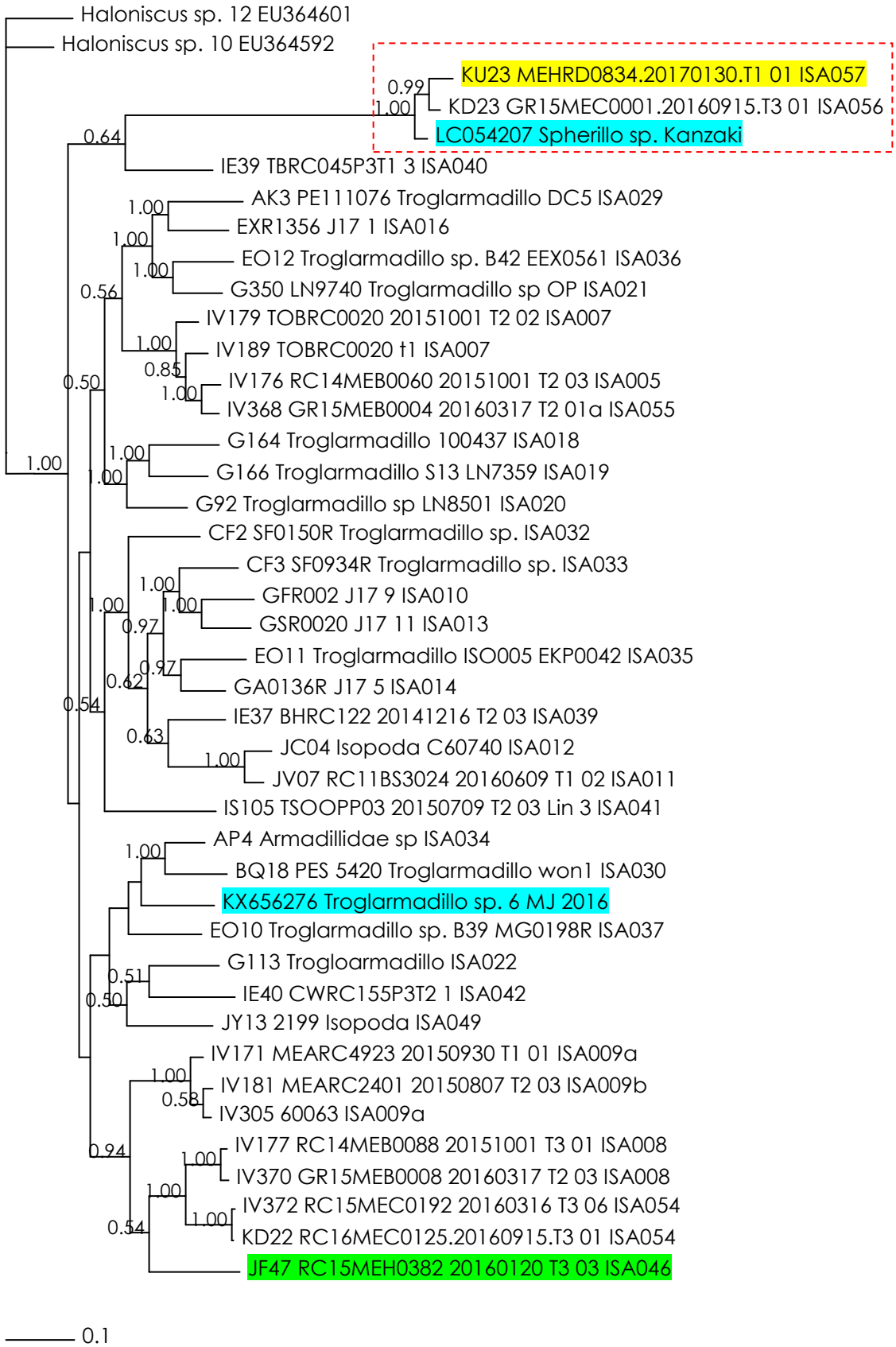


Figure 3. Bayesian analysis of COI haplotypes of Philosciidae (Isopoda) from the present study and reference specimens from Genbank and previous surveys in the Pilbara. Numbers on major nodes correspond to posterior probabilities; values <50% are not shown. Specimens from the present study are highlighted in yellow; specimens from previous phases at Mesa H are highlighted in green; GenBank voucher specimens highlighted in turquoise. Scale bar= number of substitutions per site. Red boxes with solid lines enclose species with high confidence; red boxes with dashed lines represent groups requiring further investigation.

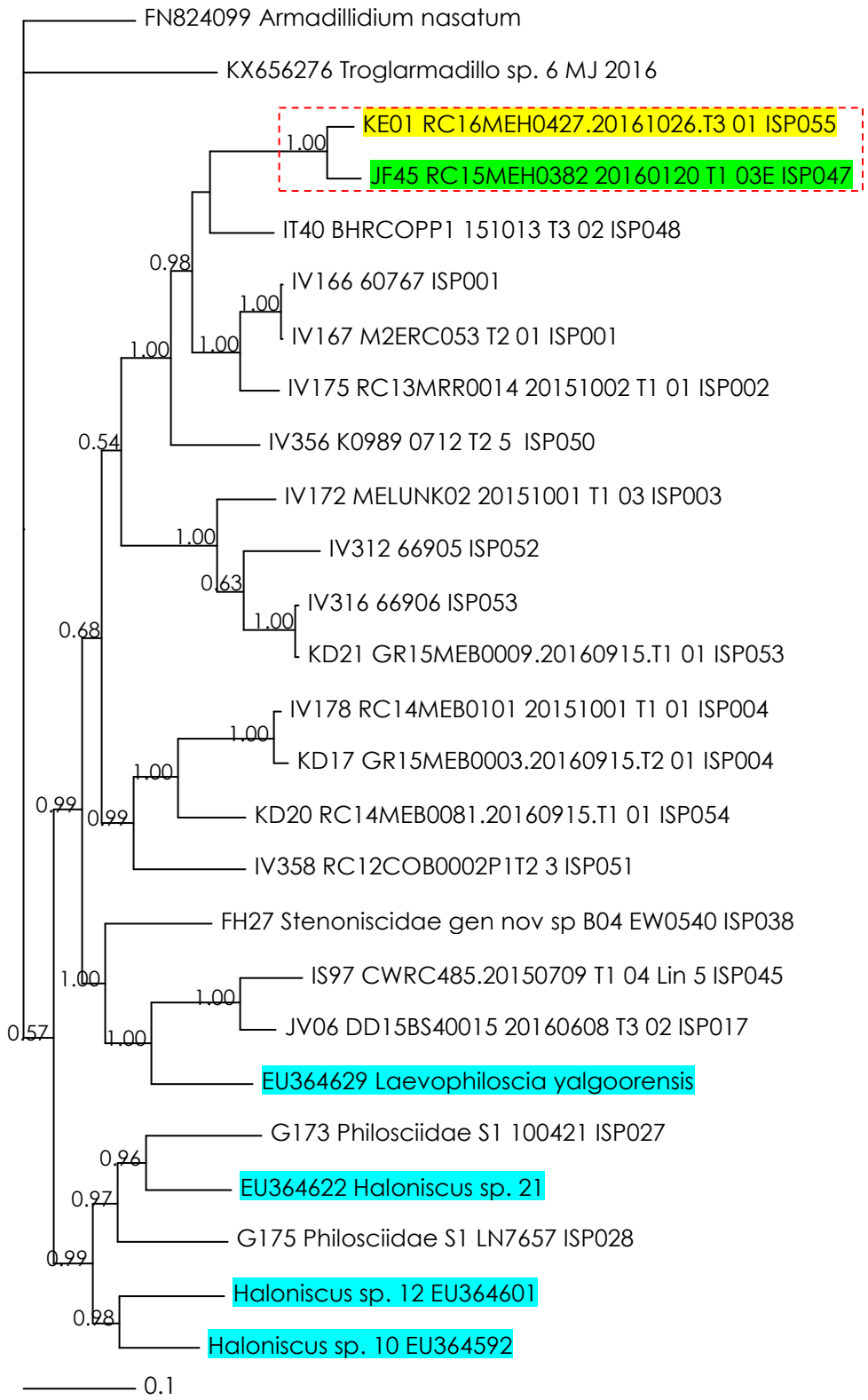


Figure 4. Bayesian analysis of COI haplotypes of Diplura from the present study and reference specimens from Genbank and previous surveys in the Pilbara. Numbers on major nodes correspond to posterior probabilities; values <50% are not shown. Specimens from the present study are highlighted in yellow; specimens from previous phases at Mesa H are highlighted in green; GenBank voucher specimens highlighted in turquoise. Scale bar= number of substitutions per site. Red boxes with solid lines enclose species with high confidence; red boxes with dashed lines represent groups requiring further investigation.

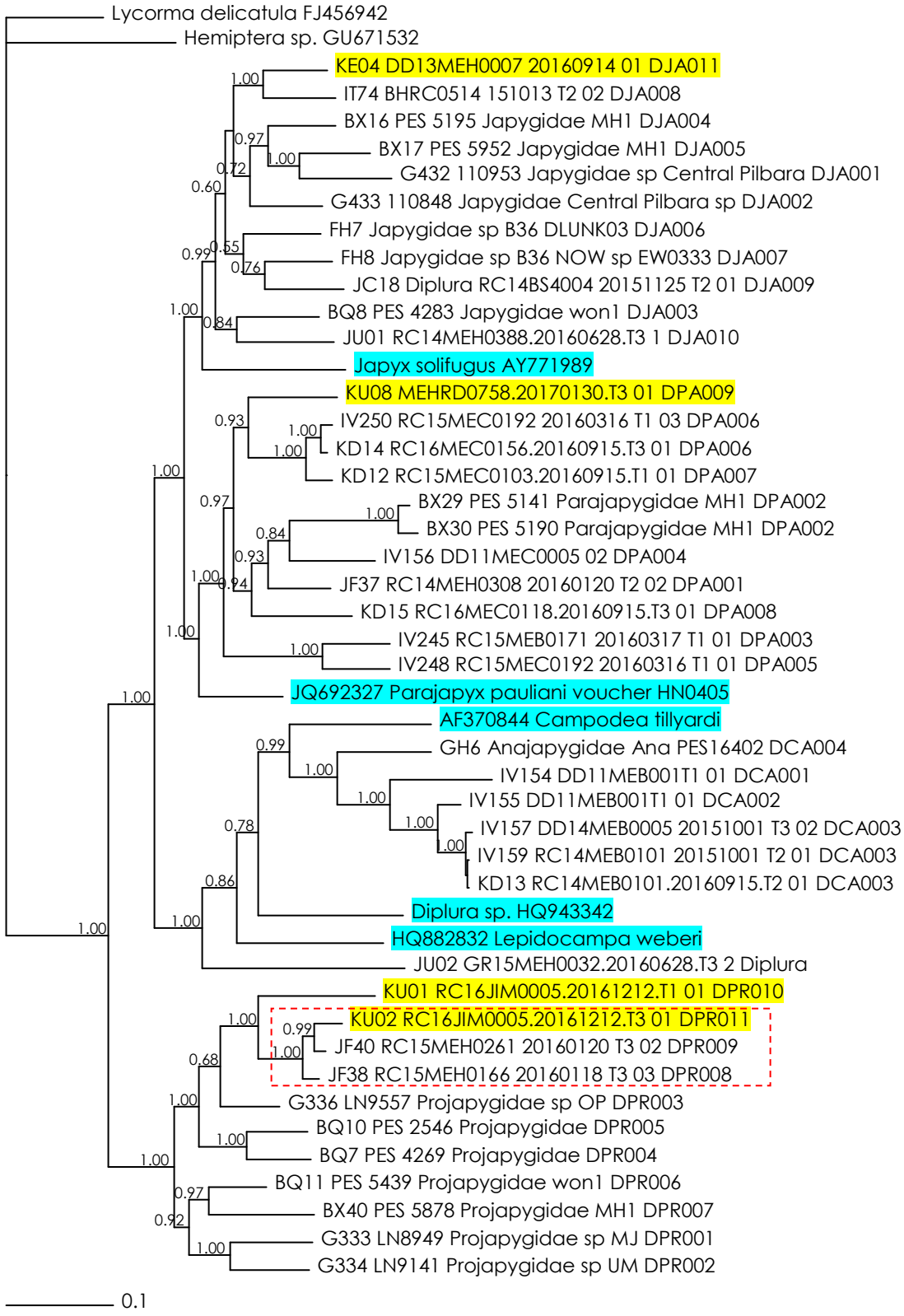


Figure 5. Bayesian analysis of COI haplotypes of Hyiidae (Pseudoscorpiones) from the present study and reference specimens from Genbank and previous surveys in the Pilbara. Numbers on major nodes correspond to posterior probabilities; values <50% are not shown. Specimens from the present study are highlighted in yellow; specimens from previous phases at Mesa H are highlighted in green; GenBank voucher specimens highlighted in turquoise. Scale bar= number of substitutions per site. Red boxes with solid lines enclose species with high confidence; red boxes with dashed lines represent groups requiring further investigation.

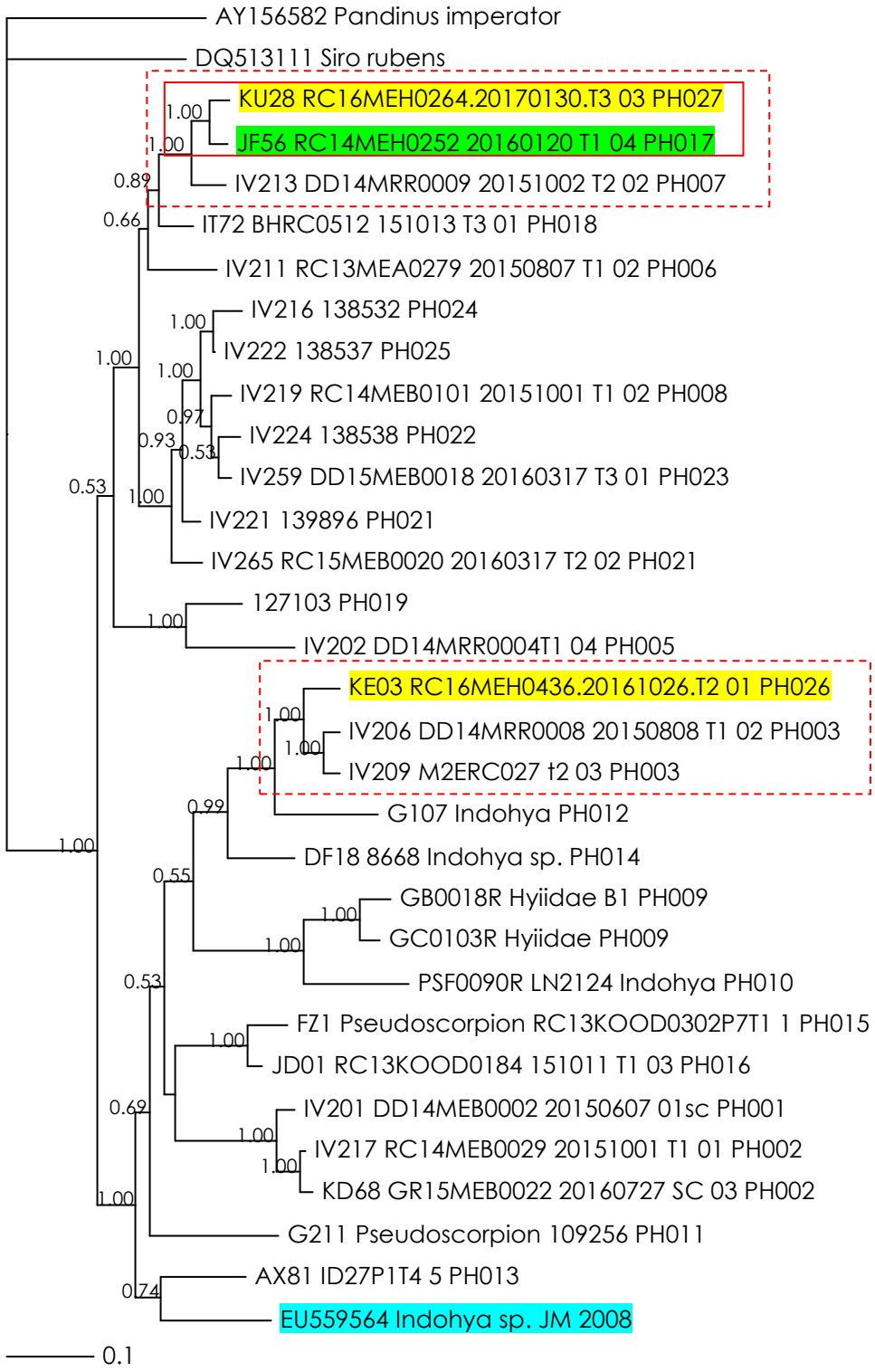


Figure 6. Bayesian analysis of COI haplotypes of Olpiidae and Atemnidae (Pseudoscorpiones) from the present study and reference specimens from Genbank and previous surveys in the Pilbara. Numbers on major nodes correspond to posterior probabilities; values <50% are not shown. Specimens from the present study are highlighted in yellow; specimens from previous phases at Mesa H are highlighted in green; GenBank voucher specimens highlighted in turquoise. Scale bar= number of substitutions per site. Red boxes with solid lines enclose species with high confidence.

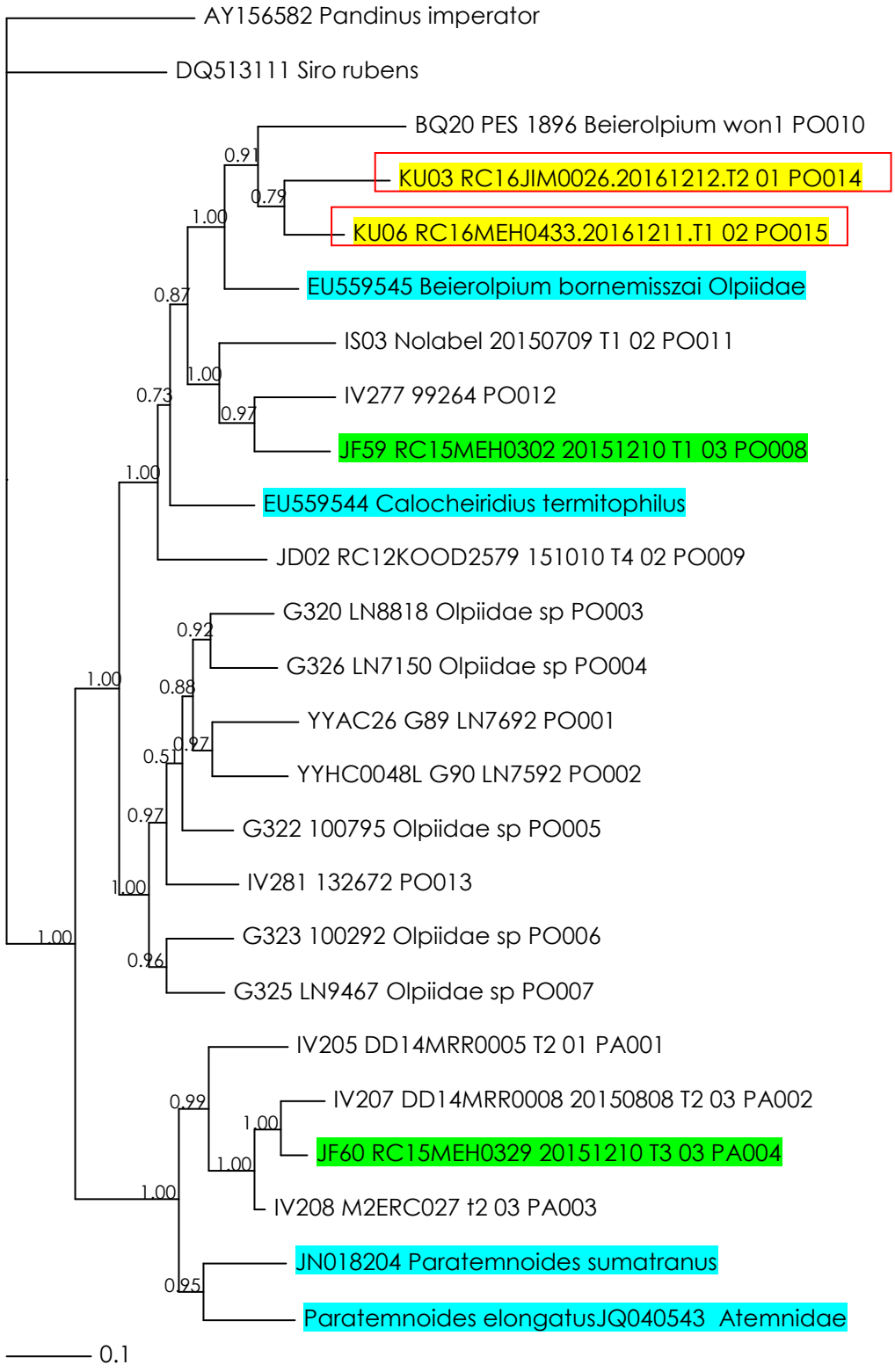


Figure 7. Bayesian analysis of COI haplotypes of Chthoniidae (Pseudoscorpiones) from the present study and reference specimens from Genbank and the Pilbara. Numbers on major nodes correspond to posterior probabilities; values <50% are not shown. Specimens from the present study are highlighted in yellow; specimens from previous phases at Mesa H are highlighted in green; GenBank voucher specimens highlighted in turquoise. Scale bar= number of substitutions per site. Red boxes with solid lines enclose species with high confidence.

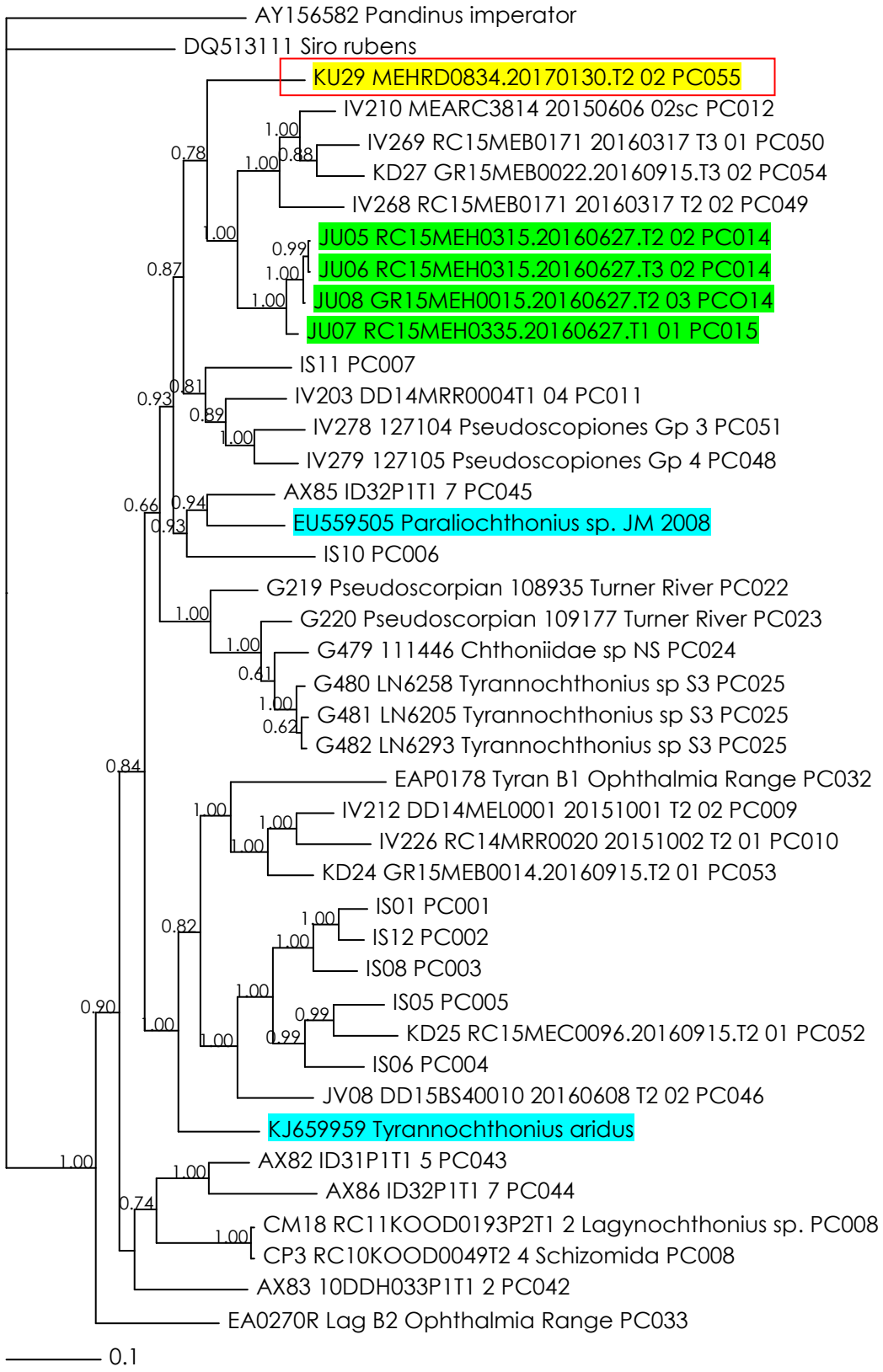
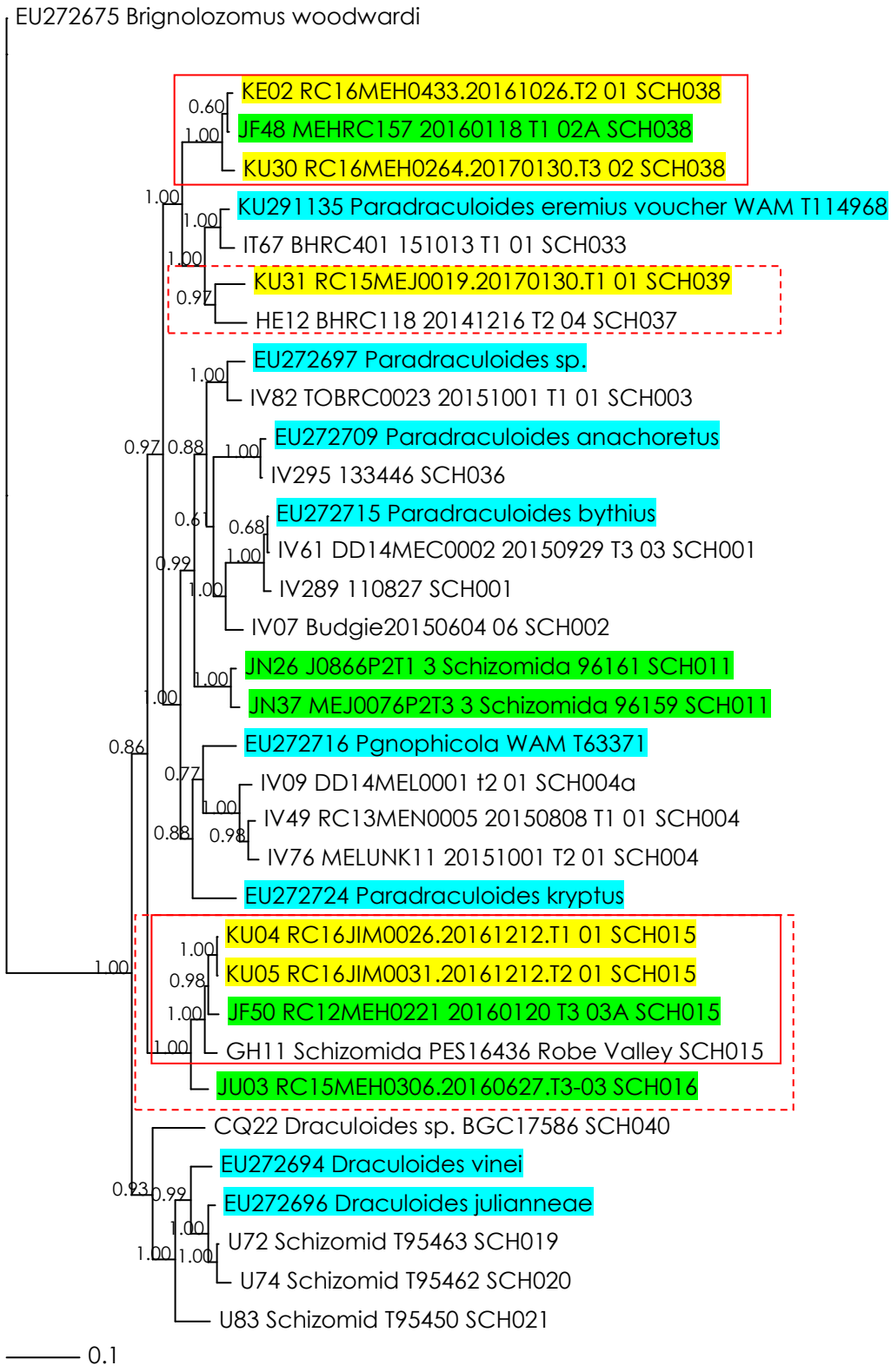


Figure 8. Bayesian analysis of COI haplotypes of Schizomida from the present study and reference specimens from Genbank and previous surveys in the Pilbara. Numbers on major nodes correspond to posterior probabilities; values <50% are not shown. Specimens from the present study are highlighted in yellow; specimens from previous phases at Mesa H are highlighted in green; GenBank voucher specimens highlighted in turquoise. Scale bar= number of substitutions per site. Red boxes with solid lines enclose species with high confidence.



Appendix 1. All specimens of Isopoda from Mesa H phases 1-6, and the lineage to which they were assigned. Lineages with name changes between phases are highlighted in yellow.

Specimen ID	Phase	Helix ID	Old lineage	New Lineage
RC15MEH0382-20160120-T1-03A	1	JF41	I1	ISP047
RC15MEH0382-20160120-T1-03B	1	JF42	I1	ISP047
RC15MEH0382-20160120-T1-03C	1	JF43	I1	ISP047
RC15MEH0382-20160120-T1-03D	1	JF44	I1	ISP047
RC15MEH0382-20160120-T1-03E	1	JF45	I1	ISP047
RC15MEH0382-20160120-T2-03	1	JF46	I1	ISP047
RC15MEH0382-20160120-T3-03	1	JF47	I2	ISA046
RC16MEH0427.20161026.T3-01	4	KE01		ISP055*
MEHRD0577.20170130.T1-02	6	KU09		No amp
MEHRD0577.20170130.T1-02	6	KU10		No amp
MEHRD0577.20170130.T1-02	6	KU11		No amp
MEHRD0577.20170130.T2-01	6	KU12		No amp
MEHRD0577.20170130.T2-01	6	KU13		ISA057*
MEHRD0577.20170130.T2-01	6	KU14		ISA057*
MEHRD0577.20170130.T3-01	6	KU15		No amp
MEHRD0577.20170130.T3-01	6	KU16		No amp
MEHRD0577.20170130.T3-01	6	KU17		No amp
MEHRD0577.20170130.T3-01	6	KU18		No amp
MEHRD0577.20170130.T3-01	6	KU19		ISA057*
MEHRD0577.20170130.T3-01	6	KU20		ISA057*
MEHRD0577.20170130.T3-01	6	KU21		No amp
MEHRD0834.20170130.T1-01	6	KU22		ISA057*
MEHRD0834.20170130.T1-01	6	KU23		ISA057*
MEHRD0834.20170130.T1-01	6	KU24		ISA057*
MEHRD0834.20170130.T1-01	6	KU25		ISA057*
MEHRD0834.20170130.T1-01	6	KU26		No amp
MEHRD0834.20170130.T2-01	6	KU27		ISA057*

Appendix 2. All specimens of Diplura from Mesa H phases 1-6, and the lineage to which they were assigned. Lineages with name changes between phases are highlighted in yellow.

Specimen ID	Phase	Helix ID	Old lineage	New lineage
RC14MEH0308-20160120-T2-02	1	JF37	D1	DPA001
RC15MEH0166-20160118-T3-03	1	JF38	D3	DPR008
RC15MEH0175-20151210-T1-01	1	JF39	D3	DPR008
RC15MEH0261-20160120-T3-02	1	JF40	D2	DPR009
RC14MEH0388.20160628.T3-1	3	JU01	DU	DJA003
GR15MEH0032.20160628.T3-2	3	JU02	DV	DCA005
DD13MEH0007-20160914-01	4	KE04		DJA011*
RC16JIM0005.20161212.T1-01	5	KU1		DPR010*
RC16JIM0005.20161212.T3-01	5	KU2		DPR011*
RC16MEH0264.20170130.T3-01	6	KU7		No amp
MEHRD0758.20170130.T3-01	6	KU8		DPA009*

Appendix 3. All specimens of Pseudoscorpiones from Mesa H phases 1-6, and the lineage to which they were assigned. Lineages with name changes between phases are highlighted in yellow.

Specimen ID	Phase	Helix ID	Old lineage	New lineage
RC14MEH0252-20160120-T1-04	1	JF56	P1	PH017
RC12MEH0120-20151211-T1-01A	1	JF57	No amp	No amp
RC12MEH0120-20151211-T1-01B	1	JF58	No amp	No amp
RC15MEH0302-20151210-T1-03	1	JF59	P2	PO008
RC15MEH0329-20151210-T3-03	1	JF60	P3	PA004
RC15MEH0315.20160627.T2-02	3	JU05	P14	PC014
RC15MEH0315.20160627.T3-02	3	JU06	P14	PC014
RC15MEH0335.20160627.T1-01	3	JU07	P15	PC015
GR15MEH0015.20160627.T2-03	3	JU08	P14	PC014
RC16MEH0436.20161026.T2-01	4	KE03		PH026*
RC16JIM0026.20161212.T2-01	5	KU03		PO014*
RC16MEH0433.20161211.T1-02	5	KU06		PO015*
RC16MEH0264.20170130.T3-03	6	KU28		PH027*
MEHRD0834.20170130.T2-02	6	KU29		PC055*

Appendix 4. All specimens of Schizomida from Mesa H phases 1-6, and the lineage to which they were assigned. Lineages with name changes between phases are highlighted in yellow.

Specimen ID	Phase	Helix ID	Old lineage	New lineage
MEHRC157-20160118-T1-02A	1	JF48	S2	SCH038
MEHRC157-20160118-T1-02B	1	JF49	S2	SCH038
RC12MEH0221-20160120-T3-03A	1	JF50	S1	SCH015
RC12MEH0221-20160120-T3-03B	1	JF51	S1	SCH015
RC14MEH0252-20160120-T3-02	1	JF52	S1	SCH015
RC15MEH0329-20160118T3-01A	1	JF53	S2	SCH038
RC15MEH0329-20160118T3-01B	1	JF54	No amp	
DD13MEH0007-20160119-03	1	JF55	S1	SCH015
J0866P2T1-3	2	JN26	S1	SCH011
J0866P2T2-1	2	JN27	S1	SCH011
J0867P2T1-1	2	JN28	S1	SCH011
J0867P2T3-1	2	JN29	S1	SCH011
J0928P2T1-5	2	JN30	S1	SCH011
J0928P2T1-5A	2	JN31	S1	SCH011
MEJ0007P1T1-1	2	JN32	S1	SCH011
MEJ0007P1T2-1	2	JN33	S1	SCH011
MEJ0007P1T2-1A	2	JN34	No amp	
MEJ0048P2T2-3	2	JN35	S1	SCH011
MEJ0076P2T2-4	2	JN36	No amp	
MEJ0076P2T3-3	2	JN37	S1	SCH011
MEJ0085P2T3-3	2	JN38	S1	SCH011
MEJ0085P2T3-3A	2	JN39	S1	SCH011
J0866P1T1-1	2	JN40	S1	SCH011
J0866P1T2-1	2	JN41	No amp	
MEJ5548altP1T2-2	2	JN42	S1	SCH011
MEJ5548altP1T3-2	2	JN43	S1	SCH011
MEJ5548altP1T3-2A	2	JN44	S1	SCH011
RC08MEJ0015P4T1-5	2	JN45	S1	SCH011
RC08MEJ0015P4T2-3	2	JN46	S1	SCH011
RC08MEJ0004P4T2-4	2	JN47	S1	SCH011
RC08MEJ0023P4T2-3	2	JN48	S1	SCH011
RC15MEH0306.20160627.T3-03	3	JU03		SCH016
RC16MEH0433.20161026.T2-01	4	KE02		SCH038
RC16JIM0026.20161212.T1-01	5	KU04		SCH015
RC16JIM0031.20161212.T2-01	5	KU05		SCH015
RC16MEH0264.20170130.T3-02	6	KU30		SCH038
RC15MEJ0019.20170130.T1-01	6	KU31		SCH039

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29 Aug, 2016

Penny Brooshooft
Biota Environmental Sciences
Level 1, 228 Carr Place
Leederville, WA 6007

Via email

Re. Report on the molecular systematics of subfauna from Mesa H, phase 2 (Biota job 1146B)

Dear Penny,

Following is a summary of the results of the subfauna study we have completed on the additional specimens from Mesa H from four taxonomic groups (Diplura, Pseudoscorpiones, Scolopendrida and Schizomida). Six distinct genetic lineages from the four taxonomic groups were detected. The six lineages likely represent five species. None of the species appear to have been detected previously in the Pilbara, based on the material available for comparison, although the species of Schizomida is closely related to a species detected previously at Mesa H and Pannawonica.

Thanks once again for collaborating on this project with Helix. We hope we can continue to provide you with useful information, and feel free to contact us if you have any questions or would like to discuss the results in detail.

Sincerely,

Dr. Terrie Finston, Yvette Hitchen and Dr. Oliver Berry
Helix Molecular Solutions

Background and Objective

Eight specimens of subfauna (belonging to four taxonomic groups (Diplura, Pseudoscorpiones, Scolopendrida, and Schizomida) were collected from Mesa H and sequenced for variation at the mitochondrial COI gene. The molecular data were assessed in order to determine the number of species present in each group and compare the results to those obtained during previous surveys that have been undertaken for the these groups in the in the Pilbara.

Executive summary

- Eight specimens from Mesa H belonging to four taxonomic groups were sequenced for variation at the COI gene.
- Six lineages were detected among the four groups.
- The six lineages likely represent five species.
- None of the species appear to have been detected previously in the Pilbara, based on the material available for comparison, although the species of Schizomida is closely related to a species detected previously at Mesa H and Pannawonica.

Methods

Eight specimens of subfauna collected from Mesa H were sequenced for variation at the mitochondrial cytochrome oxidase subunit I gene (COI) using primers LCOI/HCO2 and LCOI/CIN2341.

Sequences were edited using GENEIOUS software (Drummond *et al.* 2011). Alignment was performed with CLUSTAL W (Thompson *et al*. 1994) using default parameters. Genetic distances between unique genetic sequences (haplotypes) were measured using uncorrected p-distances (total percentage of nucleotide differences between sequences).

MODELTEST software (Posada and Crandall, 1998) was used to determine the model of sequence evolution that best fitted the data for each taxonomic group. Bayesian analysis was used to construct the phylogenetic trees, incorporating the model as identified in MODELTEST for each taxonomic group. The phylogeny, branch lengths and posterior probabilities were obtained by running two trees simultaneously, each running four simultaneous MCMC chains. The number of cycles needed was determined by the standard deviation of the split frequencies of the two trees. The analysis was paused after every 1 x 10^6 generations and when the standard deviation fell below 0.01, the analysis was stopped. A majority rule consensus tree was constructed after discarding the "burn-in" trees in both analyses. The burn-in value was determined by plotting the posterior probabilities obtained after every generation and identifying the point at which the values reach stationarity (= the asymptote). Trees produced prior to stationarity were discarded.

For the purposes of this report, lineages were defined as haplotypes or groups of haplotypes differing from other such groups by >3% sequence divergence. This cut-off was selected based on bar-coding data, which indicates that intra-specific variation rarely exceeds 3% (Hebert et al., 2003b).

Results

Diplura

Reference specimens and outgroups

Two specimens of Diplura from two drillholes at Mesa H were sequenced (Table 1). The two specimens were analysed with 30 specimens of Diplura from the Pilbara belonging to four families: Anajapygidae, Japygidae, Parajapygidae and Projapygidae, as well as four Genbank voucher specimens, Diplura sp. (Genbank accession #HQ943342), *Japyx solifugus* (Japygidae; Genbank accession #AY771989) *Campodea tillyardi* (Campodeidae; Genbank accession # AF370844), *Lepidocampa weberi* (Campodeidae: Genbank accession #HQ882832). The planthopper *Lycorma delicatula* (Genbank accession # FJ456942) and a specimen of Fulgoridae (Hemiptera; Genbank accession #GU671563) were used as outgroups.

Phylogenetic analysis

The phylogenetic analysis, which included the two specimens of Diplura from Mesa H, in addition to 34 reference specimens, placed the Mesa H specimens in two distinct lineages (Figure 1). The Mesa H specimens showed no close relationship to any of the reference specimens, and thus were assigned to the new lineages DU and DV for JU01 and JU02, respectively (Figure 1). However, one, DU, was placed in a well-supported clade containing the Pilbara and GenBank reference specimens of Japygidae, while DV was placed in a well-supported clade containing the Pilbara and GenBank reference specimens of Campodeidae (Figure 1).

Differentiation within and between lineages

The two lineages of Diplura differed from one another by 25% sequence divergence (Table 2). DU (JU01) differed from the reference specimens by between 16.2 and 27.2% sequence divergence (Table 2). DV (JU02) differed from the reference specimens by between 23.5 and 28.6% sequence divergence (Table 2).

Distribution of lineages

Lineages DU and DV were each detected in single drillholes.

Pseudoscorpiones

Reference sequences and outgroups

Four pseudoscorpions were sequenced from three drillholes at Mesa H (Table 1). In order to reduce analysis time and to simplify the presentation of results, a preliminary search of similar sequences on Genbank and in the Helix database indicated that the specimen most closely matched specimens in the family Chthoniidae. Based on those results, GenBank voucher sequences were included as references as follows: four sequences belonging to three genera of Chthoniidae: *Tyrannochthonius* sp JM 2008 (Genbank accession # EU559506) from South America (Columbia), *Lagynochthonius johni* (Genbank accession # EU559503; from Indonesia), *Austrochtonia* sp JM 2008 (Genbank accession # EU559513; from Australia) and *Tyrannochthonius aridus* (GenBank accession # KJ659959 from Western Australia). As local references, 27 specimens of Chthoniidae from 12 sites in the Pilbara (Helix, 2012) were included in the analysis. Sequences of the scorpion *Pandinus imperator* (Genbank accession # AY1565821) and harvestman spider *Siro rubens* (Genbank accession # DQ5131111) were used as outgroups.

Phylogenetic analyses

The phylogenetic analysis, which included the four specimens from Mesa H, in addition to 31 reference specimens, placed the Mesa H specimens in two distinct genetic lineages that formed a well-supported clade (Figure 2). The Mesa H lineages did not show a close relationship to any of the Pilbara reference specimens, and were assigned to the new lineages P14 and P15; however they formed a well-supported clade with a specimen from the Highway and Tod bore deposit in the Robe Valley (Figure 2). Specimens assigned to *Tyrannochthonius* and *Lagynochthonius* on the basis of morphology did not form monophyletic clades (Figure 2).

Differentiation within and between lineages

The two lineages of pseudoscorpion from Mesa H differed from one another by 3.0% mean sequence divergence. The three specimens within lineage P14 differed from one another by 0.1% mean sequence divergence. Mesa H lineages P14 and P15 differed the reference specimens by between 13.3 and 28.0% and 13.6 and 28.8% sequence divergence, respectively (Table 3).

Distribution of lineages

The Mesa H pseudoscorpion lineage P14 was detected in two drillholes: RC15MEH0315 and GR15MEH0015, and lineage P15 was detected in one drillhole, RC15MEH0335.

Schizomids

Preliminary analysis - Reference sequences and outgroups

One schizomid was sequenced from drillhole RC12MEH0221 at Mesa H (Table 1). In order to reduce analysis time and to simplify the presentation of results, a preliminary neighbour-joining (NJ) analysis was conducted with the new Mesa H specimen and >500 reference sequences of schizomids from previous surveys in the Pilbara to compile a manageable and relevant reference data set. The reference sequences were selected based on the criteria that they showed ≤ 15% sequence divergence from the Mesa H lineage. In addition, representatives of the five described species of *Paradraculoides* and the four described species of *Draculoides* were included in the analysis. Two specimens of schizomids from the family Hubbardiidae, *Brignolozomus woodwardi* (GenBank accession # EU272675) and Bamazomus sp. (GenBank accession # EU272676) were used as outgroups.

Phylogenetic analysis
The phylogenetic analysis, which included the single Mesa H specimen, in addition to 11 reference specimens of schizomids, placed the Mesa H specimen in a distinct lineage within a well-supported clade containing reference specimens from previous surveys at Mesa H and Pannawonica (Figure 3). It was assigned to the new lineage SCH016 (Figure 3).

Differentiation within and between lineages
The Mesa H specimen differed from the closest reference specimens (JF50 and GH11, from Mesa H and Pannawonica, respectively) by 5.2% and 5.3% sequence divergence (Table 4).

Distribution of lineages
The new Mesa H specimen was detected in drillhole RC12MEH0221.

Scolopendrida

One specimen of Scolopendrida from Mesa H was sequenced (Table 1). A search of similar sequences on GenBank and the Helix database indicated that the specimen belongs to the family Cryptopidae, thus the specimen was analysed with a Genbank vouchers of Cryptopidae as follows: Cryptops japonicas (Genbank accession # AB610778 as well as 15 reference specimens of Cryptopidae from nine sites in the Pilbara. Two specimens of Onychophora, *Metaperipatus inae* (Genbank accession # HQ453464) and *Opisthopatus cinctipes* (Genbank accession #NC014273) were used as outgroups.

Phylogenetic analysis

The phylogenetic analysis, which included the specimen from Mesa H, in addition to 16 reference specimens, placed the Mesa H specimen in a genetically distinct lineage and thus was assigned to the new lineage SC18 (Figure 4). The specimen formed a well-supported clade with the Genbank specimen of *Cryptops japonicas* as well as reference specimens from the Pilbara assigned to the genus *Cryptops* (Figure 4).

Differentiation within and between lineages

The Mesa H lineage of Scolopendrida differed from the reference specimens by between 16.4 and 22.8% sequence divergence (Table 5).

Distribution of lineages

The Mesa H lineage of Scolopendrida was detected at drillhole RC14MEH0388.

Conclusions
COI is widely considered to show suitable variation to distinguish species (Hebert et al., 2003a). In a comparison of COI sequences for over 13,000 pairs of taxa, Hebert et al (2003b) found a mean of 11.1% sequence divergence between distinct species. Nearly 80% of the comparisons showed that species pairs differed from one another by greater than 8% sequence divergence. However, a taxon by taxon approach examining the amount of phylogenetic variation within and between species is the most widely accepted method of defining species.

Diplura

Two distinct lineages of Diplura were detected at Mesa H, representing two species, owing to the high level of sequence divergence between them. Lineage DU belongs to the Japygidae, however it differed from the nearest reference specimens by >16% sequence divergence, indicating that it is likely to belong to a new species, which has so far not been detected in the Pilbara, based on the material available for comparison. Lineage DV may belong to the Campodeidae, but differs from the nearest reference specimen by >20% and in the phylogenetic analysis, was the most external branch in the Campodeidae clade. Thus it is only tentatively assigned to this family, until further reference sequences become available. The large sequence divergence between it and the reference specimens indicates that it is a new species, which has so far not been detected in the Pilbara, based on the material available for comparison.

Pseudoscorpiones

Two lineages, of Pseudoscorpiones, P14, P15, were detected at Mesa H, differing from one another by 3% mean sequence divergence. The two lineages belong to the family Chthoniidae and are likely to represent a single species, showing genetic divergence owing to their occurrence in different drillholes and poor dispersal abilities of the taxon. The species differs from the reference specimens by >13% sequence divergence, and hence is likely to be a new species based on the material available for comparison. The taxonomy of the Chthoniidae is in need of revision (M. Harvey, pers. comm.), so we did not attempt to place the Mesa H specimen into a genus.

Schizomida

Previous analyses of genetic variation between morphologically distinct species of Schizomida can be used as a genetic 'yardstick' to interpret the current data set. The five described species of *Paradraculoides* (Harvey et al, 2008) differ from one another by between 8.4 to 12.1% sequence divergence (uncorrected p-distances; calculated by us from the Harvey et al., 2008 data). Similarly, the four described species of *Draculoides* differ from one another by between 4.5 to 13.7% sequence divergence (uncorrected p-distances calculated by us from Harvey et al., 2008).

One lineage of schizomid was detected at Mesa H, SCH016. The lineage was placed in a clade with specimens from a previous survey at Mesa H and the Pannawonica area. It shows a moderately low level of sequence divergence from these reference specimens (approximately 5%), but more than is usually detected between species of schizomids as described above. Thus it may represent a new species, however sampling of intermediate sites and or morphological data are needed to confirm the relationship between these specimens. We cannot assign the specimen to a genus, as it was placed outside the clade containing the reference specimens of both *Draculoides* and *Paradraculoides*.

Scolopendrida

A single genetically distinct lineage of Scolopendrida, SC18, was detected at Mesa H, likely belonging to the family Cryptopidae. The lineage differed from the nearest reference specimen by >15% sequence divergence, and is likely to be a new species, based on the material available for comparison.

Summary

Six lineages from four taxonomic groups (Diplura, Pseudoscorpiones, Scolopendrida, Schizomida) were detected at Mesa H, as summarised below. The six lineages likely represent five species. None of the species appear to have been detected previously in the Pilbara, based on the material available for comparison, although the species of Schizomida is closely related to a species detected previously at Mesa H and Pannawonica.

Diplura

Two lineages of Diplura were detected at Mesa H, one Japygidae and one Campodeidae. The lineages differed from the reference specimens by >15% sequence divergence, and hence both are likely to be new species, based on the material available for comparison.

Pseudoscorpiones
Two lineages of Pseudoscorpiones were detected at Mesa H, belonging to the family Chthoniidae. They likely represent a single species, which appears to be new, based on the material available for comparison.

Schizomida
A single lineage was detected at Mesa H, corresponding to a single species. The lineage likely cannot be placed in a genus. The species is similar to one detected previously at Mesa H and Pannawonica, however shows enough genetic divergence from these reference specimens to warrant further investigation.

Scolopendrida
A single genetically distinct lineage of Scolopendrida was detected at Mesa H, likely belonging to the family Cryptopidae. The lineage differed from the nearest reference specimen by >15% sequence divergence, and is likely to be a new species, based on the material available for comparison.

References

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Table 1. Specimens used in the present study and the lineage to which they were assigned, based on variation at the COI gene.

Tracking Number	Taxonomic group	Cap #	Helix ID	Lineage
RC14MEH0388.20160628.T3-1	Diplura	7	JU01	DU
GR15MEH0032.20160628.T3-2	Diplura	20	JU02	DV
RC15MEH0306.20160627.T3-03	Schizomida	71	JU03	SCH016
RC14MEH0388.20160628.T2-2	Scolopendrida	6	JU04	SC18
RC15MEH0315.20160627.T2-02	Pseudoscorpion	56	JU05	P14
RC15MEH0315.20160627.T3-02	Pseudoscorpion	59	JU06	P14
RC15MEH0335.20160627.T1-01	Pseudoscorpion	60	JU07	P15
GR15MEH0015.20160627.T2-03	Pseudoscorpion	47	JU08	P14

Table 2 (attached). Mean genetic distance (below diagonal) and standard error (above diagonal, in blue) between lineages of Diplura detected in the present study and the reference lineages as shown in Figure 1. Distances between the lineages from the present study and the reference lineages are highlighted in yellow.

Table 3. (attached). Genetic distances (below diagonal) and standard error (above diagonal, in blue) between specimens of Pseudoscorpiones detected at in the present study and the reference lineages as shown in Figure 2. Distances between the lineages from the present study and the reference lineages are highlighted in yellow.

Table 4. (attached). Genetic distances (below diagonal) and standard error (above diagonal, in blue) between specimens of Schizomida detected at in the present study and the reference lineages as shown in Figure 3. Distances between the lineages from the present study and the reference lineages are highlighted in yellow.

Table 5. (attached). Genetic distances (below diagonal) and standard error (above diagonal, in blue) between specimens of Scolopendrida detected at in the present study and the reference lineages as shown in Figure 4. Distances between the lineages from the present study and the reference lineages are highlighted in yellow.

Figure 1. Bayesian analysis of COI haplotypes of Diplura from the present study and reference specimens from previous surveys in the Pilbara. Numbers on major nodes correspond to posterior probabilities; values <50% are not shown. Specimens from the present study are highlighted in yellow; GenBank voucher specimens highlighted in turquoise. Scale bar= number of substitutions per site.

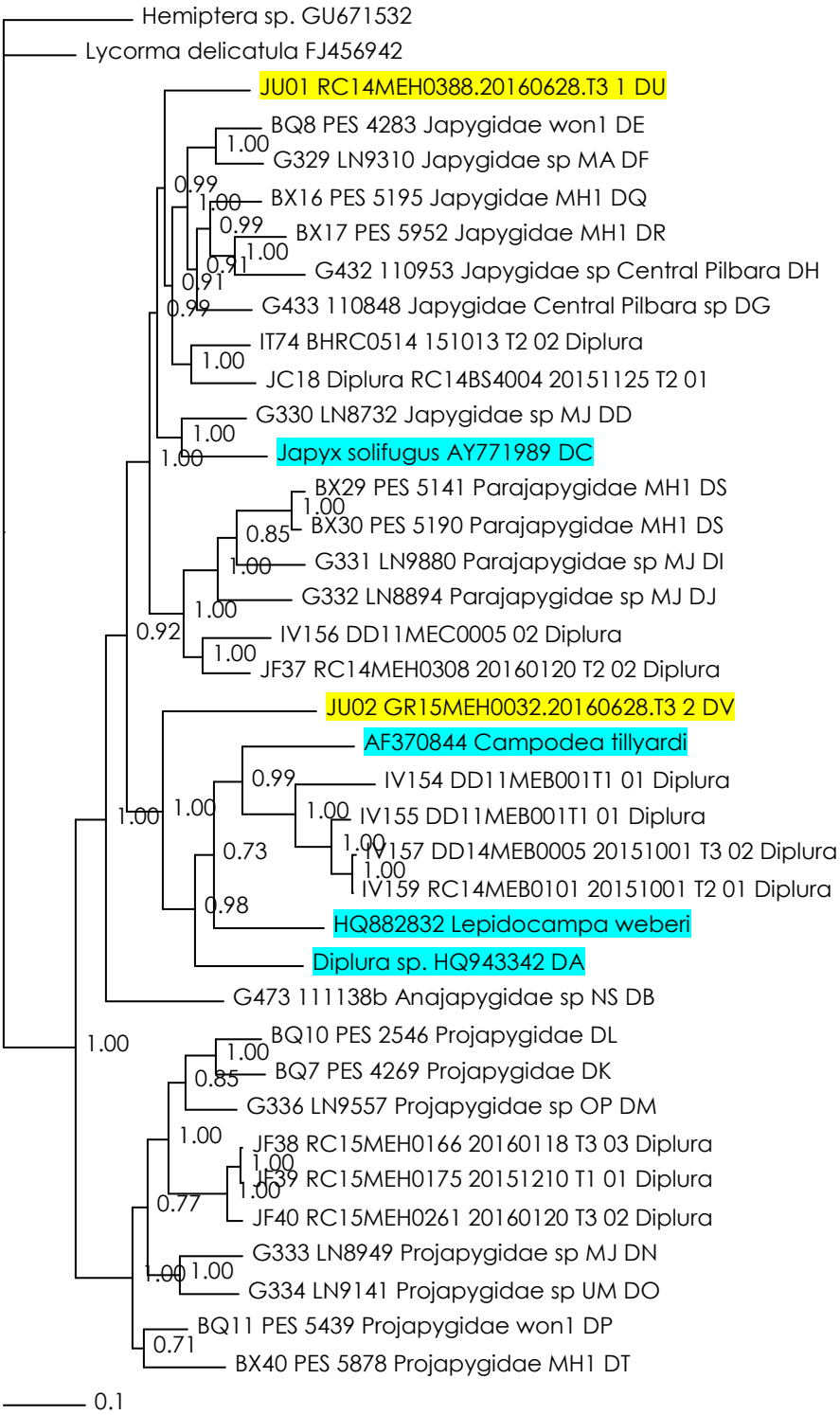

Figure 2. Bayesian analysis of COI haplotypes of Pseudoscorpiones from the present study and reference specimens from previous surveys in the Pilbara. Numbers on major nodes correspond to posterior probabilities; values <50% are not shown. Specimens from the present study are highlighted in yellow; GenBank voucher specimens highlighted in turquoise. Scale bar= number of substitutions per site.

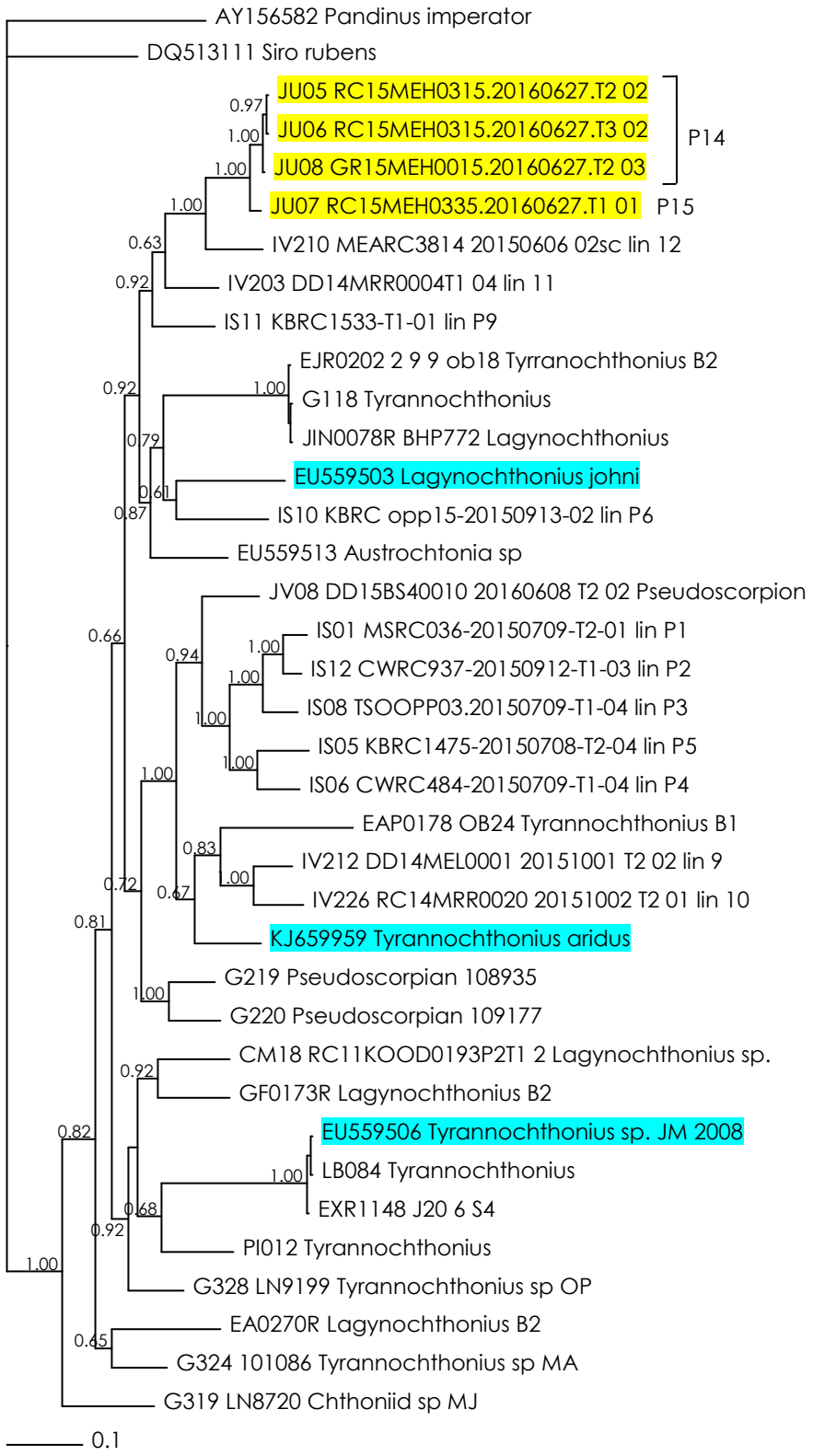

Figure 3. Bayesian analysis of COI haplotypes of Schizomida from the present study and reference specimens from previous surveys in the Pilbara. Numbers on major nodes correspond to posterior probabilities; values <50% are not shown. Specimens from the present study are highlighted in yellow; GenBank voucher specimens highlighted in turquoise. Scale bar= number of substitutions per site.

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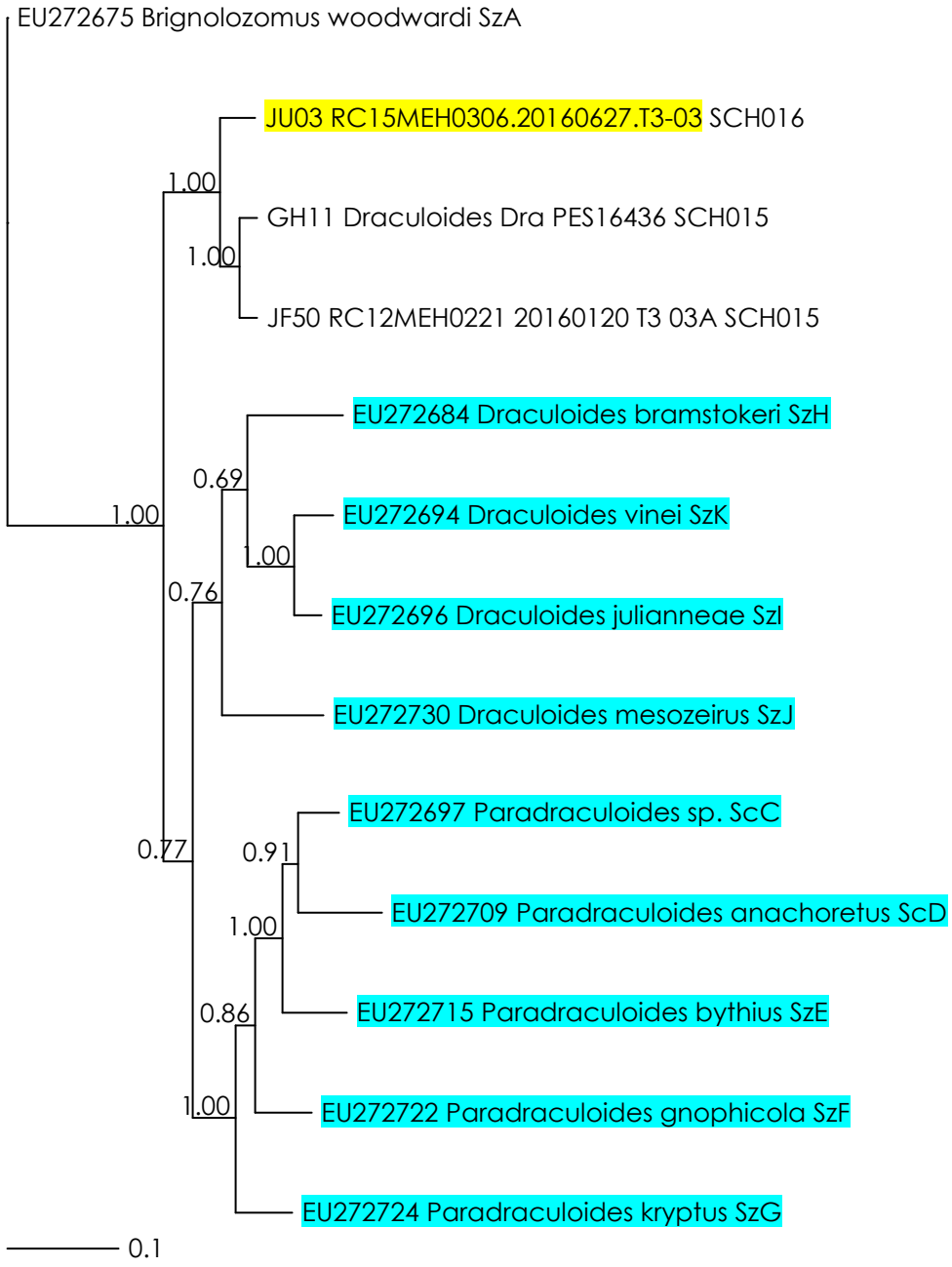
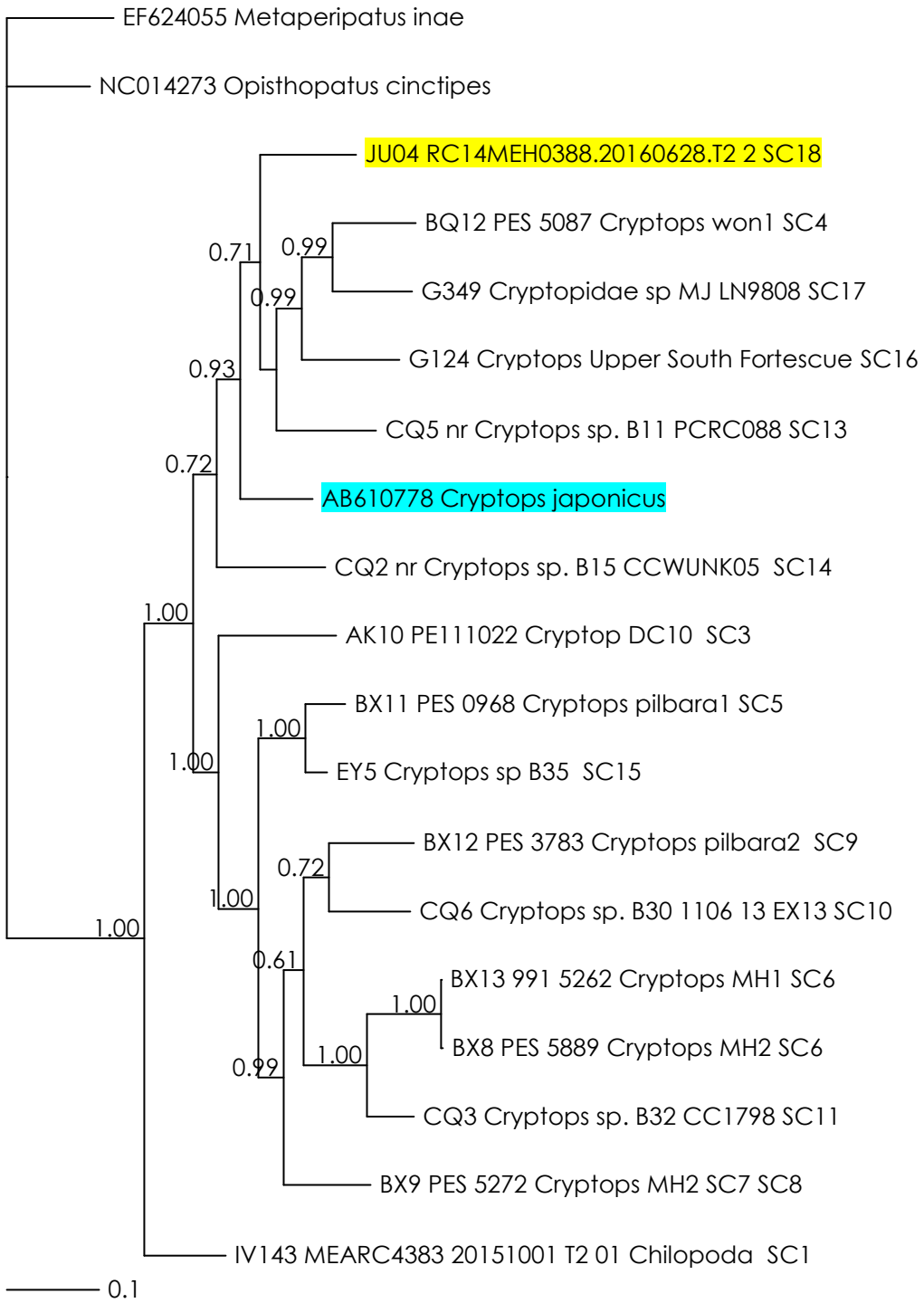


Figure 4. . Bayesian analysis of COI haplotypes of Scolopendrida from the present study and reference specimens from previous surveys in the Pilbara. Numbers on major nodes correspond to posterior probabilities; values <50% are not shown. Specimens from the present study are highlighted in yellow; GenBank voucher specimens highlighted in turquoise. Scale bar= number of substitutions per site.



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23 August, 2017

Nicola Watson
Biota Environmental Sciences
Level 1, 228 Carr Place
Leederville, WA 6007

Via email

Re. Report on the molecular systematics of additional subfauna from Mesa H

Dear Nicola,

Following is a summary of the results of the subfauna study we have completed on three additional taxonomic groups (Blattodea, Coleoptera, Thysanura) collected at Mesa H. Eight distinct genetic lineages were detected among the three groups. Two of the eight lineages have been detected previously in the Pilbara, whereas the remaining six are new, based on the material available for comparison.

Thanks once again for collaborating on this project with Helix. We hope we can continue to provide you with useful information, and feel free to contact us if you have any questions or would like to discuss the results in detail.

Sincerely,

Dr. Terrie Finston, Yvette Hitchen and Dr. Oliver Berry
Helix Molecular Solutions

Background and Objective

Twenty-two specimens of subfauna belonging to three taxonomic groups (Blattodea, Coleoptera, Thysanura) were collected from Mesa H and sequenced for variation at the mitochondrial COI or 12s gene. The molecular data were assessed in order to determine the number of species present in each group and compare the results to those obtained during previous surveys that have been undertaken for these groups elsewhere in the Pilbara.

Executive summary

- Twenty-two specimens of subfauna belonging to three taxonomic groups (Blattodea, Coleoptera, Thysanura) were collected from Mesa H and sequenced for variation at the mitochondrial COI or 12s gene
- Eight lineages were detected among the three groups
- Two of the lineages have been detected previously in the Pilbara, whereas the remaining six appear to be new, based on the material available for comparison

Methods

Twenty-two specimens of subfauna belonging to three taxonomic groups (Blattodea, Coleoptera, Thysanura) were collected from Mesa H and sequenced for variation at the mitochondrial COI or 12s gene using multiple pairs of primers (LCOI/HCO2, LCOI /HCO-out, L2020/H2619 for COI and 12Sai/12SRJ for 12s).

Sequences were edited using GENEIOUS software (Drummond *et al.* 2011). Alignment was performed with CLUSTAL W (Thompson *et al*. 1994) using default parameters. Genetic distances between unique genetic sequences (haplotypes) were measured using uncorrected p-distances (total percentage of nucleotide differences between sequences).

MODELTEST software (Posada and Crandall, 1998) was used to determine the model of sequence evolution that best fitted the data for each taxonomic group. Bayesian analysis was used to construct the phylogenetic trees, incorporating the model as identified in MODELTEST for each taxonomic group. The phylogeny, branch lengths and posterior probabilities were obtained by running two trees simultaneously, each running four simultaneous MCMC chains. The number of cycles needed was determined by the standard deviation of the split frequencies of the two trees. The analysis was paused after every 1 x 10^6 generations and when the standard deviation fell below 0.01, the analysis was stopped. A majority rule consensus tree was constructed after discarding the "burn-in" trees in both analyses. The burn-in value was determined by plotting the posterior probabilities obtained after every generation and identifying the point at which the values reach stationarity (= the asymptote). Trees produced prior to stationarity were discarded.

For the purposes of this report, lineages were defined as haplotypes or groups of haplotypes differing from other such groups by >3% sequence divergence. This cut-off was selected based on bar-coding data, which indicates that intra-specific variation rarely exceeds 3% (Hebert et al., 2003b).

We are currently developing a consistent and unique lineage and species naming system, so all lineages from previous phases will be consolidated in this report to aid in comparisons between phases.

Results

Blattodea

Reference specimens and outgroups

Two specimens of Blattodea from two bores were sequenced from Mesa H (Table 1). A search of the reference database GenBank indicated that both specimens were most closely matched to the genus *Nocticola*. A reference database of 35 *Nocticola* specimens from previous surveys in the Pilbara were analysed with the specimens from Mesa H. Two Genbank reference specimens of *Nocticola* from the Pilbara were also included as references, *N. quartermaini* (Genbank accession #KU258365) and *N. cockingi* (Genbank accession #KU258378). Two specimens of the closely related Blattodea family Coryiidae, *Latindia* sp. 13

FL2015 (Genbank accession # KP986417) and *Eupoyphaga sinensis* (Genbank accession #NC014274) were used as outgroups.

Phylogenetic analysis

The phylogenetic analysis, which included the two specimens from Mesa H in addition to 37 reference specimens, placed the Mesa H specimens in two distinct lineages (Figure 2). Neither of those lineages contained reference specimens and thus were assigned to the new lineages BN020 and BN021 (Figure 2). Specimen MF01 (lineage BN020) formed a moderately well-supported clade with seven specimens of Nocticolidae from Western Hub, Red Hill and Buckland Hills (Figure 1). Specimen MF02 (lineage BN021), formed a clade with three specimens from the Central Pilbara, Buckland Hills and the Hamersley Range, however the relationship was not well-supported (Figure 1). The two lineages were placed in a large widespread clade containing the Genbank reference specimen *N. quartermaini* and reference specimens of *Nocticola* and Nocticolidae from the Pilbara (Figure 1).

Differentiation within and between lineages

The two Mesa H lineages of *Nocticola* differed from one another by 6.3% sequence divergence (Table 2). The Mesa H specimens of *Nocticola* differed from the reference specimens by between 4.2 and 8.1% sequence divergence (Table 2). Specifically, lineage BN020 differed from the nearest reference specimens at Western Hub, Red Hill and Buckland Hills by between 4.2 and 5.1% sequence divergence and lineage BN021 differed from the nearest reference specimens from the Central Pilbara, Buckland Hills and the Hamersely Range by between 5.0 and 6.0% (Table 2). Specimens in the large, widespread clade differed from one another by between 0.2 and 9.1% sequence divergence (Table 2).

Coleoptera

Reference specimens and outgroups

Eighteen specimens of Coleoptera from Mesa H were sequenced for COI (Table 1). In order to reduce analysis time and to simplify the presentation of results, a preliminary neighbour-joining (NJ) analysis was conducted on the Mesa H specimens in order to identify the number of lineages present. Four distinct genetic lineages were detected among the 16 specimens for which sequences were obtained (Figure 2). A representative of each lineage was compared to the GenBank sequence database. One lineage was most closely matched to reference specimens of Curculionidae and three lineages were most closely matched to reference specimens of Ptilidae. Thus, four haplotypes, representing the four lineages were analysed with 44 reference sequences of Curculionidae and Ptilidae, including 14 provided by the WAM and 30 from previous surveys in the Pilbara, including Mesas B and C. Two specimens of Coleoptera from the family Dermestidae, *Dermestes maculatus* (Genbank accession # HM909035) and *Dermestes frischii* (Genbank accession # KM578824) were used as outgroups.

Phylogenetic analysis

The phylogenetic analysis, which included the four specimens from Mesa H, in addition to 44 reference specimens, placed the Mesa H specimens in four distinct genetic lineages, two of which also contained reference specimens (Figure 3). Specifically one lineage contained reference specimens of Ptilidae sp. 1 from the WAM and one lineage contained reference specimens of Ptilidae from the Robe Valley, and thus were assigned to the existing lineages CP001 (Ptilidae sp. 1) and CP002 (Figure 3). The remaining two lineages did not contain reference specimens, and thus were assigned to the new lineages CP003 and CCU014 (Figure 3).

Differentiation within and between lineages

Differentiation within the four lineages of Coleoptera detected at Mesa H ranged from 0 to 1.6% mean sequence divergence (Table 3). The three lineages of Ptilidae from Mesa H differed from one another by between 4.6 and 15.9% mean sequence divergence (Table 4).

The one lineage of Curculionidae detected at Mesa H, CCU014, differed from the nearest reference specimens by ≥ 13.0% (Table 5).

The three lineages of Ptilidae differed from the reference specimens by between 1.6 and 16.1% sequence divergence (Table 6). In particular, lineage CP001 differed from the nearest reference specimens (WAM Ptilidae sp. 1) by 1.7% sequence divergence and lineage CP002 differed from the nearest reference specimens (IV44 – IV47) by 1.6% sequence divergence (Table 6). Lineage CP003 differed from the nearest reference specimens (WAM Ptilidae sp. 1) by 4.4% sequence divergence (Table 6).

Thysanura

Reference specimens and outgroups

Two specimens of Thysanura from Mesa H were sequenced for 12s (Table 1). A search of similar sequences on Genbank and in the Helix database indicated that the specimens most closely matched database specimens of the subfamily Nicoletiinae. Based on those results, GenBank voucher sequences were included as reference sequences of Nicoletiinae (two specimens) as follows: *Trinemura callawa* and *T. cundalin* (GenBank accession #JQ282164 and JQ282165, respectively). In addition, as local references, 43 specimens of Nicoletiinae were included in the analysis. A specimen of Atelurinae was used as an outgroup: *Atelura formicaria* (Genbank accession # EU084035).

Phylogenetic analyses

The phylogenetic analysis, which included the two new specimens from Mesa H, in addition to 45 reference specimens, placed the Mesa H specimens in two distinct genetic lineages, neither of which contained reference specimens, thus the two were assigned to the new lineages TN019 and TN020 (Figure 4). Mesa H lineage TN020 formed a well-supported clade with lineage TN011 from the Robe Valley, and lineage TN019 formed a clade with lineage TN008 from Christmas Creek, but the relationship was not well-supported (Figure 4).

Differentiation within and between lineages

Mesa H lineage TN019 differed from the nearest reference specimens (CQ8, CQ10) by >10% sequence divergence, and lineage TN020 differed from nearest reference specimen (IV334) by 7.2% sequence divergence (Table 7).

Conclusions

COI is widely considered to show suitable variation to distinguish species (Hebert et al., 2003a). In a comparison of COI sequences for over 13,000 pairs of taxa, Hebert et al (2003b) found a mean of 11.1% sequence divergence between distinct species. Nearly 80% of the comparisons showed that species pairs differed from one another by greater than 8% sequence divergence. However, a taxon by taxon approach, examining the amount of phylogenetic variation within and between species is the most widely accepted method of defining species.

Blattodea

Two distinct genetic lineages of Nocticolidae (Blattodea) were detected at Mesa H (BN020, BN021). The two lineages differed from one another by 6.3 % sequence divergence. This is generally more sequence divergence than would be expected within a single species, however, it suggests that the lineages are closely related and may represent incipient species or a species complex. Morphological evidence or sampling additional specimens from intermediate areas may help resolve this relationship. The two Mesa H lineages are placed within a large clade containing reference specimens of *Nocticola* and Nocticolidae from Pannawonica, the Western Hamersley Range and Central Pilbara. This widely distributed clade has an average genetic distance of approximately 6% (range 0.2 – 9.1) across a large geographical range, thus it may represent a species complex of closely related, recently diverged species (possibly in the genus *Nocticola*).

Nocticola

BN020 = new lineage, may belong to a species complex detected at Western Hub, Red Hill and Buckland Hills

BN021 = new lineage, may belong to a species complex detected at Buckland Hills, the Central Pilbara and Hamersley Range.

Coleoptera

A single genetic lineage of Curculionidae and three lineages of Ptilidae were detected at Mesa H. They differed from the nearest reference specimens by between 1.6 and >13% sequence divergence.

For comparison, differentiation within the four WAM species of Curculionidae for which there are multiple sequences (species 1, 3, 4, 8) ranges from a mean of 0.9% (species 1) to a mean of 5.2% (species 4). The eight species differed by a mean of 11.3 to 24.3% sequence divergence. The two specimens of Pitlidae sp. 1 shared the same haplotype.

The Curculionidae lineage from Mesa H differed from the nearest reference specimens by ≥ 13%, indicating that the specimen likely represents a new lineage and species of Curculionidae that has not been detected previously.

Two of the Mesa H lineages of Ptilidae were placed in a clade containing reference specimens from the WAM, assigned to the species Ptilidae sp. 1. The Mesa H lineages CP001 and CP003 differed from the WAM reference specimens of Ptilidae sp. 1 by between 1.6 and 4.4% sequence divergence, suggesting that the lineages from Mesa H belong to Ptilidae sp. 1. However, owing to the moderate level of sequence divergence (4.4%) morphological characters may be useful to confirm this placement.

Curculionidae

CCU014 = new lineage and species, not detected previously in the Pilbara

Ptilidae

CP001 = WAM Ptilidae sp. 1, previously detected in the Pilbara
CP002 = lineage and species detected previously in the Robe Valley
CP003 = new lineage; likely to belong to previously detected species WAM Ptilidae sp. 1, but morphology should be used to confirm.

Thysanura

The mitochondrial gene 12S is widely used in insect systematics (Simon, 1991; Caterino et al., 2000), although in contrast to the mitochondrial gene COI, fewer broadscale comparative studies are available to provide a basis for species discrimination. Nonetheless, 12S has proven useful for establishing phylogenetic relationships in many insect groups (Caterino et al., 2000). The 12S gene evolves approximately 1.5 times (Mueller, 2006) more slowly than COI. Hence we would expect that the threshold for species discrimination using 12S would be, by inference, lower than COI.

Two distinct genetic lineages of Thysanura were detected at Mesa H, Nicoletiinae lineages TN019 and TN020. Both differed from the nearest reference specimens by >7% sequence divergence.

For comparison, the six specimens of *Trimenura callawa* differ by a mean of 0.4% sequence divergence (range = 0 to 0.9% at 12s) and *T. callawa* and *T. cundaline* differ by 6.5% mean sequence divergence at 12s. Given the relatively high genetic distance between Mesa H lineages TN019 and TN020 and the reference specimens (>7%), but keeping in mind that our conclusions are based on current understanding of 12s evolution rates, it is likely that both new lineages from Mesa H represent new species of Nicoletiinae.

Nicoletiinae

TN019 = new lineage and species
TN020 = new lineage and species

References

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Table 1. Specimens of troglofauna used in the present study and the lineage to which they were assigned, based on variation at COI or 12s (for Thysanura). *=new lineage this study.

Tracking Number	Taxonomy	Cap #	Helix ID	Lineage
RC12MEH022120151210-T2-01	Blattodea	163	MF01	BN020
RC16MEH0427.20161211.T2	Blattodea	36	MF02	BN021
RC12MEH022120151210-T2-04A	Coleoptera	166	MF03	CCU014
RC12MEH022120151210-T2-04B	Coleoptera	166	MF04	CCU014
RC12MEH0221.20161026.T1-01	Coleoptera	61	MF05	CP003
RC12MEH0221.20161026.T1-01	Coleoptera		MF06	No data
RC12MEH0221.20161026.T1-01	Coleoptera		MF07	CP003
RC12MEH0221.20161026.T1-01	Coleoptera		MF08	CP003
RC12MEH0221.20161026.T1-01	Coleoptera		MF09	CP003
RC14MEH023820151211-T1-03	Coleoptera	182	MF10	CP002
RC14MEH023820151211-T1-03	Coleoptera		MF11	CP002
RC14MEH023820151211-T1-03	Coleoptera		MF12	CP002
RC14MEH023820151211-T1-03	Coleoptera		MF13	CP002
RC14MEH023820151211-T1-03	Coleoptera		MF14	No d
RC14MEH025220151210-T1-04	Coleoptera	154	MF15	CCU014
RC15MEH030220151210-T2-02	Coleoptera	58	MF16	CCU014
RC16MEH0264.20170130.T3-04	Coleoptera	6	MF17	CP001/Ptilidae sp. 1
RC16MEH0264.20170130.T3-04	Coleoptera		MF18	CP001/Ptilidae sp. 1
RC16MEH0264.20170130.T3-04	Coleoptera		MF19	CP001/Ptilidae sp. 1
RC16MEH0264.20170130.T3-04	Coleoptera		MF20	CP001/Ptilidae sp. 1
RC12JIM000620160119T2-02	Thysanura	115	MF21	TN019
RC14MEH025220151210-T1-03	Thysanura	153	MF22	TN020

Table 2. Genetic distances (below diagonal) and standard error (above diagonal, in blue) between specimens of Nocticolidae (Blattodea) detected at Mesa H and the reference lineages as shown in Figure 1. Distances between the Mesa H specimens and the reference specimens are highlighted in yellow.

Specimen ID	MF01	MF02	14705.000	15055.000	15057.000	15137.000	8785.000	AL14	AL15	AL21	BH6	BH8	BQ23	C21-	EJR0201	FH10
MF01 RC12MEH022120151210-T2-01		0.009	0.012	0.010	0.009	0.010	0.011	0.009	0.010	0.010	0.010	0.009	0.011	0.011	0.012	0.008
MF02 RC16MEH0427.20161211.T2	0.063		0.010	0.009	0.010	0.009	0.009	0.009	0.010	0.010	0.010	0.009	0.010	0.010	0.012	0.009
14705 C9 Yaraloola Station	0.062	0.060		0.011	0.011	0.012	0.011	0.012	0.012	0.013	0.011	0.010	0.012	0.005	0.012	0.011
15055 C24 Trinity	0.068	0.058	0.068		0.010	0.010	0.009	0.008	0.009	0.011	0.010	0.009	0.008	0.010	0.010	0.010
15057 C26 Cane Upper Cane	0.054	0.062	0.068	0.066		0.011	0.012	0.010	0.012	0.012	0.010	0.011	0.010	0.011	0.012	0.010
15137 C41 Upper Cane	0.065	0.051	0.065	0.071	0.073		0.010	0.011	0.011	0.012	0.011	0.010	0.011	0.011	0.011	0.011
8785 C105 Trinity	0.066	0.056	0.062	0.060	0.072	0.053		0.010	0.011	0.012	0.010	0.010	0.010	0.010	0.012	0.010
AL14 Nocticola sp B1 Deposit E	0.062	0.060	0.078	0.050	0.060	0.079	0.072		0.008	0.010	0.008	0.008	0.005	0.011	0.010	0.008
AL15 Nocticola sp B1 Orebody 18	0.060	0.063	0.066	0.050	0.058	0.065	0.064	0.042		0.010	0.009	0.008	0.009	0.010	0.005	0.010
AL21 Nocticola sp B1 Iron Valley	0.072	0.076	0.083	0.080	0.080	0.088	0.082	0.076	0.071		0.009	0.011	0.011	0.013	0.012	0.011
BH6 RIO141 Nocticola sp	0.073	0.071	0.074	0.060	0.070	0.079	0.074	0.067	0.067	0.073		0.009	0.009	0.012	0.011	0.009
BH8 RIO090 Nocticola sp	0.057	0.052	0.060	0.064	0.054	0.067	0.064	0.050	0.052	0.070	0.058		0.010	0.010	0.009	0.009
BQ23 PES 5535 Nocticola sp. indet.	0.062	0.068	0.076	0.052	0.062	0.073	0.070	0.017	0.041	0.082	0.066	0.052		0.011	0.009	0.010
C21-Robe Valley	0.062	0.062	0.016	0.062	0.072	0.067	0.064	0.070	0.054	0.083	0.074	0.052	0.064		0.011	0.010
EJR0201	0.062	0.068	0.070	0.054	0.062	0.061	0.070	0.047	0.016	0.080	0.068	0.050	0.045	0.058		0.011
FH10 Nocticola sp DL0097	0.042	0.063	0.060	0.066	0.056	0.065	0.060	0.057	0.054	0.065	0.065	0.052	0.058	0.056	0.056	
FH11 Nocticola sp EW0528	0.057	0.067	0.070	0.062	0.062	0.065	0.054	0.060	0.063	0.073	0.068	0.050	0.060	0.066	0.058	0.054
FH12 Nocticola sp EW0003	0.072	0.081	0.076	0.078	0.082	0.081	0.076	0.075	0.075	0.081	0.076	0.065	0.070	0.068	0.076	0.060
FH13 Nocticola sp B28 BG0082	0.047	0.054	0.064	0.054	0.054	0.065	0.060	0.052	0.052	0.062	0.055	0.047	0.056	0.060	0.054	0.034
FH14 Nocticola sp B28 EW0460	0.052	0.055	0.068	0.060	0.017	0.069	0.062	0.055	0.057	0.070	0.058	0.047	0.058	0.068	0.058	0.049
G109 Nocticola	0.060	0.055	0.064	0.062	0.058	0.059	0.066	0.062	0.060	0.075	0.057	0.049	0.062	0.066	0.058	0.058
G131 Mount Dove	0.067	0.060	0.072	0.070	0.066	0.075	0.076	0.068	0.062	0.084	0.083	0.067	0.072	0.072	0.068	0.065
G391 LN9122a Nocticola indet OP	0.062	0.062	0.078	0.058	0.062	0.075	0.064	0.052	0.055	0.078	0.067	0.054	0.052	0.066	0.054	0.055
G441 110850 Nocticolidae sp.	0.055	0.060	0.066	0.060	0.060	0.061	0.058	0.062	0.055	0.075	0.067	0.055	0.062	0.072	0.060	0.062
GF0215R 1 SH1	0.066	0.068	0.083	0.056	0.066	0.081	0.078	0.010	0.049	0.085	0.074	0.058	0.023	0.076	0.052	0.062
IS73 KBDD025 T2 01 sp	0.049	0.070	0.072	0.074	0.064	0.073	0.066	0.065	0.062	0.070	0.077	0.058	0.070	0.068	0.064	0.016
IS74 KBRC1533 T1 04 sp	0.049	0.067	0.072	0.070	0.066	0.069	0.063	0.060	0.063	0.070	0.072	0.054	0.064	0.064	0.063	0.016

IS77 KBRC1353 T1 01 sp	0.046	0.069	0.070	0.076	0.059	0.071	0.064	0.063	0.060	0.069	0.076	0.056	0.068	0.066	0.063	0.014
IS79 KBRC1353 T2 01 sp	0.046	0.067	0.068	0.074	0.061	0.069	0.063	0.062	0.058	0.067	0.074	0.054	0.066	0.064	0.061	0.012
IS81 Tbrc596 20150912 t2 02 sp	0.063	0.062	0.070	0.033	0.055	0.069	0.057	0.065	0.062	0.079	0.065	0.063	0.059	0.061	0.061	0.060
IS83 Kbrc147520150910 t1 03 sp	0.051	0.069	0.070	0.072	0.066	0.071	0.064	0.060	0.063	0.072	0.074	0.056	0.064	0.063	0.063	0.014
IS85 Cwrc48020150912t1 03 sp	0.042	0.063	0.063	0.068	0.059	0.067	0.061	0.058	0.058	0.067	0.065	0.054	0.061	0.059	0.059	0.002
IT28 BHRC0442-151013-T2-01	0.052	0.050	0.060	0.054	0.052	0.063	0.060	0.062	0.059	0.073	0.054	0.052	0.056	0.066	0.062	0.049
IT36 BHRC331-151012-T1-02	0.045	0.061	0.068	0.064	0.062	0.071	0.062	0.062	0.059	0.072	0.064	0.054	0.060	0.060	0.058	0.013
IT37 BHRCOPP1-151013-T4-01	0.063	0.063	0.070	0.064	0.074	0.053	0.050	0.065	0.060	0.091	0.067	0.062	0.066	0.068	0.062	0.062
KU258365 Nocticola quartermaini isolate EP3	0.060	0.058	0.076	0.049	0.058	0.077	0.070	0.002	0.041	0.075	0.065	0.049	0.016	0.068	0.045	0.055
KU258378 Nocticola cockingi isolate EP14	0.156	0.163	0.163	0.171	0.165	0.157	0.167	0.170	0.163	0.167	0.172	0.159	0.173	0.160	0.161	0.147
P2	0.050	0.054	0.060	0.058	0.052	0.063	0.068	0.057	0.054	0.067	0.063	0.055	0.054	0.056	0.056	0.050
PSF0065R LN6278A P6 S3	0.066	0.076	0.083	0.060	0.070	0.084	0.082	0.021	0.050	0.087	0.078	0.066	0.023	0.076	0.054	0.062

FH11	FH12	FH13	FH14	G109	G131	G391	G441	GF0215R 1	IS73	IS74	IS77	IS79	IS81	IS83	IS85	IT28	IT36	IT37	KU258365	KU258378	P2	PSF0065R
0.010	0.010	0.008	0.009	0.010	0.009	0.009	0.009	0.011	0.009	0.009	0.009	0.009	0.009	0.010	0.008	0.008	0.008	0.009	0.010	0.014	0.008	0.011
0.010	0.011	0.008	0.008	0.009	0.009	0.009	0.009	0.010	0.010	0.009	0.010	0.010	0.010	0.010	0.009	0.008	0.009	0.008	0.009	0.014	0.009	0.010
0.012	0.013	0.011	0.011	0.011	0.011	0.011	0.013	0.012	0.012	0.012	0.012	0.011	0.013	0.012	0.011	0.011	0.010	0.012	0.012	0.015	0.010	0.012
0.010	0.012	0.008	0.010	0.010	0.011	0.009	0.010	0.008	0.012	0.010	0.011	0.011	0.008	0.011	0.010	0.009	0.010	0.010	0.008	0.015	0.010	0.009
0.011	0.012	0.010	0.005	0.011	0.010	0.011	0.011	0.010	0.011	0.011	0.010	0.010	0.009	0.011	0.010	0.010	0.010	0.012	0.010	0.015	0.009	0.011
0.012	0.011	0.010	0.011	0.010	0.011	0.010	0.010	0.012	0.012	0.010	0.011	0.011	0.011	0.011	0.011	0.009	0.012	0.008	0.011	0.015	0.011	0.012
0.011	0.012	0.009	0.011	0.010	0.010	0.009	0.009	0.010	0.011	0.010	0.011	0.011	0.010	0.010	0.010	0.009	0.011	0.009	0.010	0.016	0.011	0.010
0.010	0.010	0.009	0.008	0.010	0.010	0.007	0.009	0.004	0.010	0.009	0.010	0.010	0.009	0.009	0.009	0.010	0.009	0.010	0.002	0.015	0.009	0.006
0.011	0.011	0.009	0.010	0.010	0.010	0.009	0.009	0.010	0.011	0.010	0.011	0.011	0.009	0.010	0.010	0.010	0.009	0.010	0.008	0.014	0.010	0.011
0.011	0.010	0.010	0.011	0.009	0.010	0.010	0.010	0.011	0.011	0.010	0.011	0.011	0.010	0.011	0.011	0.010	0.010	0.011	0.010	0.014	0.009	0.012
0.009	0.011	0.009	0.009	0.009	0.011	0.009	0.009	0.010	0.011	0.009	0.010	0.011	0.010	0.010	0.010	0.008	0.009	0.009	0.008	0.013	0.010	0.011
0.009	0.009	0.008	0.009	0.009	0.009	0.008	0.009	0.010	0.011	0.010	0.011	0.011	0.010	0.010	0.010	0.010	0.009	0.010	0.008	0.015	0.009	0.011
0.012	0.010	0.010	0.010	0.010	0.012	0.009	0.010	0.006	0.011	0.010	0.011	0.011	0.010	0.010	0.010	0.010	0.009	0.010	0.005	0.017	0.010	0.006
0.012	0.011	0.010	0.011	0.012	0.010	0.011	0.012	0.011	0.011	0.011	0.011	0.011	0.012	0.011	0.010	0.012	0.010	0.012	0.011	0.015	0.009	0.012
0.012	0.013	0.010	0.012	0.011	0.011	0.010	0.010	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.010	0.016	0.010	0.012
0.010	0.010	0.007	0.009	0.010	0.009	0.008	0.009	0.010	0.006	0.006	0.005	0.005	0.010	0.005	0.002	0.009	0.005	0.010	0.008	0.014	0.008	0.010
	0.011	0.009	0.010	0.010	0.010	0.010	0.010	0.011	0.011	0.011	0.012	0.012	0.010	0.012	0.011	0.010	0.010	0.011	0.010	0.014	0.009	0.011
0.073		0.009	0.010	0.010	0.010	0.011	0.011	0.012	0.012	0.011	0.012	0.012	0.012	0.011	0.011	0.012	0.010	0.010	0.010	0.015	0.010	0.013
0.054	0.062		0.007	0.009	0.008	0.008	0.009	0.010	0.008	0.008	0.008	0.008	0.009	0.008	0.007	0.009	0.008	0.009	0.009	0.014	0.009	0.010
0.057	0.067	0.042		0.009	0.010	0.008	0.009	0.010	0.010	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.010	0.008	0.015	0.009	0.011
0.057	0.063	0.052	0.052		0.010	0.009	0.008	0.011	0.011	0.011	0.012	0.012	0.010	0.012	0.011	0.006	0.010	0.009	0.009	0.014	0.009	0.012
0.073	0.076	0.062	0.067	0.068		0.010	0.010	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.010	0.009	0.010	0.010	0.010	0.014	0.009	0.012
0.062	0.073	0.055	0.049	0.057	0.071		0.009	0.009	0.010	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.008	0.009	0.007	0.014	0.010	0.009
0.065	0.076	0.059	0.054	0.037	0.068	0.065		0.010	0.010	0.010	0.011	0.011	0.010	0.011	0.010	0.008	0.010	0.008	0.009	0.014	0.009	0.011
0.064	0.082	0.060	0.062	0.066	0.072	0.060	0.066		0.011	0.010	0.011	0.011	0.010	0.010	0.010	0.010	0.010	0.011	0.003	0.016	0.010	0.006
0.065	0.074	0.048	0.053	0.070	0.074	0.060	0.070	0.074		0.007	0.003	0.003	0.010	0.006	0.006	0.010	0.007	0.011	0.010	0.014	0.009	0.011
0.062	0.067	0.042	0.053	0.067	0.074	0.056	0.074	0.068	0.021		0.006	0.006	0.010	0.002	0.006	0.009	0.007	0.010	0.009	0.015	0.010	0.010

Table 3. Mean genetic distance (D) and standard error (s.e.) within lineages of Coleoptera as shown in Figure 2. N= number of specimens in the lineage; Rep= specimen used to represent the lineage in the model-based phylogenetic analysis. n/c= not calculated where the number of specimens in the lineage is 1.

Lineage	D	s.e.	N	rep
1	0.000	0.000	4	MF09
2	0.003	0.002	4	MF20
3	0.009	0.003	4	MF11
4	0.016	0.003	4	MF03

Table 4. Mean genetic distance (D; below diagonal) and standard error (s.e.; above diagonal, in blue) between lineages of Coleoptera as shown in Figure 2.

Lineage	1	2	3	4
1		0.007	0.012	0.016
2	0.046		0.013	0.015
3	0.159	0.157		0.016
4	0.264	0.265	0.260	

Table 5. Genetic distances (below diagonal) and standard error (above diagonal, in blue) between specimens of Curculionidae (Coleoptera) detected at Mesa H and the reference lineages as shown in Figure 3. Distances between the Mesa H specimens and the reference specimens are highlighted in yellow.

Specimen ID	MF03	CF10	CF13	CF5	CF6	CF7	CF8	CF9	G115	GU213687	HE615891	IV148	IV150	IV152	IV234	IV395	KD03	KD04	KD05	KU519717	KU5197
MF03		0.018	0.018	0.017	0.017	0.017	0.017	0.018	0.021	0.016	0.017	0.017	0.012	0.013	0.012	0.013	0.012	0.013	0.012	0.013	0.013
CF10	0.218		0.004	0.008	0.005	0.008	0.007	0.004	0.017	0.016	0.016	0.014	0.018	0.018	0.018	0.016	0.017	0.018	0.018	0.018	0.018
CF13	0.223	0.014		0.008	0.005	0.007	0.007	0.004	0.018	0.017	0.017	0.014	0.017	0.018	0.018	0.016	0.017	0.017	0.017	0.018	0.018
CF5	0.223	0.038	0.035		0.007	0.008	0.008	0.007	0.017	0.017	0.017	0.014	0.017	0.018	0.017	0.017	0.017	0.017	0.017	0.017	0.017
CF6	0.224	0.024	0.021	0.036		0.008	0.007	0.005	0.017	0.017	0.017	0.014	0.017	0.017	0.017	0.016	0.016	0.017	0.017	0.017	0.017
CF7	0.220	0.039	0.038	0.046	0.045		0.005	0.007	0.016	0.016	0.015	0.014	0.018	0.018	0.018	0.015	0.018	0.018	0.018	0.018	0.018
CF8	0.218	0.035	0.033	0.042	0.038	0.013		0.007	0.018	0.016	0.016	0.014	0.018	0.019	0.019	0.016	0.018	0.018	0.018	0.018	0.018
CF9	0.218	0.014	0.014	0.029	0.024	0.041	0.039		0.018	0.017	0.016	0.014	0.017	0.017	0.017	0.016	0.017	0.017	0.017	0.017	0.017
G115	0.252	0.152	0.158	0.154	0.152	0.158	0.165	0.152		0.018	0.020	0.020	0.022	0.022	0.022	0.021	0.022	0.022	0.022	0.022	0.022
GU213687	0.218	0.208	0.207	0.208	0.202	0.198	0.199	0.205	0.189		0.015	0.014	0.016	0.016	0.016	0.014	0.016	0.016	0.016	0.015	0.015
HE615891	0.218	0.193	0.195	0.209	0.202	0.190	0.201	0.192	0.208	0.198		0.017	0.014	0.014	0.014	0.015	0.014	0.014	0.014	0.015	0.015
IV148	0.190	0.176	0.171	0.173	0.180	0.177	0.177	0.167	0.224	0.214	0.224		0.015	0.015	0.015	0.016	0.015	0.015	0.015	0.015	0.015
IV150	0.130	0.220	0.220	0.224	0.217	0.215	0.217	0.209	0.235	0.190	0.196	0.190		0.006	0.000	0.011	0.001	0.002	0.000	0.006	0.006
IV152	0.139	0.221	0.218	0.228	0.218	0.223	0.224	0.214	0.240	0.195	0.204	0.190	0.032		0.006	0.013	0.007	0.007	0.006	0.005	0.005
IV234	0.130	0.222	0.222	0.226	0.219	0.217	0.219	0.212	0.232	0.190	0.196	0.192	0.000	0.033		0.011	0.001	0.002	0.000	0.006	0.006
IV395	0.141	0.217	0.220	0.226	0.219	0.213	0.217	0.216	0.252	0.213	0.224	0.179	0.129	0.135	0.129		0.012	0.011	0.011	0.013	0.013
KD03	0.131	0.217	0.217	0.221	0.214	0.215	0.217	0.206	0.238	0.191	0.198	0.189	0.001	0.034	0.001	0.130		0.003	0.001	0.006	0.006
KD04	0.130	0.218	0.218	0.220	0.213	0.217	0.215	0.208	0.237	0.193	0.196	0.190	0.003	0.035	0.003	0.132	0.004		0.002	0.006	0.006
KD05	0.130	0.219	0.219	0.223	0.216	0.215	0.216	0.209	0.235	0.190	0.196	0.190	0.000	0.032	0.000	0.129	0.001	0.003		0.006	0.006
KU519717	0.131	0.228	0.228	0.236	0.225	0.229	0.231	0.220	0.226	0.193	0.207	0.198	0.029	0.021	0.029	0.140	0.030	0.032	0.029		0.000
KU519718	0.131	0.228	0.228	0.236	0.225	0.229	0.231	0.220	0.226	0.193	0.207	0.198	0.029	0.021	0.029	0.140	0.030	0.032	0.029	0.000	
LI44	0.131	0.216	0.216	0.221	0.213	0.215	0.216	0.206	0.238	0.191	0.198	0.189	0.001	0.034	0.001	0.130	0.000	0.004	0.001	0.030	0.030
LI45	0.131	0.226	0.226	0.230	0.223	0.221	0.226	0.215	0.253	0.192	0.198	0.198	0.006	0.034	0.005	0.129	0.009	0.011	0.006	0.027	0.027
WAME89091	0.227	0.036	0.040	0.049	0.041	0.017	0.018	0.040	0.129	0.198	0.198	0.184	0.226	0.234	0.226	0.223	0.228	0.226	0.226	0.233	0.233
WAME89114	0.231	0.038	0.035	0.044	0.043	0.041	0.033	0.035	0.136	0.201	0.204	0.184	0.229	0.234	0.229	0.217	0.228	0.233	0.229	0.233	0.233
WAME89115	0.228	0.035	0.032	0.041	0.040	0.035	0.033	0.029	0.129	0.195	0.196	0.175	0.225	0.229	0.225	0.216	0.223	0.228	0.225	0.228	0.228
WAME89116	0.222	0.036	0.040	0.052	0.047	0.014	0.015	0.040	0.134	0.198	0.195	0.182	0.216	0.223	0.216	0.222	0.217	0.219	0.216	0.222	0.222

WAME89146	0.220	0.116	0.120	0.122	0.117	0.126	0.128	0.114	0.002	0.181	0.190	0.193	0.211	0.216	0.211	0.225	0.213	0.208	0.211	0.213	0.213
WAME89147	0.223	0.114	0.119	0.123	0.119	0.125	0.129	0.112	0.014	0.175	0.187	0.191	0.208	0.216	0.208	0.225	0.210	0.208	0.208	0.210	0.210
WAME89148	0.222	0.117	0.122	0.123	0.119	0.128	0.129	0.116	0.014	0.176	0.189	0.193	0.208	0.216	0.208	0.226	0.210	0.205	0.208	0.210	0.210
WAME89151	0.218	0.119	0.119	0.116	0.122	0.103	0.106	0.114	0.132	0.190	0.209	0.199	0.210	0.207	0.210	0.217	0.211	0.213	0.210	0.210	0.210
WAME89154	0.218	0.138	0.141	0.140	0.144	0.137	0.135	0.137	0.139	0.185	0.183	0.201	0.213	0.217	0.213	0.213	0.214	0.213	0.213	0.216	0.216
WAME89157	0.223	0.117	0.116	0.123	0.119	0.125	0.123	0.116	0.018	0.181	0.187	0.193	0.213	0.220	0.213	0.231	0.214	0.210	0.213	0.214	0.214
WAME89172	0.223	0.128	0.126	0.132	0.132	0.126	0.129	0.123	0.127	0.190	0.181	0.167	0.216	0.220	0.216	0.216	0.217	0.216	0.216	0.222	0.222
WAME89176	0.241	0.219	0.219	0.217	0.217	0.208	0.214	0.222	0.215	0.208	0.215	0.233	0.242	0.237	0.242	0.234	0.240	0.239	0.242	0.237	0.237
WAME89177	0.202	0.204	0.198	0.199	0.199	0.198	0.195	0.195	0.224	0.217	0.198	0.138	0.191	0.191	0.191	0.195	0.190	0.191	0.191	0.191	0.191
WAME89186	0.131	0.228	0.228	0.236	0.225	0.229	0.231	0.220	0.226	0.193	0.207	0.198	0.029	0.021	0.029	0.140	0.030	0.032	0.029	0.000	0.000
WAME89188	0.144	0.229	0.226	0.237	0.226	0.231	0.233	0.222	0.229	0.193	0.204	0.198	0.032	0.002	0.032	0.137	0.033	0.035	0.032	0.021	0.021

' 18	LI44	LI45	WAME89091	WAME89114	WAME89115	WAME89116	WAME89146	WAME89147	WAME89148	WAME89151	WAME89154	WAME89157	WAME89172	WAME89176	WAME89177	WAME89186	WAME89188
0.012	0.012	0.017	0.018	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.018	0.016	0.017	0.013	0.013	
0.017	0.018	0.007	0.007	0.006	0.007	0.011	0.011	0.011	0.014	0.013	0.012	0.013	0.015	0.016	0.018	0.019	
0.017	0.017	0.008	0.006	0.006	0.008	0.012	0.012	0.012	0.014	0.013	0.012	0.012	0.015	0.015	0.018	0.018	
0.017	0.017	0.010	0.008	0.008	0.009	0.013	0.012	0.013	0.012	0.014	0.013	0.013	0.015	0.015	0.017	0.018	
0.016	0.017	0.008	0.007	0.006	0.008	0.012	0.011	0.011	0.014	0.013	0.012	0.013	0.015	0.015	0.017	0.018	
0.018	0.018	0.005	0.007	0.006	0.005	0.012	0.012	0.012	0.013	0.013	0.012	0.012	0.014	0.015	0.018	0.019	
0.018	0.018	0.006	0.007	0.007	0.004	0.013	0.013	0.013	0.013	0.013	0.012	0.013	0.015	0.015	0.018	0.019	
0.016	0.017	0.008	0.006	0.005	0.007	0.012	0.012	0.012	0.013	0.013	0.012	0.012	0.014	0.015	0.017	0.018	
0.022	0.022	0.015	0.016	0.016	0.015	0.002	0.005	0.005	0.015	0.017	0.006	0.016	0.020	0.020	0.022	0.022	
0.016	0.016	0.016	0.017	0.016	0.017	0.016	0.016	0.016	0.017	0.016	0.016	0.017	0.015	0.016	0.015	0.015	
0.014	0.014	0.016	0.016	0.016	0.015	0.015	0.015	0.015	0.016	0.014	0.015	0.015	0.015	0.015	0.015	0.014	
0.015	0.016	0.015	0.014	0.013	0.015	0.016	0.016	0.016	0.016	0.014	0.016	0.013	0.017	0.013	0.015	0.015	
0.001	0.003	0.018	0.018	0.017	0.019	0.017	0.018	0.018	0.017	0.016	0.017	0.015	0.016	0.013	0.006	0.007	
0.007	0.007	0.019	0.018	0.018	0.019	0.017	0.018	0.018	0.018	0.016	0.018	0.015	0.016	0.014	0.005	0.001	
0.001	0.002	0.018	0.018	0.017	0.019	0.017	0.018	0.018	0.017	0.016	0.017	0.015	0.016	0.013	0.006	0.007	
0.012	0.012	0.016	0.017	0.017	0.016	0.015	0.016	0.016	0.017	0.014	0.015	0.015	0.016	0.016	0.013	0.013	
0.000	0.004	0.018	0.018	0.017	0.019	0.018	0.018	0.018	0.017	0.016	0.018	0.015	0.016	0.013	0.006	0.007	
0.003	0.004	0.019	0.018	0.017	0.019	0.018	0.018	0.018	0.017	0.016	0.018	0.015	0.016	0.014	0.006	0.007	
0.001	0.003	0.018	0.018	0.017	0.019	0.017	0.018	0.018	0.017	0.016	0.017	0.015	0.016	0.013	0.006	0.007	
0.006	0.006	0.018	0.017	0.017	0.018	0.017	0.017	0.017	0.017	0.015	0.017	0.015	0.016	0.013	0.000	0.005	
0.006	0.006	0.018	0.017	0.017	0.018	0.017	0.017	0.017	0.017	0.015	0.017	0.015	0.016	0.013	0.000	0.005	
	0.004	0.018	0.018	0.017	0.019	0.018	0.018	0.018	0.017	0.016	0.018	0.015	0.016	0.013	0.006	0.007	
0.009		0.018	0.018	0.017	0.019	0.018	0.018	0.018	0.017	0.016	0.017	0.015	0.017	0.013	0.006	0.007	
0.228	0.228		0.007	0.007	0.005	0.012	0.012	0.012	0.014	0.013	0.012	0.013	0.015	0.016	0.018	0.019	
0.228	0.228	0.036		0.004	0.007	0.013	0.012	0.012	0.014	0.013	0.013	0.013	0.015	0.015	0.017	0.018	
0.223	0.223	0.033	0.012		0.006	0.012	0.012	0.012	0.013	0.013	0.012	0.012	0.014	0.015	0.017	0.018	
0.217	0.217	0.015	0.040	0.033		0.012	0.012	0.012	0.012	0.013	0.012	0.013	0.014	0.015	0.018	0.019	

Table 6. Genetic distances (below diagonal) and standard error (above diagonal, in blue) between specimens of Ptilidae (Coleoptera) detected at Mesa H and the reference lineages as shown in Figure 3. Distances between the Mesa H specimens and the reference specimens are highlighted in yellow.

Specimen ID	MF09	MF11	MF20	IV144	IV145	IV146	IV147	WAME89165	WAME89168
MF09		0.014	0.007	0.014	0.014	0.014	0.014	0.008	0.008
MF11	0.160		0.014	0.005	0.005	0.005	0.005	0.015	0.015
MF20	0.047	0.156		0.015	0.015	0.015	0.015	0.004	0.004
IV144	0.161	0.016	0.160		0.000	0.000	0.000	0.015	0.015
IV145	0.161	0.016	0.160	0.000		0.000	0.000	0.015	0.015
IV146	0.161	0.016	0.160	0.000	0.000		0.000	0.015	0.015
IV147	0.161	0.016	0.160	0.000	0.000	0.000		0.015	0.015
WAME89165	0.044	0.158	0.017	0.166	0.166	0.166	0.166		0.000
WAME89168	0.044	0.158	0.017	0.166	0.166	0.166	0.166	0.000	

Table 7. Genetic distances (below diagonal) and standard error (above diagonal, in blue) between specimens of Thysanura detected at Mesa H and the reference lineages as shown in Figure 4. Distances between the Mesa H specimens and the reference specimens are highlighted in yellow.

Specimen ID	MF21	MF22	AY2	AY3	BX42	BX43	CA0006 2	CA0006 3	CA0006 4	CA0124	CA0144	CA35	CA36	CA37	CA38
MF21 RC12JIM000620160119T2-02		0.018	0.025	0.020	0.019	0.017	0.024	0.024	0.024	0.024	0.024	0.016	0.016	0.016	0.017
MF22 RC14MEH025220151210-T1-03	0.125		0.025	0.023	0.022	0.021	0.023	0.023	0.023	0.023	0.023	0.019	0.019	0.019	0.019
AY2 BES16311 B10 TN005	0.220	0.204		0.003	0.024	0.022	0.023	0.023	0.023	0.023	0.023	0.022	0.022	0.022	0.021
AY3 BES15706 S9 Trinemura TN005	0.249	0.253	0.003		0.020	0.020	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.020
BX42 PES-5266 Trinemura MH1 TN006	0.160	0.170	0.243	0.244		0.016	0.022	0.022	0.022	0.022	0.023	0.017	0.017	0.017	0.017
BX43 PES-5964 Trinemura MH1 TN007	0.171	0.192	0.190	0.200	0.146		0.021	0.021	0.021	0.020	0.021	0.019	0.019	0.019	0.019
CA0006 2 Trinemura callawa	0.188	0.171	0.173	0.160	0.178	0.169		0.000	0.000	0.003	0.005	0.020	0.020	0.020	0.021
CA0006 3 Trinemura callawa	0.188	0.171	0.173	0.160	0.178	0.169	0.000		0.000	0.003	0.005	0.020	0.020	0.020	0.021
CA0006 4 Trinemura callawa	0.188	0.171	0.173	0.160	0.178	0.169	0.000	0.000		0.003	0.005	0.020	0.020	0.020	0.021
CA0124 Trinemura callawa	0.191	0.174	0.177	0.163	0.181	0.172	0.003	0.003	0.003		0.004	0.020	0.020	0.020	0.020
CA0144 LN1020 Trinemura callawa	0.191	0.177	0.180	0.169	0.187	0.178	0.009	0.009	0.009	0.006		0.020	0.020	0.020	0.021
CA35 11 1513 Trinemura indet. TN013	0.142	0.141	0.185	0.212	0.156	0.166	0.149	0.149	0.149	0.152	0.158		0.000	0.000	0.004
CA36 11 1456 Trinemura indet. TN013	0.142	0.141	0.185	0.212	0.156	0.166	0.149	0.149	0.149	0.152	0.158	0.000		0.000	0.004
CA37 12 0096 Trinemura indet. TN013	0.142	0.141	0.185	0.212	0.156	0.166	0.149	0.149	0.149	0.152	0.158	0.000	0.000		0.004
CA38 12 0107 Trinemura indet. TN013	0.149	0.147	0.182	0.210	0.159	0.171	0.152	0.152	0.152	0.155	0.162	0.008	0.008	0.008	
CA39 11 1511 Trinemura indet. TN013	0.149	0.147	0.182	0.210	0.159	0.171	0.152	0.152	0.152	0.155	0.162	0.008	0.008	0.008	0.000
CA40 11 1527 Trinemura indet. TN013	0.149	0.147	0.182	0.210	0.159	0.171	0.152	0.152	0.152	0.155	0.162	0.008	0.008	0.008	0.000
CQ10 Trinemura sp. B18 CC1886 TN008	0.121	0.128	0.211	0.246	0.181	0.203	0.179	0.179	0.179	0.182	0.185	0.153	0.153	0.153	0.156
CQ11 Trinemura sp. B15 CC0179 TN009	0.175	0.161	0.170	0.171	0.171	0.148	0.163	0.163	0.163	0.167	0.167	0.164	0.164	0.164	0.168
CQ12 Trinemura sp. B15 CCMUNK11 TN009	0.167	0.146	0.173	0.173	0.174	0.142	0.150	0.150	0.150	0.154	0.154	0.162	0.162	0.162	0.167
CQ13 Trinemura sp. B19 CC0748 TN016	0.161	0.185	0.205	0.234	0.183	0.155	0.172	0.172	0.172	0.175	0.178	0.166	0.166	0.166	0.172
CQ8 Trinemura sp. GNGCUNK011 TN008	0.107	0.120	0.211	0.244	0.170	0.203	0.179	0.179	0.179	0.182	0.185	0.144	0.144	0.144	0.147
CQ9 Trinemura sp. B20 CC3527 TN009	0.172	0.160	0.173	0.201	0.157	0.143	0.159	0.159	0.159	0.155	0.155	0.160	0.160	0.160	0.163
EJ0245R BHP165 J2 36 OB18 TN011	0.206	0.194	0.217	0.206	0.218	0.171	0.211	0.211	0.211	0.215	0.215	0.184	0.184	0.184	0.191
EXR0524 OB21 OB22 TN016	0.198	0.171	0.205	0.202	0.202	0.167	0.207	0.207	0.207	0.210	0.204	0.189	0.189	0.189	0.196
EXR0919 J16-1 TN001	0.180	0.189	0.115	0.117	0.193	0.158	0.142	0.142	0.142	0.145	0.151	0.174	0.174	0.174	0.178
EXR0983 BHP821 J8 13 Jimblebar W TN015	0.134	0.120	0.201	0.193	0.166	0.174	0.169	0.169	0.169	0.172	0.172	0.137	0.137	0.137	0.143

EXR1136 BHP1364 J8 15 Mudlark TN016	0.190	0.193	0.180	0.174	0.182	0.160	0.172	0.172	0.172	0.175	0.175	0.172	0.172	0.172	0.172
FL3 TOBRC0011PIT2-1 A TN014	0.128	0.128	0.208	0.228	0.146	0.160	0.172	0.172	0.172	0.175	0.181	0.104	0.104	0.104	0.109
FL4 TOBRC0011PIT2-1 B TN014	0.128	0.128	0.208	0.228	0.146	0.160	0.172	0.172	0.172	0.175	0.181	0.104	0.104	0.104	0.109
FL5 TOBRC0011-02 TN014	0.128	0.128	0.208	0.228	0.146	0.160	0.172	0.172	0.172	0.175	0.181	0.104	0.104	0.104	0.109
G126 TN003	0.181	0.205	0.209	0.192	0.170	0.134	0.213	0.213	0.213	0.210	0.216	0.174	0.174	0.174	0.180
G205 100101 TN003	0.175	0.193	0.212	0.217	0.168	0.129	0.205	0.205	0.205	0.208	0.215	0.166	0.166	0.166	0.171
G206 108042 TN004	0.169	0.188	0.223	0.225	0.157	0.123	0.198	0.198	0.198	0.201	0.207	0.173	0.173	0.173	0.178
G207 107781 TN003	0.171	0.193	0.208	0.212	0.161	0.127	0.211	0.211	0.211	0.208	0.215	0.166	0.166	0.166	0.171
G317 LN8923 Nicoletiidae sp. OP TN002	0.172	0.214	0.207	0.216	0.159	0.098	0.206	0.206	0.206	0.209	0.209	0.170	0.170	0.170	0.175
G318 LN8588 Nicoletiidae sp. MC TN001	0.206	0.226	0.115	0.108	0.212	0.170	0.132	0.132	0.132	0.135	0.141	0.190	0.190	0.190	0.193
IV227 MEARC4383 TN010	0.132	0.122	0.203	0.225	0.154	0.167	0.149	0.149	0.149	0.152	0.159	0.128	0.128	0.128	0.133
IV333 MEBRC0020T1-20 TN010	0.127	0.125	0.199	0.210	0.137	0.141	0.140	0.140	0.140	0.143	0.149	0.128	0.128	0.128	0.133
IV334 M2ERC0057T1-21 TN011	0.111	0.072	0.224	0.238	0.152	0.171	0.183	0.183	0.183	0.186	0.186	0.129	0.129	0.129	0.134
IV338 GR15MEC0001-20160316-T2-06 TN012	0.116	0.122	0.185	0.214	0.168	0.177	0.155	0.155	0.155	0.158	0.164	0.117	0.117	0.117	0.119
IV339 RC15MEC0197-20160316-T2-01 TN012	0.113	0.128	0.188	0.213	0.161	0.170	0.155	0.155	0.155	0.158	0.164	0.114	0.114	0.114	0.116
JIN0037R J8 25 Jinaryi TN002	0.167	0.164	0.197	0.183	0.174	0.119	0.173	0.173	0.173	0.170	0.170	0.170	0.170	0.170	0.177
JIN0182R BHP465 J2 37 Jinaryi TN016	0.166	0.180	0.194	0.180	0.174	0.139	0.178	0.178	0.178	0.181	0.187	0.136	0.136	0.136	0.142
JQ282164 Trinemura callawa CA0006	0.188	0.171	0.173	0.160	0.178	0.169	0.000	0.000	0.000	0.003	0.009	0.149	0.149	0.149	0.152
JQ282165 Trinemura cundalin CU0060R LN1093	0.199	0.187	0.187	0.171	0.180	0.175	0.065	0.065	0.065	0.062	0.062	0.164	0.164	0.164	0.167
LI33 MEAWO4086-20170308-04 12S	0.122	0.125	0.196	0.210	0.136	0.136	0.137	0.137	0.137	0.140	0.146	0.128	0.128	0.128	0.133
PROP003 J16-2 Trimenura TN002	0.183	0.202	0.205	0.205	0.190	0.125	0.201	0.201	0.201	0.204	0.204	0.189	0.189	0.189	0.196

CA39	CA40	CQ10	CQ11	CQ12	CQ13	CQ8	CQ9	EJ0245R	EXR0524	EXR0919	EXR0983	EXR1136	FL3	FL4	FL5	G126	G205	G206	G207	G317	G318	IV227	IV333
0.017	0.017	0.016	0.017	0.019	0.017	0.015	0.017	0.023	0.022	0.022	0.019	0.021	0.016	0.016	0.016	0.019	0.018	0.017	0.017	0.019	0.019	0.016	0.016
0.019	0.019	0.017	0.019	0.020	0.019	0.018	0.019	0.024	0.023	0.023	0.018	0.025	0.016	0.016	0.016	0.021	0.019	0.020	0.020	0.023	0.021	0.016	0.017
0.021	0.021	0.022	0.025	0.025	0.026	0.022	0.025	0.025	0.024	0.020	0.025	0.022	0.022	0.022	0.022	0.024	0.025	0.025	0.024	0.023	0.020	0.021	0.022
0.020	0.020	0.022	0.024	0.024	0.023	0.022	0.022	0.023	0.023	0.019	0.024	0.020	0.020	0.020	0.020	0.020	0.023	0.023	0.022	0.021	0.017	0.020	0.020
0.017	0.017	0.022	0.019	0.021	0.018	0.024	0.018	0.023	0.021	0.021	0.020	0.020	0.019	0.019	0.019	0.017	0.017	0.017	0.016	0.018	0.020	0.018	0.017
0.019	0.019	0.022	0.019	0.019	0.018	0.023	0.017	0.021	0.020	0.021	0.021	0.019	0.018	0.018	0.018	0.017	0.016	0.016	0.016	0.014	0.019	0.020	0.018
0.021	0.021	0.021	0.023	0.022	0.024	0.021	0.021	0.024	0.023	0.019	0.020	0.021	0.022	0.022	0.022	0.022	0.022	0.024	0.022	0.022	0.019	0.019	0.020
0.021	0.021	0.021	0.023	0.022	0.024	0.021	0.021	0.024	0.023	0.019	0.020	0.021	0.022	0.022	0.022	0.022	0.022	0.024	0.022	0.022	0.019	0.019	0.020
0.021	0.021	0.021	0.023	0.022	0.024	0.021	0.021	0.024	0.023	0.019	0.020	0.021	0.022	0.022	0.022	0.022	0.022	0.024	0.022	0.022	0.019	0.019	0.020
0.020	0.020	0.021	0.023	0.022	0.024	0.021	0.022	0.024	0.023	0.020	0.020	0.021	0.022	0.022	0.022	0.022	0.022	0.024	0.022	0.022	0.020	0.019	0.020
0.021	0.021	0.021	0.023	0.022	0.024	0.021	0.022	0.023	0.023	0.020	0.020	0.021	0.022	0.022	0.022	0.023	0.023	0.024	0.023	0.022	0.020	0.020	0.021
0.004	0.004	0.017	0.020	0.021	0.021	0.018	0.019	0.024	0.023	0.021	0.019	0.022	0.013	0.013	0.013	0.020	0.018	0.020	0.018	0.018	0.020	0.017	0.017
0.004	0.004	0.017	0.020	0.021	0.021	0.018	0.019	0.024	0.023	0.021	0.019	0.022	0.013	0.013	0.013	0.020	0.018	0.020	0.018	0.018	0.020	0.017	0.017
0.004	0.004	0.017	0.020	0.021	0.021	0.018	0.019	0.024	0.023	0.021	0.019	0.022	0.013	0.013	0.013	0.020	0.018	0.020	0.018	0.018	0.020	0.017	0.017
0.000	0.000	0.017	0.020	0.022	0.021	0.018	0.019	0.024	0.023	0.021	0.019	0.022	0.014	0.014	0.014	0.020	0.018	0.020	0.018	0.018	0.020	0.017	0.017
	0.000	0.017	0.020	0.022	0.021	0.018	0.019	0.024	0.023	0.021	0.019	0.022	0.014	0.014	0.014	0.020	0.018	0.020	0.018	0.018	0.020	0.017	0.017
0.000		0.017	0.020	0.022	0.021	0.018	0.019	0.024	0.023	0.021	0.019	0.022	0.014	0.014	0.014	0.020	0.018	0.020	0.018	0.018	0.020	0.017	0.017
0.156	0.156		0.021	0.022	0.020	0.008	0.019	0.026	0.025	0.023	0.017	0.025	0.016	0.016	0.016	0.022	0.022	0.019	0.021	0.023	0.022	0.015	0.016
0.168	0.168	0.183		0.006	0.015	0.021	0.007	0.021	0.019	0.024	0.020	0.020	0.017	0.017	0.017	0.017	0.018	0.019	0.017	0.019	0.023	0.019	0.019
0.167	0.167	0.181	0.011		0.016	0.021	0.009	0.021	0.019	0.023	0.020	0.020	0.018	0.018	0.018	0.020	0.020	0.018	0.020	0.022	0.023	0.020	0.020
0.172	0.172	0.181	0.107	0.099		0.020	0.015	0.021	0.019	0.023	0.022	0.018	0.017	0.017	0.017	0.016	0.016	0.018	0.016	0.018	0.022	0.019	0.019
0.147	0.147	0.031	0.186	0.184	0.175		0.018	0.026	0.025	0.023	0.017	0.026	0.018	0.018	0.018	0.022	0.021	0.020	0.021	0.024	0.022	0.016	0.017
0.163	0.163	0.172	0.016	0.021	0.105	0.174		0.021	0.020	0.022	0.021	0.020	0.017	0.017	0.017	0.017	0.017	0.017	0.016	0.019	0.020	0.018	0.017
0.191	0.191	0.207	0.142	0.139	0.153	0.201	0.146		0.014	0.023	0.024	0.021	0.022	0.022	0.022	0.021	0.022	0.021	0.022	0.020	0.023	0.023	0.022
0.196	0.196	0.212	0.138	0.139	0.165	0.218	0.145	0.086		0.022	0.022	0.020	0.023	0.023	0.023	0.021	0.022	0.022	0.022	0.017	0.021	0.022	0.021
0.178	0.178	0.203	0.153	0.144	0.173	0.199	0.143	0.186	0.187		0.022	0.022	0.022	0.022	0.022	0.024	0.025	0.024	0.024	0.022	0.005	0.021	0.021
0.143	0.143	0.137	0.157	0.154	0.170	0.134	0.156	0.184	0.173	0.159		0.023	0.017	0.017	0.017	0.021	0.022	0.021	0.021	0.021	0.022	0.014	0.014

Figure 1. Bayesian analysis of COI haplotypes of Blattodea (Nocticolidae) from the present study and reference specimens from Genbank and previous surveys in the Pilbara. Numbers on major nodes correspond to posterior probabilities; values <50% are not shown. Specimens from the present study are highlighted in yellow; specimens from previous phases at Mesa H are highlighted in green; GenBank voucher specimens highlighted in turquoise. Scale bar= number of substitutions per site. Red boxes enclose species with high confidence; red boxes with dashed lines represent groups requiring further investigation.

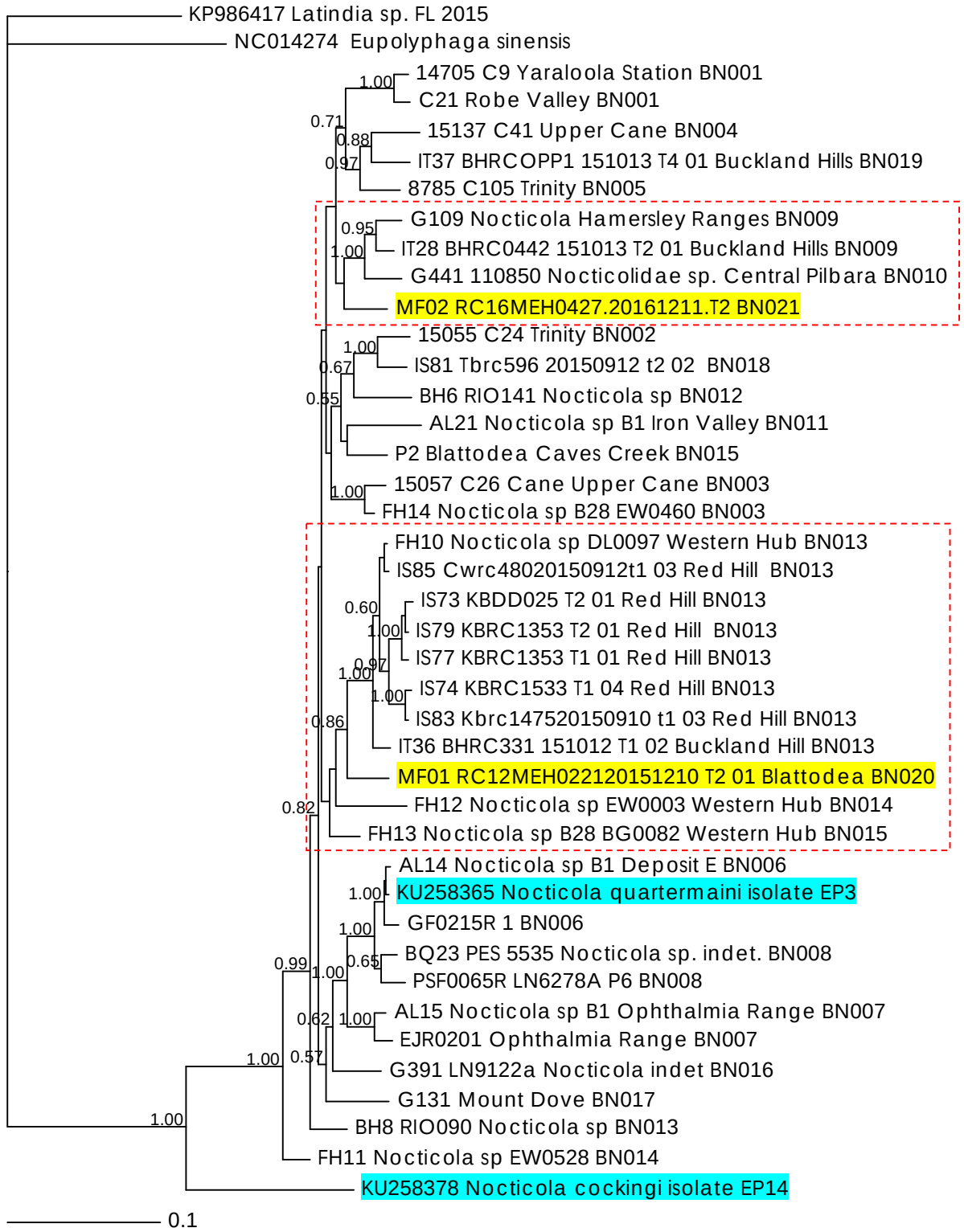


Figure 2. Neighbour-joining analysis of specimens of Coleoptera from the present study. Numbers on major nodes correspond to bootstrap support over 100 iterations; values <50% are not shown. Scale bar= genetic distance. The specimens used to represent each lineage in the model-based phylogenetic analysis are highlighted in yellow.

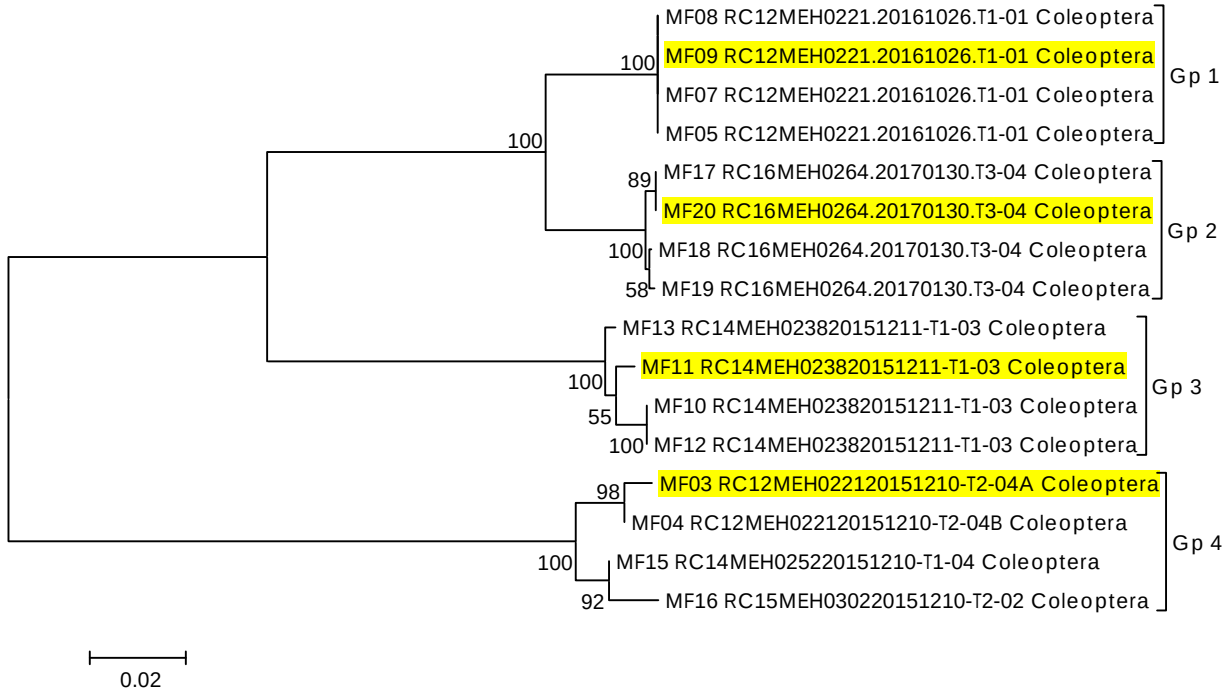


Figure 3. Bayesian analysis of COI haplotypes of Ptilidae and Curculionidae (Coleoptera) from the present study and reference specimens from the WAM and previous surveys in the Pilbara. Numbers on major nodes correspond to posterior probabilities; values <50% are not shown. Specimens from the present study are highlighted in yellow; specimens from previous phases at Mesa H are highlighted in green; GenBank voucher specimens highlighted in turquoise. Scale bar= number of substitutions per site. Red boxes with solid lines enclose species with high confidence; red boxes with dashed lines represent groups requiring further investigation.

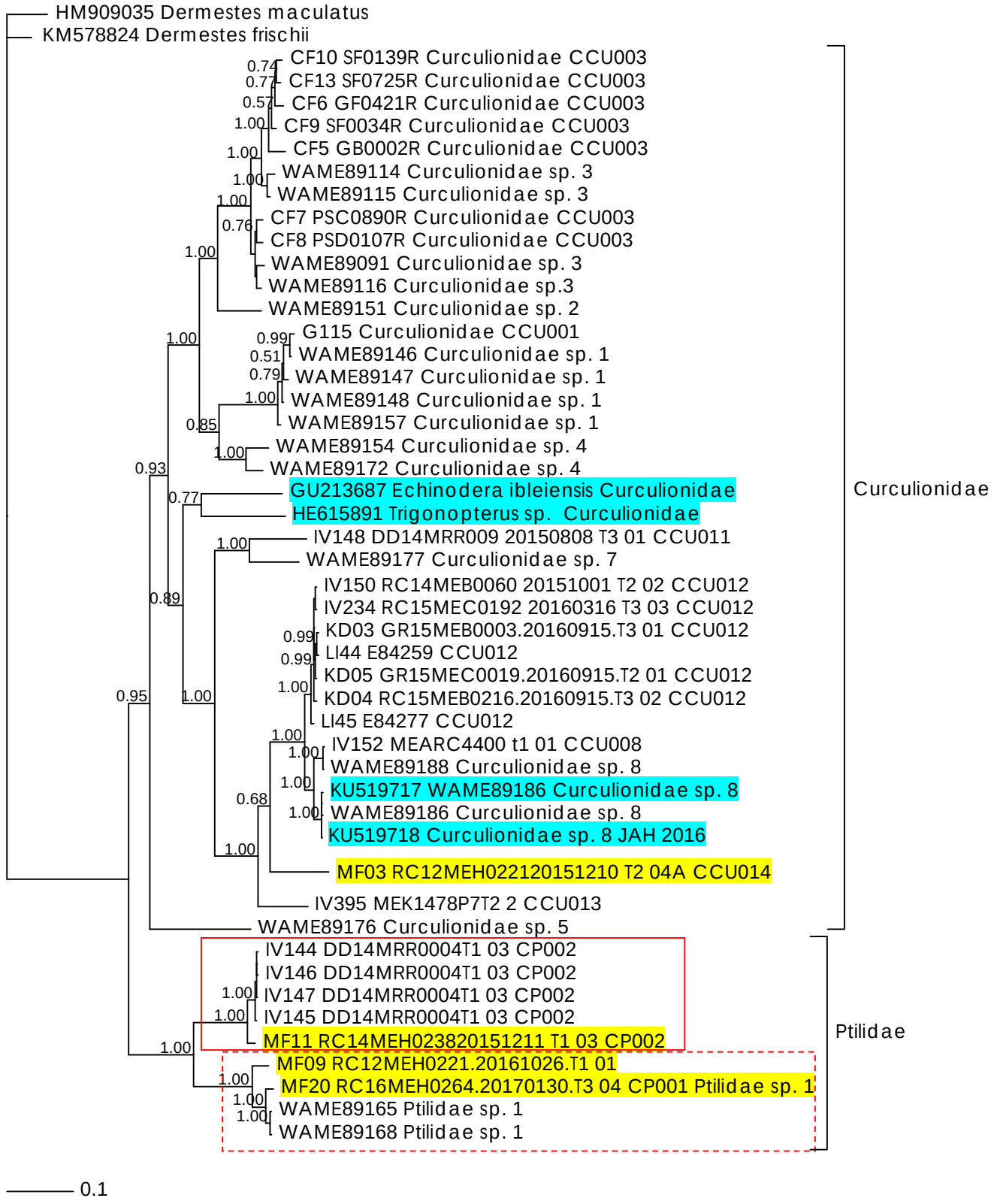
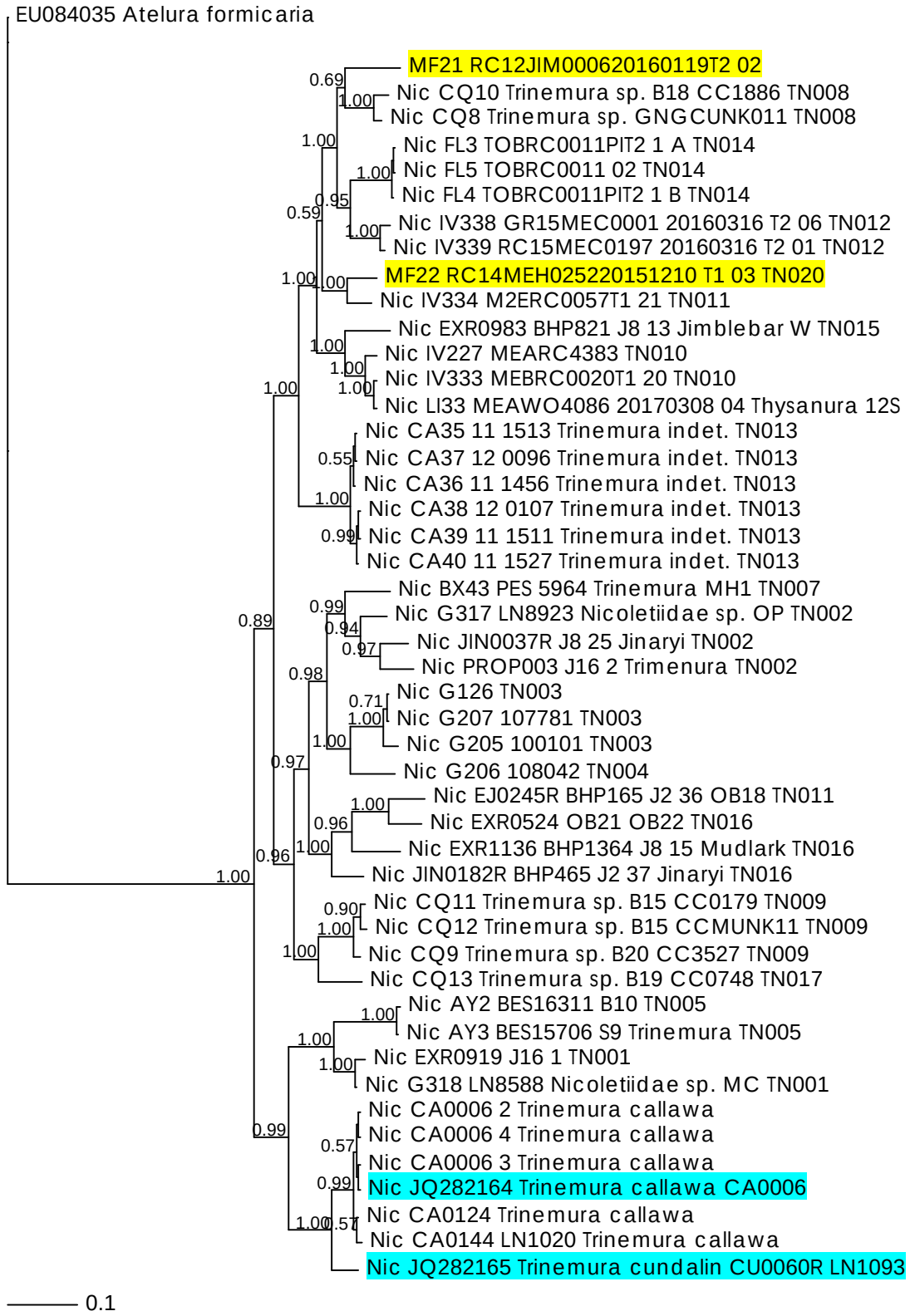


Figure 4. Bayesian analysis of 12s haplotypes of Thysanura from the present study and reference specimens from Genbank and previous surveys in the Pilbara. Numbers on major nodes correspond to posterior probabilities; values <50% are not shown. Specimens from the present study are highlighted in yellow; specimens from previous phases at Mesa H are highlighted in green; GenBank voucher specimens highlighted in turquoise. Scale bar= number of substitutions per site.



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12 April, 2017

Garth Humphreys
Biota Environmental Sciences
Level 1, 228 Carr Place
Leederville, WA 6007

Via email

Re. Report on the molecular systematics of Amphipoda from Mesa H (Biota 1146f)

Dear Garth,

Following is a summary of the results of the Amphipoda study we have completed from Mesa H. Fifteen distinct genetic lineages from three families (Melitidae/Eriopisidae, Neoniphargidae, Paramelitidae) were detected in the collections, nine of which have been detected previously in the Pilbara.

Thanks once again for collaborating on this project with Helix. We hope we can continue to provide you with useful information, and feel free to contact us if you have any questions or would like to discuss the results in detail.

Sincerely,

Dr. Terrie Finston, Yvette Hitchen and Dr. Oliver Berry
Helix Molecular Solutions

Background and Objective

One hundred twenty-one specimens of Amphipoda were collected from Mesa H and sequenced for variation at the mitochondrial COI gene. The molecular data were assessed in order to determine the number of species present and compare the results to those obtained during previous surveys in the Pilbara.

Executive summary

- One hundred twenty-one specimens of amphipods from Mesa H were sequenced for variation at the COI gene.
- Fifteen distinct genetic lineages (eight Melitidae/ Eriopisidae, two Neoniphargidae and five Paramelitidae) were detected among the 95 specimens for which sequences were obtained.
- Nine of the lineages have been detected previously in the Pilbara, whereas six (two Melitidae/Eriopisidae and four Paramelitidae) appear to be new, based on the material available for comparison.

Methods

One hundred twenty-one specimens of Amphipoda from 12 drillholes at Mesa H were sequenced for variation at the mitochondrial cytochrome oxidase subunit I gene (COI) using primers LCOI/HCO2.

Sequences were edited using GENEIOUS software (Drummond *et al.* 2011). Alignment was performed with CLUSTAL W (Thompson *et al*. 1994) using default parameters. Genetic distances between unique genetic sequences (haplotypes) were measured using uncorrected p-distances (total percentage of nucleotide differences between sequences).

MODELTEST software (Posada and Crandall, 1998) was used to determine the model of sequence evolution that best fitted the data for each taxonomic group. Bayesian analysis was used to construct the phylogenetic trees, incorporating the model as identified in MODELTEST for each taxonomic group. The phylogeny, branch lengths and posterior probabilities were obtained by running two trees simultaneously, each running four simultaneous MCMC chains. The number of cycles needed was determined by the standard deviation of the split frequencies of the two trees. The analysis was paused after every 1 x 10^6 generations and when the standard deviation fell below 0.01, the analysis was stopped. A majority rule consensus tree was constructed after discarding the "burn-in" trees in both analyses. The burn-in value was determined by plotting the posterior probabilities obtained after every generation and identifying the point at which the values reach stationarity (= the asymptote). Trees produced prior to stationarity were discarded.

For the purposes of this report, lineages were defined as haplotypes or groups of haplotypes differing from other such groups by >3% sequence divergence. This cut-off was selected based on bar-coding data, which indicates that intra-specific variation rarely exceeds 2-3% (Hebert et al., 2003b).

Results

Preliminary analysis - Reference sequences and outgroups

One hundred twenty-one specimens of amphipods from Mesa H were sequenced for COI (Table 1). In order to reduce analysis time and to simplify the presentation of results, a preliminary neighbour-joining (NJ) analysis was conducted on the 95 amphipods for which sequences were obtained, to identify unique haplotypes to include in a model-based phylogenetic analysis. Thirty-eight unique haplotypes were detected among the 95 sequences; these haplotypes were further sorted into 15 lineages. Comparisons to the GenBank sequence database indicated that five lineages were most similar to Paramelitidae and two were most similar to Niphargidae (Figure 1). Eight lineages were most similar to sequences of Melitidae/ Eriopisidae (Figure 2).

The three families were analysed in separate phylogenetic analyses with relevant reference specimens. The Niphargidae are not found in Australia, thus the lineages are likely to belong to

the closely related family Neoniphargidae, which is represented in Australia by seven genera (World Register of Marine Species – WORMS). Genbank lacks sequences of Neoniphrgidae for COI, thus the closest matches appear to be from the family Niphargidae. Ten reference sequences of presumptive Neoniphargidae from previous surveys in the Robe Valley were included in the analysis, one from a borehole in which other specimens were identified as *Wesniphargus* sp. on the basis of morphology. Two Genbank reference sequences of Niphargidae, *Niphargus*: *N. fontanus* (Genbank accession number KC315635) and *N. glenniei* (Genbank accession number KC315646) were also included. Two sequences of Melitidae/ Eriopisidae, *Nedsia* sp. 1 (Genbank accession #EU304458), and *Norcapensis mandibulis* (Genbank accession # JQ608487) were used as outgroups.

For the Paramelitidae, 48 reference sequences were included in the phylogenetic analysis, nine GenBank vouchers of Paramelitidae, as well as 39 specimens from previous surveys of the Robe Valley, Central Pilbara, Barrow Island, Lower Shaw River, Fortescue River, and Marillana Creek. Two sequences of the amphipod genus *Niphargus* were used as outgroups as follows: *N. fontanus* (Genbank accession number KC315635) and *N. glenniei* (Genbank accession number KC315646). Two sequences of Melitidae/Eriopisidae, *Nedsia* sp. 1 (Genbank accession #EU304458), and *Norcapensis mandibulis* (Genbank accession # JQ608487) were used as outgroups.

For the Melitidae/Eriopisidae, 52 reference sequences were included in the phylogenetic analysis. The genus *Nedsia* has been reassigned to the family Eriopsidae (WAM, pers. comm.) so GenBank vouchers of both Melitidae and Eriopisidae, *Nedsia* sp. 1 (Genbank accession #EU304458), and *Norcapensis mandibulis* (Genbank accession # JQ608487) as well as 50 specimens from previous surveys of the Robe Valley, Central Pilbara, Barrow Island, Lower Shaw River, Fortescue River, and Marillana Creek were included in the phylogenetic analysis. Two sequences of the amphipod genus *Niphargus* were used as outgroups as follows: *N. fontanus* (Genbank accession number KC315635) and *N. glenniei* (Genbank accession number KC315646).

Phylogenetic analysis- Neoniphargidae

The phylogenetic analysis, which included the five haplotypes of Neoniphargidae from Mesa H in addition to 13 reference specimens, placed the Mesa H haplotypes in two distinct genetic lineages. One lineage contained several reference specimens from Dave's and Budgie bores, and thus was assigned to the existing lineage AMN008 (Figure 3). The second lineage contained a reference specimen from a bore where other individuals were identified as *Wesniphargus* sp. on the basis of morphology and thus was assigned to the existing lineage *Wesniphargus* sp. AMN004 (Figure 3). Lineages AMN004 and AMN008 formed a well-supported clade (Figure 3).

Differentiation between lineages –Neoniphargidae

The Mesa H Neoniphargidae assigned to lineage AMN008, represented by three haplotypes (NH20, NH29 and NH32), differed from the nearest reference specimens KJ64, KD39, KE07, IV100, JN08 and LI20 (reference lineage AMN008) by between 0.4 and 1.4% sequence divergence, and from the remaining reference specimens by >12% sequence divergence (Table 2). The Mesa H Neoniphargidae assigned to lineage AMN004, represented by two haplotypes (NH67 and NH69) differed from the nearest reference specimen KE33 (reference lineage *Wesniphargus* sp. AMN004) by between 0.5 and 0.6% sequence divergence, and from the remaining reference specimens by >12 sequence divergence (Table 2). Lineages AMN004 and AMN008 differed from one another by ≥12% sequence divergence (Table 2).

Phylogenetic analysis- Paramelitidae

The phylogenetic analysis, which included the seven haplotypes of Paramelitidae from Mesa H in addition to 48 reference specimens, placed the Mesa H haplotypes in five distinct genetic lineages (Figure 4). One of the lineages also contained reference specimens. Specifically, haplotype NH12 was placed in the existing lineage AMP009 containing two haplotypes from Barrow Island and Budgie bore (Figure 4). The remaining six haplotypes were placed in four lineages that did not contain reference specimens, so were assigned to the new lineages AMP035, AMP036, AMP037 and AMP038 (Figure 4). Three of those new lineages, AMP036, AMP037 and AMP038, were placed in well supported clades with other reference lineages

(Figure 4). Specifically, lineage AMP036 was placed in a moderately well-supported clade containing reference specimens of *Chydaekata*, and lineage AMP037 was placed in a well-supported clade with lineage AMP032 from Mesa B (Figure 4). Lineage AMP038 was placed in a well-supported clade containing lineage AMP033 from Mesa C (Figure 4). The remaining new lineage, AMP035, did not show close relationships to reference specimens (Figure 4).

Differentiation between lineages –Paramelitidae

The Mesa H haplotype NH12 that was assigned to lineage AMP009 differed from the reference specimens in lineage AMP009 by 0.9 to 1.1% sequence divergence and from the remaining reference specimens by >12% sequence divergence (Table 3). Haplotype NH53D, which was assigned to the new lineage AMP037, differed from the nearest reference specimen, IS39 in lineage AMP032, by 4.1% sequence divergence and from the remaining reference specimens by approximately 8% sequence divergence (Table 3). Specifically, it differed from specimens in lineage AMP023 by between 7.9 and 8.0% sequence divergence (Table 3). Haplotypes NH54 and NH90, assigned to the new lineage AMP038, differed from the nearest reference specimen, IT25 in lineage AMP033 by between 3.7 and 4.0% sequence divergence and from the remaining reference specimens by >14% (Table 3). The remaining two new lineages, AMP035 and AMP036 differed from the nearest reference specimens by >17% sequence divergence (Table 3).

Phylogenetic analysis- Melitidae/ Eriopisidae

The phylogenetic analysis, which included the 26 haplotypes of Melitidae/ Eriopisidae from Mesa H, in addition to 52 reference specimens, placed the Mesa H specimens in eight distinct genetic lineages, all but two of which also contained reference specimens from previous surveys in the Pilbara (Figure 5). Specifically, haplotypes NH37 and NH39 were placed in existing lineage AMM006, containing reference specimen IV134 from Warramboo, and haplotype NH104 was placed in lineage AMM022, containing reference specimen IS37 from Red Hill (Figure 5). Haplotype NH63 was placed in existing lineage AMM026, containing reference specimens JN22, JF21 and LI10 from Mesas C and H, and haplotypes NH33 , NH35 and NH38 were placed in lineage AMM004, containing reference specimens IV128, JN05, KE10 and LI11 from Mesa C and Red Hill (Figure 5). Haplotype NH36 was placed in existing lineage AMM031 with specimens LI25, KE05, KD45 and KD55 from Budgie bore and Mesa C (Figure 5). Fifteen haplotypes were placed in existing lineage AMM001 with eight reference specimens from Budgie bore, Mesa H and other bores in the Robe River valley (Figure 5).

Three haplotypes from Mesa H were placed in two lineages that did not contain any reference specimens. Specifically, haplotype NH62 was placed in a distinct lineage that did not contain any reference specimens and was assigned to the new lineage AMM032 (Figure 5). Likewise, NH46 and NH 110 were placed in a second distinct lineage that did not contain any reference specimens and were assigned to lineage AMM033 (Figure 5).

Three of the lineages, AMM001, AMM026, and AMM031 were placed in well supported clades with other reference lineages (Figure 5). Specifically, lineage AMM001 was placed in a large, well-supported clade containing multiple lineages, AMM025, AMM024, AMM029, AMM030 and AMM002 (Figure 5). Lineage AMM026 was placed in a well-supported clade containing reference lineage AMM021 from Red Hill, and lineage AMM031 was placed in a well-supported clade with lineage AMP027 from Budgie bore, and more distantly, with the AMM001 lineage complex (Figure 5). The remaining lineages did not show close relationships to reference specimens (Figure 5), although both lineage AMM026 and AMM004 showed significant relationships with reference specimens of *Nedsia*, suggesting they may belong to that genus.

Differentiation between lineages – Melitidae/Eriopisidae

The six Melitidae/Eriopisidae lineages detected at Mesa H that were assigned to existing lineages AMM001, AMM004, AMM006, AMM022, AMM026 and AMM031 differed from the nearest reference specimens by ≤2.5%, with the exception of lineage AMM031 where distances between haplotypes ranged from 0 – 3.5% (Table 4). Lineages AMM004, AMM006 and AMM022 differed from the remaining reference specimens by >9.5% (Table 4). Lineage AMM026 formed a well-supported clade with AMM021 and differed from that lineage by 4.6%, and from the remaining reference specimens by >8% (Table 4).

Lineage AMM031 formed a well-supported clade with AMM027 and differed from that lineage by 4% (Table 5). Lineage AMM001 formed a well-supported clade with multiple lineages (=AMM001 lineage complex) as well as with lineage complex AMM031 + AMM027 (Figure 5). Genetic distances between specimens in lineage complex AMM001 (enclosed by a dashed red box in Figure 5), ranged from 0 – 7.8% and the mean was 4.9% sequence divergence.

Haplotype NH62, in the new lineage AMM032, differed from the reference specimens by >14% sequence divergence (Table 4). Haplotypes NH46 and NH110, in the new lineage AMM033, differed from the reference specimens by >9% sequence divergence (Table 4).

Conclusions

COI is widely considered to show suitable variation to distinguish species (Hebert et al., 2003a). In a comparison of COI sequences for over 13,000 pairs of taxa, Hebert et al (2003b) found a mean of 11.1% sequence divergence between distinct species. Nearly 80% of the comparisons showed that species pairs differed from one another by greater than 8% sequence divergence. However, a taxon by taxon approach, examining the amount of phylogenetic variation within and between species is the most widely accepted method of defining species.

Neoniphargidae

Two lineages of Neoniphargidae, AMN004 and AMN008, were detected at Mesa H during the current collection phase, both of which have been detected previously in the Pilbara. The two lineages differ from other reference lineages by >12% sequence divergence, thus they are likely to correspond to two distinct species. Lineage AMN004 is tentatively assigned to the genus *Wesniphargus*, owing to it containing a reference specimen from a bore at Mesa H where another individual was assigned to that genus, while lineage AMN008 has been detected previously at Mesa C and other sites in the Robe Valley.

AMN004 = species detected previously at Mesa H; may belong to the genus *Wesniphargus*.

AMN008 = species detected previously in the Robe Valley at Dave's and Budgie bores in the Robe Valley.

Paramelitidae

Five lineages of Paramelitidae were detected at Mesa H, differing from one another by >15%, indicating that each is likely to represent a distinct species. One of the lineages has been detected previously (AMP009) and four appear to be new (AMP035, AMP036, AMP037 and AMP038), based on the material available for comparison. Of the four new lineages, two (AMP037 and AMP038) showed close relationships with other lineages. Specifically, lineage AMP037 formed a well-supported clade with lineage AMP032 from Mesa B and differed from it by 4.1% sequence divergence. While there are two lineages present, we cannot say if they represent one or two species, based on the current information; for this reason we will refer to the clade as a species complex. Similarly, lineage AMP038 formed a well-supported clade with lineage AMP033 from Mesa C, and differed from it by between 3.7 and 4.1%, again suggesting the presence of a species complex – two distinct lineages represented by an unknown number of species. Further research into these groups is necessary to define species boundaries.

AMP009: species previously detected at Barrow Island and Budgie bore
AMP035; new lineage and species, forms poorly supported clade with a reference specimen of *Yilgarus*
AMP036; new lineage and species, forms moderately well-supported clade with reference specimens of *Chydaekata*
AMP037; new lineage; belongs to a species complex with lineage AMP032 detected previously at Red Hill
AMP038; new lineage; belongs to a species complex with lineage AMP033 detected previously at Buckland Hill

Melitidae/Eriopisidae

Eight lineages of Melitidae/Eriopisidae were detected at Mesa H, six of which were assigned to existing lineages. With the exception of distances between lineages AMM001 and AMM031, the lineages differed from one another by >9.0% sequence divergence, indicating that each is likely to represent a distinct species. One of the lineages, AMM026, formed a well-supported clade with reference lineage AMM021 and differed from that lineage by 4.6%. While there are two lineages present, we cannot say if they represent one or two species, based on the current information; for this reason we will refer to the clade as a species complex. Further research into this group is necessary to define species boundaries.

Lineages AMM001 and AMM031 formed a well-supported clade with one another and with multiple, closely related lineages that require further consideration (enclosed by a dashed red box in Figure 5). The specimens in this group differed by <5% mean sequence divergence (range = 0 – 7.8%). While there are clearly multiple lineages present, we cannot say how many species they represent, based on the current information; for this reason we will refer to the clade as a species complex. Further research into this group is necessary to define species boundaries.

AMM004 = species detected previously at Mesa H and Dave's bore in the Robe Valley.
AMM006 = species detected previously at Warramboo.
AMM022 = species detected previously at Red Hill.
AMM026 = lineage detected previously at Mesa C and Mesa H; forms a species complex with lineage AMM021 from Red Hill

AMM001
AMM031
} = large species complex comprised of multiple lineages; relationships among the clade members requires further investigation.

AMM032 = new lineage and species based on the material available for comparison
AMM033 = new lineage and species based on the material available for comparison

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Table 1. Specimens of Amphipoda used in the present study and the lineage to which they were assigned, based on variation at the COI gene. * = new lineage this study

Cap #	Site name	Tracking number	Helix ID	Lineage
1	Budgie	Budgie-20171212-01	NH01	no data
1	Budgie	Budgie-20171212-01	NH02	no data
1	Budgie	Budgie-20171212-01	NH03	no data
1	Budgie	Budgie-20171212-01	NH04	AMM001
1	Budgie	Budgie-20171212-01	NH05	no data
1	Budgie	Budgie-20171212-01	NH06	AMM001
1	Budgie	Budgie-20171212-01	NH07	no data
1	Budgie	Budgie-20171212-01	NH08	AMN008
1	Budgie	Budgie-20171212-01	NH09	AMM001
1	Budgie	Budgie-20171212-01	NH10	no data
1	Budgie	Budgie-20171212-01	NH11	AMM001
1	Budgie	Budgie-20171212-01	NH12	AMP009
1	Budgie	Budgie-20171212-01	NH13	no data
1	Budgie	Budgie-20171212-01	NH14	no data
1	Budgie	Budgie-20171212-01	NH15	AMM001
1	Budgie	Budgie-20171212-01	NH16	no data
1	Budgie	Budgie-20171212-01	NH17	no data
1	Budgie	Budgie-20171212-01	NH18	no data
1	Budgie	Budgie-20171212-01	NH19	no data
1	Budgie	Budgie-20171212-01	NH20	AMN008
1	Budgie	Budgie-20171212-01	NH21	no data
1	Budgie	Budgie-20171212-01	NH22	no data
1	Budgie	Budgie-20171212-01	NH23	AMM001
1	Budgie	Budgie-20171212-01	NH24	no data
1	Budgie	Budgie-20171212-01	NH25	no data
1	Budgie	Budgie-20171212-01	NH26	no data
1	Budgie	Budgie-20171212-01	NH27	AMN008
1	Budgie	Budgie-20171212-01	NH28	AMN008
1	Budgie	Budgie-20171212-01	NH29	AMN008
1	Budgie	Budgie-20171212-01	NH30	AMM001
1	Budgie	Budgie-20171212-01	NH31	no data
1	Budgie	Budgie-20171212-01	NH32	AMN008
7	200	200-20171212-03	NH33	AMM004
7	200	200-20171212-03	NH34	AMM004
7	200	200-20171212-03	NH35	AMM004
7	200	200-20171212-03	NH36	AMM031
9	MB16MEC0009	MB16MEC0009-20171212-02	NH37	AMM006
9	MB16MEC0009	MB16MEC0009-20171212-02	NH38	AMM004
14	MB16MEC0008	MB16MEC0008-20171212-03	NH39	AMM006
16	MB17MEH0010	MB17MEH0010-20171212-01	NH40	AMM033*
16	MB17MEH0010	MB17MEH0010-20171212-01	NH41	AMM033*
16	MB17MEH0010	MB17MEH0010-20171212-01	NH42	AMM033*

16	MB17MEH0010	MB17MEH0010-20171212-01	NH43	no data
19	MB17MEH0009	MB17MEH0009-20171212-02	NH44	AMM033*
19	MB17MEH0009	MB17MEH0009-20171212-02	NH45	AMM033*
19	MB17MEH0009	MB17MEH0009-20171212-02	NH46	AMM033*
19	MB17MEH0009	MB17MEH0009-20171212-02	NH47	AMM033*
19	MB17MEH0009	MB17MEH0009-20171212-02	NH48	AMM033*
19	MB17MEH0009	MB17MEH0009-20171212-02	NH49	AMM033*
19	MB17MEH0009	MB17MEH0009-20171212-02	NH50	AMM033*
19	MB17MEH0009	MB17MEH0009-20171212-02	NH51	AMM033*
22	BC186	BC186-20171213-03	NH52	no data
22	BC186	BC186-20171213-03	NH53	AMP037*
25	25	25-20171213-02	NH54	AMP038*
27	31	31-20171213-02	NH55	AMM001
27	31	31-20171213-02	NH56	AMM001
27	31	31-20171213-02	NH57	AMM001
27	31	31-20171213-02	NH58	AMM001
27	31	31-20171213-02	NH59	AMM001
27	31	31-20171213-02	NH60	AMM001
27	31	31-20171213-02	NH61	AMM001
27	31	31-20171213-02	NH62	AMM032*
27	31	31-20171213-02	NH63	AMM026
27	31	31-20171213-02	NH64	AMM026
36	JW024	JW024-20171213-06	NH65	AMM001
36	JW024	JW024-20171213-06	NH66	no data
36	JW024	JW024-20171213-06	NH67	AMN004
36	JW024	JW024-20171213-06	NH68	AMN004
36	JW024	JW024-20171213-06	NH69	AMN004
36	JW024	JW024-20171213-06	NH70	AMM001
41	RR01	RR01-20171214-05	NH71	no data
41	RR01	RR01-20171214-05	NH72	AMM001
41	RR01	RR01-20171214-05	NH73	AMM001
41	RR01	RR01-20171214-05	NH74	AMM001
41	RR01	RR01-20171214-05	NH75	AMM001
41	RR01	RR01-20171214-05	NH76	AMM001
41	RR01	RR01-20171214-05	NH77	AMM001
41	RR01	RR01-20171214-05	NH78	AMP036*
41	RR01	RR01-20171214-05	NH79	AMM001
41	RR01	RR01-20171214-05	NH80	AMM001
41	RR01	RR01-20171214-05	NH81	AMM001
41	RR01	RR01-20171214-05	NH82	AMP035*
41	RR01	RR01-20171214-05	NH83	AMM001
41	RR01	RR01-20171214-05	NH84	AMM001
41	RR01	RR01-20171214-05	NH85	AMM001
41	RR01	RR01-20171214-05	NH86	AMM001
41	RR01	RR01-20171214-05	NH87	AMM001

41	RR01	RR01-20171214-05	NH88	AMP035*
41	RR01	RR01-20171214-05	NH89	AMM001
41	RR01	RR01-20171214-05	NH90	AMP038*
41	RR01	RR01-20171214-05	NH91	no data
41	RR01	RR01-20171214-05	NH92	AMP035*
41	RR01	RR01-20171214-05	NH93	no data
41	RR01	RR01-20171214-05	NH94	AMM001
41	RR01	RR01-20171214-05	NH95	AMM001
41	RR01	RR01-20171214-05	NH96	AMM001
41	RR01	RR01-20171214-05	NH97	AMP035*
41	RR01	RR01-20171214-05	NH98	AMM001
41	RR01	RR01-20171214-05	NH99	AMM001
41	RR01	RR01-20171214-05	NH100	AMM001
41	RR01	RR01-20171214-05	NH101	no data
41	RR01	RR01-20171214-05	NH102	AMP035*
41	RR01	RR01-20171214-05	NH103	AMP035*
45	MB17MEH0007	MB17MEH0007-20171214-02	NH104	AMM022
45	MB17MEH0007	MB17MEH0007-20171214-02	NH105	AMM033*
45	MB17MEH0007	MB17MEH0007-20171214-02	NH106	AMM033*
45	MB17MEH0007	MB17MEH0007-20171214-02	NH107	AMM033*
45	MB17MEH0007	MB17MEH0007-20171214-02	NH108	AMM033*
45	MB17MEH0007	MB17MEH0007-20171214-02	NH109	AMM033*
45	MB17MEH0007	MB17MEH0007-20171214-02	NH110	AMM033*
45	MB17MEH0007	MB17MEH0007-20171214-02	NH111	AMM033*
45	MB17MEH0007	MB17MEH0007-20171214-02	NH112	no data
45	MB17MEH0007	MB17MEH0007-20171214-02	NH113	AMM033*
45	MB17MEH0007	MB17MEH0007-20171214-02	NH114	AMM033*
45	MB17MEH0007	MB17MEH0007-20171214-02	NH115	AMM033*
45	MB17MEH0007	MB17MEH0007-20171214-02	NH116	AMM033*
45	MB17MEH0007	MB17MEH0007-20171214-02	NH117	AMM033*
45	MB17MEH0007	MB17MEH0007-20171214-02	NH118	AMM033*
45	MB17MEH0007	MB17MEH0007-20171214-02	NH119	AMM033*
45	MB17MEH0007	MB17MEH0007-20171214-02	NH120	AMM033*
45	MB17MEH0007	MB17MEH0007-20171214-02	NH121	AMM033*

Table 2 (attached). Genetic distances (below diagonal) and standard error (above diagonal, in blue) between haplotypes of Neoniphargidae (Amphipoda) detected at Mesa H and the reference lineages as shown in Figure 3. Distances between the Mesa H haplotypes and the reference specimens are highlighted in yellow.

Specimen ID	NH20	NH29	NH32	NH67	NH69	IV100	IV129	JN08	KC315635	KC315646	KD39	KD41	KE07	KE18	KE28	KE33	KJ64	LI20
NH20 Budgie-20171212-01 AMN008		0.002	0.001	0.012	0.012	0.004	0.013	0.003	0.017	0.017	0.003	0.018	0.002	0.015	0.012	0.012	0.003	0.002
NH29 Budgie-20171212-01 AMM008	0.003		0.003	0.013	0.012	0.004	0.013	0.003	0.017	0.016	0.002	0.018	0.003	0.015	0.012	0.013	0.004	0.002
NH32 Budgie-20171212-01 AMM008	0.001	0.004		0.013	0.012	0.002	0.013	0.002	0.017	0.017	0.003	0.018	0.002	0.015	0.012	0.012	0.004	0.003
NH67 JW024 20171213 06 AMM004	0.120	0.121	0.122		0.002	0.013	0.012	0.012	0.016	0.017	0.013	0.018	0.012	0.014	0.012	0.003	0.012	0.013
NH69 JW024 20171213 06 AMM004	0.119	0.120	0.121	0.001		0.013	0.012	0.012	0.016	0.017	0.013	0.018	0.012	0.014	0.013	0.002	0.012	0.013
IV100 Daves-20150604-01 AMN008	0.014	0.014	0.004	0.132	0.131		0.013	0.000	0.017	0.016	0.002	0.018	0.000	0.015	0.012	0.012	0.003	0.003
IV129 DAVES-20150930-04 AMN007	0.155	0.156	0.148	0.157	0.156	0.149		0.013	0.017	0.016	0.014	0.017	0.013	0.015	0.008	0.012	0.013	0.013
JN08 200-20160505-02C AMN008	0.007	0.007	0.004	0.126	0.125	0.000	0.149		0.017	0.017	0.002	0.018	0.000	0.015	0.012	0.012	0.003	0.003
KC315635 Niphargus fontanus isolate UK HT3	0.205	0.205	0.205	0.200	0.202	0.205	0.190	0.205		0.015	0.018	0.020	0.017	0.015	0.017	0.016	0.016	0.017
KC315646 Niphargus glenniei isolate HT4	0.215	0.213	0.213	0.210	0.210	0.213	0.190	0.213	0.167		0.017	0.018	0.017	0.016	0.016	0.017	0.017	0.017
KD39 Budgie-20150930-01 Amphipoda	0.006	0.003	0.005	0.127	0.125	0.003	0.156	0.003	0.216	0.216		0.018	0.002	0.015	0.013	0.013	0.003	0.002
KD41 Budgie-20150930-01 AMN001	0.242	0.242	0.238	0.251	0.250	0.240	0.246	0.240	0.251	0.246	0.237		0.018	0.018	0.017	0.018	0.018	0.018
KE07 200-20160910-01 AMN008	0.006	0.006	0.004	0.124	0.123	0.000	0.149	0.000	0.205	0.213	0.003	0.241		0.015	0.012	0.012	0.003	0.003
KE18 RR1-20160910-01 AMN002	0.192	0.193	0.188	0.187	0.190	0.189	0.173	0.189	0.196	0.215	0.191	0.258	0.189		0.015	0.013	0.015	0.015
KE28 32-20160910-02 AMN003	0.159	0.161	0.155	0.161	0.160	0.156	0.063	0.156	0.197	0.199	0.163	0.253	0.156	0.184		0.012	0.012	0.013
KE33 25-20160910-01 AMN004	0.124	0.126	0.122	0.006	0.005	0.121	0.151	0.121	0.199	0.210	0.123	0.245	0.121	0.183	0.156		0.012	0.013
KJ64 Budgiebore-20161210-01 AMN008	0.007	0.007	0.007	0.123	0.122	0.006	0.151	0.006	0.205	0.211	0.006	0.243	0.006	0.187	0.158	0.122		0.003
LI20 MEAWO4086-20170308-01 AMN008	0.005	0.003	0.006	0.128	0.127	0.005	0.159	0.005	0.209	0.219	0.003	0.245	0.005	0.199	0.163	0.128	0.008	

Table 3 (attached). Genetic distances (below diagonal) and standard error (above diagonal, in blue) between haplotypes of Paramelitidae (Amphipoda) detected at Mesa H and the reference lineages as shown in Figure 4. Distances between the Mesa H haplotypes and the reference specimens are highlighted in yellow.

Specimen ID	NH12	NH53D	NH54	NH78	NH90	NH92	NH97	AM10	AM15	AM2	AM4	AM9	BX32	DF3	DQ255962	DQ255989	DQ490126	DQ838024	DQ838031	DQ838032	DZ24	EF118194	EF118232	EF558852	FU1
NH12 Budgie-201 AMP00971212-01		0.012	0.016	0.017	0.016	0.016	0.015	0.015	0.015	0.016	0.015	0.015	0.018	0.016	0.020	0.016	0.019	0.017	0.015	0.015	0.013	0.018	0.015	0.015	0.016
NH53D BC186-20171213-03 AMP037	0.149		0.013	0.015	0.013	0.016	0.015	0.015	0.017	0.016	0.016	0.015	0.019	0.016	0.020	0.015	0.020	0.015	0.018	0.018	0.011	0.017	0.015	0.017	0.017
NH54 25-20171213-02 AMP038	0.165	0.150		0.018	0.002	0.014	0.014	0.013	0.016	0.017	0.018	0.016	0.018	0.017	0.019	0.018	0.019	0.018	0.018	0.016	0.013	0.016	0.015	0.018	0.018
NH78 RR01-20171214-05 AMP036	0.227	0.240	0.244		0.018	0.016	0.015	0.016	0.015	0.016	0.016	0.019	0.017	0.015	0.018	0.015	0.014	0.014	0.017	0.016	0.017	0.016	0.018	0.017	0.016
NH90 RR01-20171214-05 AMP038	0.165	0.150	0.003	0.244		0.014	0.014	0.013	0.016	0.017	0.018	0.016	0.018	0.018	0.019	0.018	0.019	0.018	0.018	0.016	0.013	0.017	0.015	0.018	0.018
NH92 RR01-20171214-05 AMP	0.220	0.215	0.206	0.229	0.206		0.004	0.016	0.015	0.015	0.016	0.017	0.018	0.017	0.021	0.017	0.021	0.017	0.018	0.016	0.016	0.016	0.014	0.017	0.016
NH97 RR01-20171214-05	0.206	0.219	0.210	0.220	0.210	0.008		0.016	0.014	0.014	0.015	0.016	0.018	0.016	0.021	0.016	0.021	0.017	0.017	0.015	0.016	0.016	0.013	0.017	0.015
AM10 Paramelitidae sp 2c Weeli Wolli AMP020	0.256	0.258	0.218	0.233	0.219	0.214	0.207		0.015	0.016	0.014	0.014	0.016	0.016	0.020	0.016	0.018	0.017	0.017	0.017	0.014	0.015	0.015	0.016	0.014
AM15 Paramelitidae sp B12 Christmas Creek AMP019	0.226	0.246	0.209	0.218	0.208	0.209	0.207	0.217		0.016	0.015	0.015	0.015	0.015	0.020	0.015	0.016	0.015	0.017	0.015	0.017	0.017	0.015	0.014	0.014
AM2 Paramelitidae sp B14 Investigator AMP025	0.224	0.245	0.232	0.245	0.232	0.256	0.248	0.238	0.214		0.016	0.017	0.015	0.016	0.019	0.018	0.020	0.016	0.015	0.018	0.016	0.018	0.014	0.016	0.015
AM4 Paramelitidae sp Mindy AMP018	0.211	0.242	0.227	0.235	0.227	0.240	0.238	0.245	0.193	0.211		0.014	0.016	0.014	0.019	0.016	0.017	0.016	0.015	0.017	0.017	0.015	0.015	0.016	0.015
AM9 Paramelitidae sp 2c Weeli Wolli AMP021	0.226	0.243	0.213	0.253	0.214	0.217	0.214	0.190	0.208	0.238	0.245		0.017	0.015	0.017	0.015	0.018	0.016	0.015	0.013	0.015	0.014	0.015	0.017	0.015
BX32 PES-5173 Paramelitidae MH1 AMP026	0.219	0.233	0.207	0.221	0.209	0.227	0.219	0.226	0.178	0.204	0.195	0.207		0.016	0.018	0.016	0.016	0.018	0.017	0.018	0.018	0.017	0.014	0.019	0.016
DF3 9776 Amphipoda D2	0.230	0.236	0.215	0.205	0.215	0.237	0.237	0.235	0.229	0.250	0.221	0.210	0.209		0.017	0.014	0.016	0.017	0.016	0.017	0.017	0.016	0.015	0.017	0.015
DQ255962 Molina pleobranchos	0.230	0.241	0.221	0.217	0.223	0.232	0.232	0.226	0.243	0.278	0.250	0.219	0.226	0.199		0.017	0.016	0.018	0.017	0.020	0.018	0.020	0.018	0.020	0.018
DQ255989 Chydaekata sp. Marillana	0.236	0.255	0.208	0.201	0.207	0.216	0.219	0.231	0.207	0.260	0.234	0.226	0.210	0.190	0.193		0.017	0.013	0.016	0.015	0.016	0.015	0.016	0.017	0.015
DQ490126 Pilbarus millsi	0.241	0.256	0.219	0.191	0.221	0.249	0.249	0.245	0.226	0.245	0.217	0.223	0.234	0.197	0.210	0.174		0.015	0.018	0.019	0.019	0.017	0.017	0.016	0.017
DQ838024 Chydaekata acuminata	0.230	0.244	0.208	0.158	0.207	0.229	0.236	0.248	0.212	0.244	0.230	0.225	0.224	0.219	0.215	0.164	0.161		0.017	0.016	0.016	0.017	0.018	0.017	0.016
DQ838031 Maarrka etheli	0.225	0.252	0.224	0.236	0.221	0.265	0.261	0.254	0.231	0.229	0.231	0.229	0.233	0.228	0.230	0.240	0.236	0.228		0.016	0.018	0.018	0.016	0.014	0.016
DQ838032 Maarrka weeliwollii	0.202	0.241	0.197	0.233	0.196	0.226	0.219	0.243	0.199	0.234	0.225	0.203	0.216	0.226	0.237	0.221	0.232	0.184	0.194		0.018	0.016	0.016	0.014	0.016
DZ24 GW05.0413-04 AMP023	0.132	0.079	0.160	0.224	0.160	0.215	0.210	0.233	0.212	0.239	0.237	0.231	0.224	0.224	0.230	0.236	0.243	0.230	0.230	0.214		0.017	0.015	0.015	0.016
EF118194 Yilgarus sp	0.240	0.236	0.196	0.214	0.196	0.203	0.199	0.228	0.216	0.254	0.243	0.228	0.202	0.213	0.234	0.216	0.224	0.222	0.236	0.211	0.209		0.015	0.015	0.015
EF118232 Yilgarus sp	0.195	0.197	0.196	0.217	0.196	0.168	0.166	0.220	0.194	0.223	0.212	0.217	0.176	0.223	0.237	0.223	0.223	0.215	0.238	0.200	0.209	0.197		0.015	0.015
EF558852 Paramelitidae sp. 3	0.231	0.229	0.211	0.213	0.213	0.226	0.223	0.222	0.213	0.242	0.236	0.204	0.219	0.217	0.224	0.216	0.215	0.210	0.202	0.194	0.207	0.211	0.202		0.012
FU1 Paramelitidae sp KGST0006 AMP024	0.233	0.256	0.216	0.223	0.214	0.212	0.215	0.220	0.175	0.217	0.184	0.208	0.194	0.221	0.236	0.208	0.223	0.219	0.226	0.217	0.225	0.233	0.197	0.211	
G186 Amphipoda 100152a AE	0.222	0.243	0.216	0.183	0.216	0.242	0.240	0.253	0.217	0.229	0.209	0.222	0.221	0.189	0.205	0.173	0.051	0.177	0.229	0.220	0.230	0.221	0.211	0.203	0.222
G187 Amphipoda 100476 ACAMP011 AMP011	0.211	0.215	0.218	0.248	0.219	0.207	0.205	0.235	0.203	0.227	0.210	0.232	0.222	0.237	0.250	0.252	0.247	0.247	0.244	0.224	0.208	0.213	0.184	0.212	0.213
G193 Amphipoda 100083b	0.244	0.244	0.224	0.211	0.224	0.211	0.214	0.230	0.233	0.251	0.251	0.209	0.228	0.214	0.199	0.201	0.213	0.195	0.247	0.216	0.230	0.218	0.225	0.233	0.235
G444 110717 Paramelitidae sp AF	0.227	0.251	0.232	0.196	0.232	0.251	0.251	0.266	0.230	0.241	0.221	0.226	0.226	0.192	0.200	0.184	0.085	0.181	0.219	0.209	0.249	0.243	0.218	0.213	0.226
G496 111310 Paramelitidae sp NS AMP014	0.144	0.103	0.164	0.223	0.164	0.224	0.218	0.235	0.212	0.233	0.215	0.241	0.212	0.223	0.247	0.242	0.256	0.233	0.226	0.220	0.079	0.219	0.205	0.211	0.229
GK24 MB13YB010-180514-02 AMP030	0.217	0.234	0.186	0.255	0.184	0.229	0.230	0.229	0.190	0.218	0.221	0.202	0.204	0.204	0.224	0.210	0.219	0.219	0.205	0.140	0.208	0.202	0.187	0.179	0.212
GK48 99YJWB02-200514-01	0.236	0.253	0.215	0.204	0.214	0.223	0.226	0.230	0.205	0.256	0.229	0.223	0.209	0.181	0.199	0.006	0.182	0.167	0.243	0.223	0.238	0.220	0.222	0.217	0.208
GK56 YM119-200514-02 AMP029	0.230	0.243	0.217	0.256	0.218	0.213	0.213	0.192	0.211	0.236	0.247	0.010	0.210	0.205	0.213	0.225	0.219	0.222	0.233	0.201	0.229	0.222	0.213	0.207	0.202
GK62 D08YJ188-200514-01 AMP028	0.233	0.226	0.207	0.240	0.206	0.192	0.194	0.171	0.190	0.239	0.229	0.100	0.190	0.197	0.212	0.216	0.224	0.216	0.237	0.210	0.213	0.200	0.207	0.207	0.201
GK7 MB13YB002-180514-03 AMP027	0.217	0.203	0.206	0.224	0.204	0.216	0.216	0.196	0.205	0.215	0.210	0.156	0.177	0.207	0.217	0.210	0.237	0.218	0.226	0.204	0.192	0.220	0.207	0.204	0.208
GK91 TS3DCP1-3 AMP031	0.206	0.229	0.191	0.237	0.189	0.223	0.219	0.236	0.193	0.224	0.218	0.198	0.205	0.211	0.236	0.223	0.230	0.189	0.193	0.017	0.210	0.205	0.197	0.184	0.210
GO21 Yandi MAR03 Paramelitidae Genus 2 sp. B2 AMP033	0.255	0.253	0.215	0.230	0.217	0.212	0.207	0.012	0.217	0.236	0.244	0.187	0.224	0.231	0.219	0.228	0.241	0.244	0.255	0.242	0.231	0.228	0.220	0.219	0.221
GO29 Yandi WW3 Paramelitidae Genus 2 sp. B2	0.235	0.245	0.220	0.253	0.222	0.220	0.219	0.192	0.211	0.236	0.245	0.007	0.207	0.205	0.221	0.231	0.224	0.227	0.231	0.199	0.234	0.228	0.217	0.205	0.207
GO42 Marillana01 Paramelitidae sp. 2 (DEC code)	0.235	0.248	0.210	0.201	0.209	0.218	0.222	0.227	0.204	0.253	0.230	0.223	0.207	0.182	0.195	0.002	0.176	0.163	0.242	0.220	0.234	0.217	0.222	0.217	0.205
GO45 Plant Paramelitidae sp. 2 AMP034	0.243	0.248	0.228	0.250	0.230	0.216	0.216	0.196	0.214	0.239	0.257	0.031	0.207	0.208	0.221	0.236	0.236	0.236	0.239	0.214	0.226	0.225	0.223	0.211	0.211
GO82 MNEW1upstream Paramelitidae sp. B25 nr. B16 AMP032	0.220	0.228	0.218	0.197	0.218	0.207	0.206	0.207	0.178	0.215	0.193	0.195	0.172	0.208	0.234	0.210	0.230	0.207	0.225	0.198	0.221	0.227	0.166	0.208	0.180
GU111906 Kruptus linnaei	0.230	0.238	0.234	0.246	0.232	0.263	0.261	0.259	0.253	0.248	0.251	0.251	0.234	0.246	0.243	0.215	0.249	0.246	0.250	0.240	0.232	0.244	0.253	0.226	0.234
IS39 RHCMB042 20150910 02 AMP032	0.135	0.041	0.146	0.222	0.146	0.201	0.193	0.231	0.217	0.228	0.216	0.226	0.219	0.226	0.247	0.245	0.241	0.231	0.236	0.220	0.081	0.216	0.186	0.214	0.241
IT25 BHRC433.20151014 01 AMP033	0.161	0.188	0.037	0.240	0.040	0.220	0.219	0.233	0.238	0.240	0.228	0.212	0.209	0.248	0.232	0.226	0.246	0.216	0.214	0.183	0.155	0.195	0.224	0.214	0.231
IV115 TOBRC009 Amphipoda AMP023	0.128	0.080	0.160	0.226	0.160	0.218	0.213	0.239	0.218	0.232	0.240	0.229	0.220	0.234	0.226	0.233	0.239	0.231	0.229	0.213	0.013	0.218	0.208	0.208	0.218
J9 3 LN046 Lower Shaw River S2 SS AMP006	0.152	0.119	0.176	0.223	0.178	0.204	0.204	0.236	0.230	0.245	0.206	0.215	0.220	0.245	0.232	0.223	0.249	0.223	0.228	0.217	0.108	0.221	0.197	0.200	0.226
J9 7 LN040 Lower Shaw River S1 SS AMP007	0.230	0.232	0.200	0.258	0.202	0.217	0.217	0.212	0.191	0.245	0.230	0.176	0.192	0.221	0.234	0.215	0.241	0.249	0.213	0.195	0.215	0.215	0.182	0.208	0.182
JF19 RC13MEH0041-20160119-01 AMP003	0.140	0.140	0.147	0.226	0.146	0.204	0.195	0.239	0.205	0.221	0.201	0.217	0.189	0.210	0.236	0.220	0.243	0.218	0.223	0.201	0.126	0.199	0.174	0.217	0.210
KD48 Budgie-20150930-01 AMP009	0.011	0.152	0.162	0.241	0.163	0.219	0.214	0.252	0.223	0.225	0.204	0.220	0.212	0.217	0.223	0.230	0.237	0.228	0.220	0.202	0.131	0.236	0.196	0.222	0.228

KD63 TOBRC0099-20150930-01 AMP023	0.131	0.080	0.160	0.227	0.160	0.218	0.215	0.241	0.220	0.235	0.241	0.232	0.223	0.232	0.226	0.233	0.239	0.232	0.230	0.216	0.013	0.217	0.207	0.209	0.219
KJ43 MB16WARR0009-02 lin 1 Paramel	0.131	0.079	0.162	0.226	0.162	0.213	0.210	0.235	0.215	0.241	0.241	0.230	0.227	0.226	0.228	0.235	0.243	0.231	0.232	0.217	0.005	0.212	0.209	0.209	0.223
L10 S6-204 Paramelitidae AMP009	0.009	0.138	0.166	0.245	0.166	0.221	0.217	0.259	0.234	0.238	0.217	0.231	0.222	0.224	0.228	0.228	0.241	0.231	0.228	0.210	0.136	0.236	0.193	0.228	0.240
Q1 HCO2	0.255	0.255	0.242	0.175	0.242	0.239	0.237	0.255	0.215	0.263	0.261	0.212	0.231	0.220	0.240	0.185	0.176	0.067	0.223	0.212	0.266	0.242	0.220	0.215	0.247
Q3 WBGW010 AMP015	0.247	0.255	0.225	0.241	0.225	0.241	0.241	0.223	0.210	0.218	0.196	0.218	0.225	0.241	0.251	0.215	0.246	0.236	0.236	0.231	0.239	0.241	0.225	0.249	0.037
W6 Chykaeta Ethel Creek AMP017	0.229	0.240	0.234	0.257	0.234	0.238	0.233	0.250	0.232	0.218	0.215	0.232	0.217	0.230	0.252	0.246	0.254	0.245	0.237	0.220	0.221	0.233	0.205	0.205	0.220

G186	G187	G193	G444	G496	GK24	GK48	GK56	GK62	GK7	GK91	GO21	GO29	GO42	GO45	GO82	GU111906	IS39	IT25	IV115	J93	J97	JF19	KD48	KD63	KJ43	L10	Q1	Q3	W6
0.019	0.015	0.017	0.015	0.012	0.014	0.016	0.016	0.015	0.015	0.015	0.015	0.016	0.016	0.016	0.013	0.022	0.011	0.019	0.012	0.016	0.017	0.014	0.004	0.012	0.013	0.004	0.023	0.024	0.016
0.019	0.015	0.018	0.018	0.011	0.016	0.016	0.015	0.016	0.016	0.018	0.014	0.016	0.015	0.015	0.016	0.020	0.007	0.019	0.011	0.013	0.017	0.015	0.013	0.010	0.010	0.013	0.025	0.023	0.017
0.019	0.015	0.019	0.019	0.015	0.017	0.018	0.016	0.016	0.018	0.016	0.013	0.016	0.018	0.017	0.016	0.021	0.013	0.011	0.013	0.016	0.016	0.015	0.017	0.013	0.013	0.017	0.024	0.022	0.016
0.014	0.018	0.015	0.014	0.017	0.017	0.015	0.018	0.016	0.017	0.016	0.015	0.018	0.015	0.018	0.016	0.020	0.016	0.024	0.017	0.019	0.020	0.016	0.019	0.017	0.016	0.019	0.020	0.023	0.018
0.019	0.015	0.019	0.019	0.015	0.017	0.018	0.016	0.016	0.018	0.016	0.014	0.016	0.018	0.017	0.016	0.020	0.013	0.010	0.014	0.016	0.017	0.015	0.017	0.014	0.013	0.017	0.024	0.022	0.016
0.018	0.016	0.016	0.019	0.018	0.017	0.017	0.017	0.016	0.018	0.017	0.015	0.018	0.017	0.017	0.015	0.020	0.016	0.021	0.016	0.018	0.016	0.016	0.017	0.016	0.016	0.017	0.023	0.022	0.015
0.018	0.016	0.016	0.018	0.017	0.015	0.016	0.016	0.015	0.017	0.015	0.015	0.017	0.016	0.016	0.014	0.020	0.015	0.021	0.016	0.018	0.016	0.014	0.017	0.016	0.016	0.017	0.023	0.022	0.014
0.016	0.016	0.016	0.016	0.014	0.015	0.016	0.014	0.013	0.013	0.016	0.004	0.014	0.016	0.014	0.015	0.018	0.015	0.021	0.014	0.016	0.014	0.015	0.016	0.014	0.014	0.016	0.024	0.019	0.015
0.015	0.014	0.015	0.015	0.017	0.014	0.015	0.015	0.015	0.016	0.014	0.015	0.015	0.015	0.015	0.014	0.019	0.017	0.023	0.017	0.019	0.016	0.016	0.017	0.017	0.017	0.018	0.020	0.022	0.015
0.016	0.014	0.018	0.015	0.015	0.015	0.017	0.017	0.016	0.015	0.017	0.016	0.017	0.017	0.017	0.014	0.017	0.016	0.022	0.016	0.018	0.017	0.016	0.017	0.016	0.016	0.017	0.025	0.022	0.013
0.016	0.015	0.016	0.016	0.015	0.015	0.015	0.015	0.016	0.016	0.016	0.014	0.014	0.015	0.015	0.014	0.020	0.016	0.022	0.017	0.017	0.017	0.014	0.016	0.017	0.017	0.017	0.024	0.022	0.015
0.016	0.018	0.016	0.016	0.015	0.015	0.015	0.004	0.012	0.014	0.013	0.014	0.003	0.015	0.006	0.015	0.019	0.015	0.022	0.016	0.017	0.013	0.015	0.015	0.016	0.015	0.016	0.022	0.020	0.016
0.016	0.016	0.017	0.015	0.019	0.017	0.016	0.016	0.016	0.015	0.017	0.016	0.017	0.016	0.016	0.015	0.019	0.018	0.021	0.018	0.020	0.018	0.016	0.018	0.018	0.018	0.020	0.023	0.022	0.016
0.016	0.015	0.016	0.017	0.016	0.016	0.013	0.015	0.015	0.014	0.016	0.015	0.015	0.013	0.016	0.014	0.020	0.015	0.023	0.018	0.020	0.017	0.014	0.017	0.017	0.017	0.018	0.022	0.021	0.015
0.016	0.019	0.017	0.016	0.019	0.017	0.017	0.017	0.019	0.018	0.019	0.020	0.018	0.017	0.018	0.018	0.020	0.020	0.027	0.018	0.018	0.016	0.020	0.019	0.018	0.018	0.019	0.022	0.022	0.020
0.016	0.015	0.015	0.015	0.018	0.017	0.003	0.016	0.016	0.016	0.016	0.016	0.016	0.001	0.015	0.014	0.019	0.016	0.024	0.016	0.019	0.016	0.017	0.018	0.016	0.015	0.018	0.021	0.020	0.016
0.008	0.018	0.017	0.010	0.019	0.017	0.017	0.018	0.017	0.021	0.018	0.018	0.018	0.017	0.019	0.016	0.020	0.022	0.027	0.019	0.020	0.018	0.019	0.019	0.019	0.019	0.019	0.021	0.023	0.019
0.014	0.018	0.014	0.016	0.017	0.017	0.013	0.017	0.016	0.017	0.015	0.017	0.017	0.013	0.017	0.016	0.019	0.016	0.023	0.016	0.018	0.018	0.016	0.018	0.016	0.016	0.018	0.012	0.022	0.015
0.017	0.016	0.017	0.016	0.017	0.016	0.016	0.015	0.016	0.016	0.016	0.017	0.015	0.016	0.017	0.017	0.020	0.017	0.023	0.017	0.018	0.017	0.016	0.016	0.017	0.017	0.016	0.023	0.023	0.015
0.016	0.017	0.017	0.016	0.018	0.014	0.015	0.013	0.014	0.015	0.005	0.017	0.013	0.015	0.014	0.015	0.018	0.017	0.020	0.018	0.019	0.016	0.016	0.016	0.018	0.017	0.017	0.022	0.023	0.016
0.018	0.015	0.018	0.018	0.010	0.016	0.015	0.016	0.016	0.016	0.017	0.015	0.016	0.015	0.015	0.016	0.018	0.011	0.017	0.004	0.013	0.014	0.014	0.013	0.004	0.002	0.014	0.024	0.023	0.018
0.017	0.015	0.016	0.017	0.017	0.015	0.015	0.014	0.015	0.016	0.016	0.015	0.014	0.015	0.015	0.015	0.021	0.017	0.020	0.017	0.019	0.017	0.017	0.020	0.017	0.017	0.020	0.021	0.020	0.014
0.017	0.015	0.017	0.016	0.015	0.015	0.015	0.015	0.015	0.017	0.016	0.015	0.015	0.016	0.015	0.013	0.020	0.015	0.021	0.015	0.016	0.017	0.014	0.015	0.015	0.015	0.015	0.024	0.023	0.014
0.015	0.016	0.017	0.016	0.017	0.015	0.017	0.017	0.017	0.018	0.014	0.016	0.017	0.017	0.017	0.017	0.016	0.017	0.021	0.015	0.019	0.017	0.017	0.015	0.015	0.015	0.015	0.022	0.020	0.015
0.016	0.014	0.016	0.015	0.016	0.014	0.015	0.015	0.015	0.016	0.015	0.014	0.015	0.015	0.016	0.014	0.018	0.017	0.022	0.017	0.017	0.016	0.015	0.016	0.017	0.016	0.017	0.022	0.009	0.015
	0.015	0.016	0.010	0.019	0.017	0.016	0.017	0.015	0.018	0.016	0.016	0.016	0.016	0.017	0.015	0.019	0.020	0.025	0.018	0.020	0.018	0.019	0.020	0.018	0.018	0.020	0.019	0.023	0.018
0.229		0.016	0.018	0.016	0.016	0.015	0.018	0.018	0.017	0.016	0.016	0.018	0.015	0.019	0.015	0.018	0.015	0.024	0.015	0.017	0.015	0.014	0.015	0.015	0.015	0.014	0.023	0.019	0.014
0.203	0.248		0.015	0.016	0.016	0.015	0.016	0.016	0.019	0.017	0.016	0.016	0.015	0.016	0.015	0.020	0.018	0.022	0.018	0.021	0.016	0.016	0.019	0.017	0.018	0.020	0.022	0.022	0.016
0.090	0.243	0.196		0.018	0.016	0.014	0.016	0.018	0.018	0.016	0.016	0.016	0.014	0.017	0.016	0.019	0.018	0.022	0.018	0.020	0.019	0.018	0.016	0.018	0.018	0.017	0.022	0.022	0.016
0.237	0.208	0.241	0.254		0.016	0.017	0.016	0.016	0.017	0.017	0.014	0.016	0.017	0.015	0.017	0.018	0.010	0.019	0.010	0.011	0.016	0.013	0.013	0.011	0.010	0.013	0.022	0.022	0.015
0.202	0.207	0.206	0.204	0.212		0.016	0.015	0.015	0.016	0.012	0.015	0.015	0.016	0.015	0.013	0.019	0.015	0.019	0.016	0.018	0.017	0.015	0.015	0.016	0.016	0.017	0.022	0.021	0.014
0.179	0.254	0.199	0.181	0.242	0.190		0.015	0.015	0.015	0.014	0.015	0.015	0.002	0.015	0.013	0.018	0.016	0.023	0.016	0.019	0.017	0.016	0.018	0.015	0.015	0.018	0.020	0.020	0.016
0.220	0.229	0.208	0.226	0.245	0.187	0.208		0.012	0.013	0.013	0.014	0.003	0.015	0.005	0.015	0.019	0.016	0.023	0.017	0.017	0.013	0.015	0.016	0.016	0.016	0.017	0.022	0.020	0.016
0.209	0.215	0.205	0.218	0.227	0.180	0.200	0.099		0.012	0.014	0.012	0.011	0.015	0.012	0.015	0.018	0.015	0.021	0.016	0.018	0.016	0.015	0.017	0.016	0.016	0.018	0.023	0.023	0.016
0.225	0.211	0.232	0.235	0.187	0.186	0.198	0.149	0.128		0.015	0.012	0.013	0.015	0.013	0.016	0.018	0.015	0.021	0.016	0.017	0.017	0.015	0.016	0.016	0.016	0.016	0.023	0.023	0.017
0.224	0.219	0.212	0.207	0.211	0.117	0.209	0.184	0.193	0.184		0.016	0.012	0.014	0.013	0.014	0.017	0.016	0.020	0.017	0.018	0.015	0.015	0.016	0.017	0.017	0.017	0.022	0.023	0.015
0.250	0.235	0.224	0.262	0.233	0.216	0.214	0.177	0.159	0.184	0.222		0.013	0.015	0.013	0.014	0.019	0.015	0.020	0.014	0.016	0.014	0.015	0.015	0.014	0.014	0.016	0.024	0.020	0.015
0.224	0.234	0.211	0.227	0.244	0.190	0.211	0.008	0.096	0.151	0.183	0.176		0.015	0.005	0.015	0.018	0.016	0.022	0.017	0.017	0.013	0.015	0.016	0.016	0.016	0.017	0.022	0.020	0.016
0.174	0.253	0.199	0.181	0.238	0.191	0.004	0.208	0.200	0.194	0.207	0.209	0.212		0.014	0.013	0.019	0.016	0.024	0.016	0.019	0.017	0.016	0.018	0.015	0.015	0.018	0.020	0.020	0.016
0.232	0.232	0.214	0.241	0.247	0.194	0.218	0.028	0.098	0.151	0.197	0.180	0.028	0.216		0.015	0.019	0.016	0.023	0.016	0.018	0.013	0.015	0.016	0.015	0.015	0.018	0.022	0.020	0.016
0.225	0.218	0.227	0.215	0.221	0.191	0.193	0.189	0.189	0.177	0.180	0.192	0.181	0.192	0.192		0.019	0.015	0.022	0.017	0.018	0.017	0.014	0.015	0.016	0.016	0.015	0.022	0.019	0.016
0.228	0.253	0.248	0.246	0.226	0.238	0.219	0.250	0.228	0.228	0.236	0.261	0.250	0.217	0.244	0.257		0.020	0.026	0.018	0.019	0.020	0.018	0.022	0.018	0.018	0.022	0.026	0.021	0.019
0.232	0.203	0.229	0.238	0.089	0.219	0.243	0.231	0.210	0.188	0.211	0.232	0.232	0.238	0.238	0.216	0.244		0.018	0.010	0.012	0.017	0.013	0.012	0.011	0.011	0.013	0.026	0.023	0.015
0.225	0.244	0.224	0.231	0.173	0.195	0.236	0.216	0.204	0.195	0.180	0.228	0.216	0.228	0.224	0.221	0.244	0.166		0.017	0.018	0.022	0.018	0.019	0.017	0.016	0.019	0.024	0.023	0.023
0.229	0.209	0.229	0.242	0.083	0.213	0.235	0.227	0.214	0.194	0.210	0.237	0.232	0.230	0.226	0.219	0.228	0.081	0.149		0.013	0.014	0.014	0.013	0.000	0.003	0.013	0.025	0.022	0.018
0.233	0.223	0.250	0.252	0.076	0.228	0.226	0.224	0.221	0.184	0.210	0.232	0.213	0.224	0.223	0.199	0.239	0.111	0.173	0.109		0.016	0.015	0.016	0.013	0.013	0.016	0.024	0.022	0.017
0.226	0.219	0.219	0.234	0.221	0.193	0.217	0.178	0.178	0.212	0.189	0.212	0.180	0.217	0.176	0.213	0.243	0.232	0.223	0.215	0.224		0.017	0.018	0.014	0.014	0.018	0.021	0.020	0.017
0.222	0.207	0.230	0.233	0.125	0.204	0.217	0.214	0.206	0.191	0.191	0.233	0.217	0.213	0.223	0.203	0.217	0.128	0.151	0.130	0.134	0.204		0.014	0.014	0.013	0.016	0.021	0.022	0.015
0.218	0.201	0.237	0.219	0.138	0.206	0.228	0.222	0.223	0.204	0.195	0.249	0.227	0.227	0.235	0.214	0.232	0.133	0.159	0.129	0.152	0.228	0.136		0.013	0.013	0.003	0.023	0.024	0.016

0.229	0.211	0.230	0.241	0.087	0.213	0.235	0.229	0.216	0.194	0.211	0.238	0.233	0.230	0.227	0.221	0.228	0.084	0.157	0.000	0.109	0.215	0.129	0.133		0.003	0.013	0.025	0.022	0.018
0.232	0.213	0.230	0.248	0.085	0.211	0.236	0.227	0.213	0.192	0.213	0.231	0.231	0.231	0.225	0.222	0.230	0.082	0.162	0.008	0.104	0.215	0.126	0.133	0.008		0.014	0.024	0.023	0.018
0.221	0.202	0.245	0.224	0.143	0.214	0.228	0.233	0.233	0.210	0.207	0.260	0.238	0.226	0.247	0.219	0.236	0.136	0.166	0.133	0.158	0.232	0.143	0.005	0.134	0.134		0.023	0.024	0.017
0.168	0.242	0.215	0.185	0.242	0.226	0.188	0.212	0.218	0.223	0.210	0.253	0.210	0.188	0.218	0.210	0.263	0.253	0.242	0.266	0.240	0.235	0.247	0.250	0.266	0.266	0.255		0.021	0.023
0.233	0.223	0.279	0.239	0.241	0.252	0.223	0.215	0.223	0.220	0.231	0.231	0.215	0.218	0.220	0.204	0.239	0.268	0.228	0.231	0.240	0.191	0.233	0.249	0.231	0.236	0.255	0.245		0.022
0.250	0.213	0.245	0.256	0.223	0.214	0.245	0.233	0.224	0.214	0.208	0.247	0.232	0.244	0.226	0.183	0.263	0.222	0.243	0.224	0.210	0.236	0.223	0.217	0.225	0.222	0.226	0.266	0.239	

Table 4 (attached). Genetic distances (below diagonal) and standard error (above diagonal, in blue) between haplotypes of Melitidae/Eriopisidae (Amphipoda) detected at Mesa H and the reference lineages as shown in Figure 5. Distances between the Mesa H specimens and the reference specimens are highlighted in yellow.

Specimen ID	NH37	NH39	NH104	NH62	NH63	NH46	NH110	NH33	NH35	NH38	NH36	NH65	NH70	NH15	NH06	NH09	NH23	NH74	NH83	NH86	NH60	NH30	NH58	NH84	NH89	NH98	KC3154
NH37 MB16MEC0009-20171212-02 AMM006		0.001	0.011	0.013	0.013	0.014	0.014	0.014	0.014	0.014	0.013	0.013	0.014	0.013	0.013	0.014	0.014	0.013	0.015	0.013	0.013	0.013	0.012	0.013	0.013	0.013	0.017
NH39 MB16MEC0009-20171212-02 AMM006	0.001		0.011	0.013	0.013	0.014	0.014	0.014	0.014	0.014	0.013	0.013	0.014	0.013	0.013	0.013	0.013	0.013	0.015	0.013	0.013	0.013	0.012	0.013	0.013	0.013	0.017
NH104 MB17MEH0007-20171214-02 AMM022	0.104	0.104		0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.014	0.013	0.014	0.013	0.013	0.014	0.014	0.013	0.015	0.013	0.014	0.014	0.013	0.013	0.013	0.013	0.018
NH62 31-20171213-02 AMM032	0.145	0.143	0.135		0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.015	0.014	0.014	0.015	0.015	0.014	0.016	0.014	0.015	0.015	0.014	0.014	0.014	0.014	0.018
NH63 31-20171213-02 AMM026	0.164	0.164	0.143	0.177		0.013	0.013	0.012	0.012	0.012	0.013	0.012	0.013	0.012	0.012	0.013	0.013	0.012	0.014	0.012	0.013	0.013	0.012	0.012	0.012	0.012	0.018
NH46 MB17MEH0009-20171212-02 AMM033	0.170	0.168	0.165	0.180	0.152		0.002	0.011	0.011	0.011	0.011	0.011	0.012	0.011	0.011	0.012	0.012	0.012	0.013	0.011	0.012	0.012	0.012	0.011	0.011	0.011	0.018
NH110 MB17MEH0007-20171214-02 AMM033	0.171	0.170	0.165	0.182	0.152	0.003		0.011	0.011	0.011	0.011	0.011	0.012	0.011	0.011	0.012	0.012	0.012	0.013	0.011	0.012	0.012	0.011	0.011	0.011	0.011	0.018
NH33 200-20171212-03 AMM004	0.149	0.148	0.157	0.174	0.133	0.098	0.098		0.001	0.002	0.012	0.011	0.012	0.011	0.011	0.012	0.012	0.011	0.014	0.011	0.012	0.012	0.011	0.011	0.011	0.011	0.019
NH35 200-20171212-03 AMM004	0.148	0.146	0.155	0.173	0.132	0.097	0.097	0.001		0.002	0.012	0.011	0.012	0.011	0.011	0.012	0.012	0.011	0.014	0.011	0.012	0.012	0.011	0.011	0.011	0.011	0.019
NH38 MB16MEC0009-20171212-02 AMM004	0.146	0.145	0.154	0.171	0.130	0.095	0.095	0.003	0.001		0.012	0.011	0.012	0.011	0.011	0.012	0.012	0.011	0.013	0.011	0.012	0.012	0.011	0.011	0.011	0.011	0.019
NH36 200-20171212-03 AMM031	0.146	0.145	0.151	0.170	0.143	0.104	0.104	0.101	0.100	0.098		0.009	0.010	0.009	0.009	0.010	0.010	0.009	0.010	0.009	0.010	0.010	0.009	0.009	0.009	0.009	0.019
NH65 JW024-20171213-06 AMM001	0.143	0.142	0.149	0.174	0.135	0.107	0.107	0.094	0.092	0.091	0.061		0.002	0.003	0.003	0.004	0.003	0.005	0.005	0.004	0.005	0.005	0.004	0.004	0.004	0.004	0.018
NH70 JW024-20171213-06 AMM001	0.145	0.144	0.156	0.185	0.130	0.106	0.106	0.102	0.100	0.099	0.064	0.002		0.004	0.004	0.003	0.003	0.006	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.019
NH15 Budgie-20171212-01 AMM001	0.145	0.143	0.152	0.176	0.139	0.108	0.108	0.098	0.097	0.095	0.066	0.007	0.010		0.001	0.003	0.002	0.006	0.006	0.005	0.006	0.006	0.005	0.005	0.005	0.005	0.018
NH06 Budgie-20171212-01 AMM001	0.146	0.145	0.151	0.174	0.141	0.110	0.110	0.100	0.098	0.097	0.064	0.006	0.009	0.001		0.002	0.002	0.005	0.006	0.005	0.006	0.006	0.005	0.004	0.005	0.005	0.018
NH09 Budgie-20171212-01 AMM001	0.150	0.149	0.158	0.179	0.137	0.108	0.108	0.103	0.102	0.100	0.066	0.010	0.007	0.005	0.003		0.002	0.006	0.006	0.005	0.005	0.005	0.006	0.005	0.006	0.005	0.018
NH23 Budgie-20171212-01 AMM001	0.150	0.149	0.158	0.179	0.139	0.110	0.110	0.102	0.100	0.099	0.068	0.008	0.007	0.003	0.002	0.002		0.006	0.006	0.005	0.005	0.005	0.006	0.005	0.005	0.005	0.018
NH74 RR01-20171214-05 AMM001	0.148	0.146	0.154	0.173	0.136	0.114	0.114	0.104	0.102	0.101	0.061	0.016	0.019	0.023	0.022	0.026	0.024		0.003	0.002	0.004	0.004	0.003	0.003	0.003	0.003	0.018
NH83 RR01-20171214-05 AMM001	0.156	0.155	0.162	0.177	0.128	0.111	0.111	0.116	0.115	0.113	0.061	0.013	0.013	0.023	0.021	0.021	0.021	0.004		0.000	0.002	0.002	0.002	0.002	0.003	0.002	0.020
NH86 RR01-20171214-05 AMM001	0.146	0.145	0.152	0.171	0.135	0.111	0.111	0.101	0.100	0.098	0.057	0.012	0.014	0.019	0.018	0.021	0.019	0.004	0.000		0.002	0.003	0.001	0.002	0.002	0.002	0.018
NH60 31-20171213-02 AMM001	0.149	0.147	0.160	0.173	0.134	0.111	0.111	0.100	0.099	0.097	0.063	0.015	0.014	0.023	0.021	0.021	0.019	0.008	0.002	0.003		0.003	0.002	0.003	0.003	0.003	0.018
NH30 Budgie-20171212-01 AMM001	0.149	0.147	0.157	0.173	0.132	0.107	0.107	0.099	0.097	0.095	0.065	0.016	0.016	0.024	0.023	0.023	0.021	0.010	0.004	0.005	0.005		0.003	0.003	0.003	0.003	0.018
NH58 31-20171213-02 AMM001	0.145	0.143	0.154	0.170	0.136	0.113	0.113	0.100	0.098	0.097	0.059	0.013	0.016	0.020	0.019	0.023	0.021	0.006	0.002	0.001	0.002	0.006		0.003	0.003	0.003	0.018
NH84 RR01-20171214-05 AMM001	0.146	0.145	0.149	0.170	0.136	0.111	0.111	0.101	0.100	0.098	0.057	0.012	0.016	0.016	0.015	0.019	0.018	0.007	0.002	0.003	0.005	0.006	0.004		0.001	0.001	0.018
NH89 RR01-20171214-05 AMM001	0.148	0.146	0.148	0.171	0.135	0.113	0.113	0.100	0.098	0.097	0.059	0.013	0.017	0.018	0.016	0.021	0.019	0.009	0.004	0.004	0.006	0.008	0.006	0.001		0.002	0.018
NH98 RR01-20171214-05 AMM001	0.148	0.146	0.148	0.168	0.135	0.113	0.113	0.102	0.101	0.100	0.059	0.013	0.017	0.018	0.016	0.021	0.019	0.009	0.004	0.004	0.006	0.008	0.006	0.001	0.003		0.018
LI10 MB16MEC0009-170308-2 Amphipoda	0.167	0.167	0.150	0.179	0.013	0.153	0.153	0.144	0.142	0.140	0.136	0.128	0.127	0.131	0.132	0.133	0.134	0.129	0.124	0.128	0.131	0.129	0.129	0.128	0.126	0.126	0.316
LI11 MB16MEC0009-170308-2 Amphipoda	0.148	0.147	0.156	0.171	0.132	0.096	0.096	0.003	0.002	0.000	0.099	0.091	0.099	0.096	0.097	0.100	0.099	0.100	0.113	0.097	0.097	0.095	0.096	0.099	0.097	0.100	0.324
LI25 RC15MEC0200-20170308-01 Amphipoda	0.147	0.145	0.153	0.169	0.140	0.104	0.104	0.102	0.100	0.099	0.000	0.062	0.062	0.067	0.065	0.065	0.066	0.064	0.061	0.059	0.061	0.063	0.061	0.057	0.059	0.059	0.322
B3 60a Nedsia sp 1AMM013	0.156	0.156	0.164	0.182	0.100	0.183	0.183	0.147	0.145	0.144	0.152	0.147	0.149	0.149	0.151	0.152	0.152	0.152	0.149	0.151	0.151	0.152	0.149	0.149	0.151	0.147	0.337
BF14 X62P2-2011-01 AMM018	0.153	0.153	0.157	0.184	0.176	0.189	0.191	0.188	0.186	0.184	0.186	0.183	0.185	0.181	0.183	0.183	0.184	0.192	0.195	0.188	0.187	0.189	0.186	0.186	0.188	0.188	0.324
cob12 5a AMM009	0.160	0.160	0.158	0.191	0.105	0.172	0.172	0.158	0.155	0.153	0.143	0.143	0.143	0.145	0.147	0.147	0.147	0.155	0.155	0.151	0.153	0.149	0.153	0.149	0.147	0.149	0.330
DH1 BIL4nr-1112-03-01 AMM019	0.148	0.148	0.150	0.166	0.189	0.174	0.175	0.156	0.155	0.155	0.161	0.162	0.168	0.166	0.164	0.165	0.166	0.159	0.168	0.159	0.160	0.162	0.158	0.158	0.159	0.156	0.317
EU304458 Nedsia sp. 1 sge1m4 2	0.167	0.165	0.165	0.216	0.150	0.104	0.104	0.116	0.114	0.112	0.112	0.106	0.106	0.108	0.110	0.110	0.110	0.104	0.106	0.106	0.108	0.106	0.108	0.104	0.101	0.104	0.334
G405 110129 AMM014	0.174	0.174	0.162	0.180	0.110	0.174	0.174	0.150	0.148	0.147	0.140	0.134	0.133	0.136	0.137	0.139	0.141	0.142	0.135	0.140	0.145	0.144	0.142	0.139	0.137	0.140	0.317
G406 110196 AMM015	0.167	0.167	0.170	0.183	0.110	0.178	0.178	0.147	0.145	0.144	0.145	0.140	0.138	0.142	0.144	0.142	0.144	0.151	0.149	0.147	0.149	0.147	0.148	0.145	0.144	0.147	0.320
IS37 RHWB005 20150910 01 AMM022	0.106	0.106	0.016	0.136	0.153	0.169	0.170	0.155	0.153	0.151	0.150	0.151	0.154	0.155	0.153	0.155	0.155	0.155	0.156	0.153	0.157	0.153	0.155	0.151	0.150	0.150	0.326
IS38 RHWB005 20150910 01 AMM023	0.109	0.110	0.114	0.148	0.181	0.178	0.177	0.167	0.166	0.164	0.156	0.162	0.166	0.166	0.164	0.165	0.166	0.161	0.166	0.161	0.162	0.162	0.159	0.159	0.158	0.161	0.326
IS43 RHWB006 20150910 01 AMM021	0.189	0.189	0.150	0.188	0.046	0.159	0.159	0.148	0.147	0.145	0.148	0.137	0.133	0.139	0.140	0.139	0.141	0.142	0.135	0.137	0.139	0.137	0.139	0.136	0.134	0.134	0.325
IS59 KBRC1310 20150911 02 AMM020	0.177	0.175	0.169	0.178	0.145	0.091	0.091	0.109	0.107	0.106	0.095	0.103	0.106	0.104	0.103	0.105	0.107	0.103	0.097	0.099	0.105	0.103	0.101	0.098	0.099	0.099	0.326
IT06 BHRC118.20151013-02 AMM024	0.150	0.148	0.151	0.184	0.132	0.103	0.103	0.098	0.097	0.095	0.060	0.027	0.031	0.032	0.031	0.034	0.032	0.037	0.036	0.032	0.036	0.037	0.034	0.031	0.032	0.032	0.324
IT22 BHRC231.20151014-03 AMM025	0.145	0.142	0.164	0.193	0.116	0.103	0.103	0.111	0.108	0.106	0.077	0.042	0.045	0.050	0.047	0.051	0.051	0.055	0.053	0.047	0.048	0.051	0.045	0.047	0.047	0.047	0.348
IV108 MB13WARR001-20150605-01 Amphipoda AMM005	0.162	0.161	0.162	0.178	0.084	0.162	0.162	0.144	0.142	0.140	0.136	0.134	0.130	0.136	0.137	0.136	0.137	0.142	0.132	0.140	0.142	0.141	0.142	0.139	0.140	0.140	0.322
IV111 MB13WARR010.20150606-01 Amphipoda AMM003	0.151	0.151	0.155	0.189	0.134	0.106	0.106	0.110	0.109	0.107	0.079	0.080	0.085	0.088	0.087	0.089	0.090	0.088	0.086	0.085	0.090	0.092	0.087	0.087	0.085	0.088	0.309
IV124 Budgie AMM027	0.145	0.143	0.149	0.177	0.121	0.091	0.091	0.109	0.107	0.105	0.040	0.044	0.044	0.050	0.048	0.048	0.048	0.046	0.042	0.042	0.044	0.042	0.044	0.040	0.042	0.042	0.337
IV126 Camp-20150930-02 Amphipoda AMM001	0.150	0.148	0.158	0.178	0.139	0.110	0.110	0.103	0.101	0.099	0.066	0.009	0.012	0.005	0.003	0.006	0.005	0.025	0.025	0.021	0.024	0.026	0.022	0.019	0.021	0.021	0.319
IV128 DAVES-20150930-04 Amphipoda AMM004	0.148	0.147	0.156	0.170	0.134	0.096	0.096	0.002	0.000	0.002	0.101	0.093	0.100	0.098	0.099	0.102	0.100	0.103	0.115	0.099	0.099	0.097	0.098	0.101	0.099	0.103	0.326
IV134 TOBRC0099-20150930-01 Amphipoda AMM006	0.005	0.003	0.103	0.147	0.166	0.167	0.169	0.151	0.150	0.148	0.145	0.144	0.144	0.145	0.147	0.149	0.149	0.148	0.155	0.147	0.150	0.147	0.148	0.147	0.148	0.148	0.308
IV92 Budgie.20150604-02 Amphipoda AMM002	0.148	0.147	0.151	0.172	0.128	0.103	0.103	0.112	0.110	0.109	0.068	0.069	0.074	0.073	0.071	0.073	0.074	0.069	0.073	0.068	0.073	0.071	0.069	0.066	0.068	0.068	0.314

IV97 Camp bore AMM001	0.152	0.150	0.160	0.181	0.139	0.112	0.112	0.104	0.102	0.101	0.069	0.011	0.012	0.006	0.005	0.006	0.005	0.027	0.025	0.022	0.024	0.026	0.024	0.021	0.022	0.022	0.321
JF02 DD13MEH0007-20151024-01B AMM001	0.148	0.147	0.155	0.172	0.134	0.110	0.110	0.103	0.101	0.099	0.057	0.013	0.016	0.017	0.016	0.019	0.018	0.006	0.002	0.002	0.005	0.006	0.003	0.000	0.002	0.002	0.314
JF21 RC13MEH0097-20151024-01A AMM026	0.170	0.170	0.147	0.178	0.002	0.153	0.153	0.137	0.136	0.134	0.140	0.131	0.128	0.139	0.137	0.136	0.137	0.132	0.126	0.131	0.132	0.131	0.132	0.132	0.131	0.131	0.322
JN05 87-20160505-02E AMM004	0.147	0.145	0.155	0.172	0.133	0.095	0.095	0.003	0.002	0.003	0.100	0.092	0.099	0.096	0.098	0.100	0.099	0.101	0.113	0.098	0.097	0.095	0.096	0.100	0.098	0.101	0.325
JN17 32-20160506-01A AMM001	0.147	0.145	0.158	0.170	0.134	0.110	0.110	0.099	0.098	0.096	0.060	0.013	0.016	0.021	0.019	0.023	0.021	0.006	0.002	0.002	0.002	0.006	0.000	0.003	0.005	0.005	0.315
JN22 3120160507-03A AMM026	0.169	0.169	0.148	0.180	0.000	0.151	0.151	0.136	0.134	0.132	0.142	0.132	0.130	0.137	0.139	0.137	0.139	0.134	0.128	0.132	0.134	0.132	0.134	0.134	0.132	0.132	0.320
JQ608487 Norcapensis mandibulis	0.166	0.164	0.170	0.196	0.189	0.190	0.190	0.176	0.176	0.175	0.171	0.164	0.166	0.168	0.166	0.168	0.168	0.170	0.176	0.170	0.170	0.170	0.168	0.170	0.168	0.171	0.315
KD40 Budgie-20150930-01 AMM029	0.157	0.155	0.158	0.187	0.135	0.094	0.094	0.110	0.109	0.107	0.071	0.052	0.054	0.057	0.055	0.057	0.057	0.060	0.056	0.057	0.061	0.063	0.059	0.055	0.057	0.057	0.331
KD44 Budgie-20150930-01 AMM030	0.146	0.144	0.149	0.176	0.129	0.092	0.092	0.102	0.100	0.098	0.039	0.037	0.040	0.042	0.041	0.043	0.043	0.041	0.034	0.036	0.039	0.041	0.037	0.034	0.036	0.036	0.320
KD45 Budgie-20150930-01 AMM031	0.145	0.144	0.151	0.175	0.145	0.102	0.102	0.105	0.103	0.102	0.035	0.067	0.064	0.072	0.070	0.070	0.070	0.067	0.063	0.063	0.065	0.063	0.065	0.061	0.063	0.063	0.340
KD47 Budgie-20150930-01 AMM028	0.170	0.170	0.172	0.202	0.129	0.135	0.135	0.131	0.129	0.127	0.129	0.127	0.130	0.129	0.131	0.134	0.134	0.127	0.126	0.122	0.127	0.125	0.124	0.120	0.118	0.118	0.324
KD49 Budgie-20150930-01 AMM001	0.148	0.146	0.158	0.176	0.134	0.108	0.108	0.110	0.108	0.106	0.063	0.017	0.019	0.026	0.024	0.026	0.026	0.010	0.006	0.005	0.009	0.004	0.007	0.007	0.009	0.009	0.320
KD50 Budgie-20150930-01 AMM030	0.142	0.140	0.149	0.169	0.121	0.092	0.092	0.097	0.095	0.094	0.041	0.027	0.025	0.029	0.027	0.025	0.025	0.034	0.026	0.029	0.029	0.031	0.031	0.027	0.029	0.029	0.317
KD53 Budgie.20150604-02 AMM002	0.147	0.146	0.152	0.177	0.131	0.106	0.106	0.113	0.111	0.110	0.070	0.069	0.074	0.072	0.070	0.073	0.073	0.069	0.073	0.067	0.071	0.069	0.069	0.065	0.067	0.067	0.324
KD55 Budgie.20150604-02 AMM031	0.142	0.139	0.147	0.170	0.130	0.102	0.102	0.099	0.097	0.095	0.024	0.061	0.065	0.066	0.064	0.067	0.067	0.061	0.058	0.054	0.060	0.062	0.057	0.052	0.054	0.052	0.348
KE05 200-20160910-01 Amphipoda	0.147	0.145	0.153	0.169	0.142	0.104	0.104	0.103	0.101	0.099	0.000	0.062	0.064	0.066	0.065	0.066	0.068	0.063	0.061	0.058	0.063	0.065	0.060	0.057	0.058	0.058	0.322
KE10 87-20160919-02 Amphipoda	0.147	0.145	0.155	0.172	0.132	0.095	0.095	0.003	0.002	0.003	0.099	0.091	0.099	0.096	0.098	0.100	0.099	0.101	0.113	0.098	0.097	0.095	0.096	0.099	0.098	0.101	0.325
KE31 25-20160910-01 Amphipoda	0.150	0.148	0.156	0.170	0.136	0.109	0.109	0.101	0.099	0.098	0.058	0.014	0.017	0.019	0.017	0.021	0.019	0.008	0.004	0.003	0.006	0.008	0.005	0.002	0.003	0.003	0.316
KJ65 Budgiebore-20161210-01	0.146	0.144	0.157	0.177	0.135	0.106	0.106	0.098	0.097	0.095	0.068	0.010	0.009	0.002	0.003	0.003	0.002	0.025	0.023	0.021	0.021	0.023	0.022	0.019	0.021	0.021	0.315
KJ70 Budgiebore-20161210-01	0.147	0.146	0.151	0.171	0.125	0.101	0.101	0.111	0.109	0.108	0.070	0.071	0.073	0.074	0.073	0.071	0.073	0.071	0.073	0.070	0.071	0.069	0.071	0.068	0.070	0.070	0.314
KJ73 Budgiebore-20161210-03	0.146	0.144	0.146	0.165	0.130	0.094	0.094	0.097	0.095	0.094	0.022	0.059	0.055	0.063	0.062	0.060	0.061	0.062	0.055	0.057	0.058	0.057	0.059	0.055	0.057	0.057	0.320
L26 S5-200 AMM016	0.149	0.149	0.159	0.173	0.194	0.176	0.178	0.170	0.168	0.168	0.164	0.171	0.173	0.175	0.173	0.175	0.175	0.170	0.172	0.170	0.170	0.171	0.168	0.168	0.170	0.166	0.315
L8 107b Nedsia sp 2 AMM017	0.159	0.159	0.156	0.192	0.136	0.113	0.113	0.125	0.124	0.122	0.088	0.082	0.082	0.081	0.082	0.082	0.082	0.086	0.086	0.082	0.081	0.084	0.081	0.081	0.079	0.082	0.324
nr5miwelld AMM002	0.141	0.139	0.153	0.181	0.120	0.109	0.109	0.122	0.120	0.118	0.082	0.080	0.080	0.084	0.082	0.082	0.082	0.078	0.076	0.078	0.080	0.078	0.080	0.076	0.078	0.076	0.324
pm01a 10 AMM011	0.111	0.109	0.101	0.158	0.153	0.158	0.158	0.143	0.141	0.139	0.151	0.149	0.149	0.153	0.151	0.151	0.151	0.153	0.148	0.149	0.151	0.149	0.151	0.147	0.145	0.147	0.303
pt03 11a AMM010	0.174	0.174	0.172	0.193	0.118	0.176	0.176	0.164	0.162	0.160	0.141	0.147	0.147	0.149	0.151	0.151	0.151	0.158	0.157	0.155	0.158	0.153	0.158	0.153	0.155	0.153	0.334
rr3a 2b AMM001	0.141	0.139	0.162	0.176	0.130	0.116	0.116	0.116	0.113	0.111	0.059	0.019	0.019	0.025	0.023	0.023	0.023	0.008	0.002	0.004	0.006	0.008	0.006	0.002	0.004	0.002	0.321
wc17 1 Nedsia douglasi AMM012	0.153	0.153	0.157	0.189	0.089	0.174	0.174	0.142	0.140	0.138	0.142	0.142	0.142	0.144	0.146	0.146	0.146	0.151	0.148	0.146	0.144	0.146	0.144	0.144	0.142	0.144	0.323

35	KC315646	LI10	LI11	LI25	B3	BF14	COB12	DH1	EU304458	G405	G406	IS37	IS38	IS43	IS59	IT06	IT22	IV108	IV111	IV124	IV126	IV128	IV134	IV92	IV97	JF02	JF21	JN05	JN17	JN22	JQ608487	KD40	KD44	KD45	KD47	KD49
0.018	0.014	0.015	0.013	0.014	0.014	0.016	0.013	0.017	0.015	0.015	0.012	0.012	0.015	0.015	0.014	0.018	0.014	0.014	0.015	0.013	0.014	0.003	0.014	0.014	0.013	0.014	0.014	0.013	0.014	0.015	0.015	0.014	0.014	0.016	0.014
0.018	0.014	0.015	0.013	0.014	0.014	0.016	0.013	0.017	0.015	0.015	0.012	0.012	0.015	0.015	0.014	0.017	0.014	0.014	0.015	0.013	0.014	0.002	0.014	0.014	0.013	0.014	0.014	0.013	0.014	0.015	0.015	0.014	0.014	0.016	0.014
0.018	0.014	0.014	0.014	0.015	0.014	0.016	0.014	0.016	0.014	0.015	0.005	0.012	0.013	0.014	0.014	0.018	0.014	0.014	0.015	0.014	0.014	0.012	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.015	0.015	0.014	0.015	0.015	0.015
0.019	0.015	0.015	0.014	0.015	0.015	0.017	0.014	0.018	0.015	0.015	0.014	0.014	0.015	0.015	0.015	0.020	0.015	0.015	0.017	0.015	0.015	0.013	0.014	0.015	0.015	0.015	0.015	0.015	0.015	0.017	0.016	0.015	0.015	0.017	0.015
0.019	0.004	0.013	0.014	0.012	0.015	0.013	0.015	0.016	0.012	0.012	0.014	0.014	0.008	0.013	0.013	0.016	0.011	0.013	0.013	0.013	0.013	0.014	0.012	0.013	0.012	0.002	0.013	0.012	0.000	0.014	0.013	0.013	0.014	0.014	0.013
0.018	0.014	0.012	0.011	0.015	0.015	0.017	0.015	0.013	0.015	0.015	0.014	0.015	0.014	0.011	0.011	0.015	0.014	0.012	0.012	0.012	0.012	0.015	0.012	0.012	0.012	0.014	0.011	0.012	0.014	0.016	0.012	0.011	0.012	0.014	0.012
0.018	0.014	0.011	0.011	0.016	0.015	0.017	0.015	0.013	0.015	0.015	0.014	0.015	0.014	0.011	0.011	0.015	0.014	0.012	0.012	0.012	0.011	0.015	0.012	0.012	0.012	0.014	0.011	0.012	0.014	0.016	0.012	0.011	0.012	0.014	0.012
0.019	0.013	0.002	0.012	0.014	0.015	0.017	0.014	0.014	0.013	0.013	0.014	0.014	0.013	0.012	0.012	0.016	0.013	0.013	0.014	0.012	0.001	0.015	0.013	0.012	0.012	0.013	0.002	0.012	0.013	0.016	0.013	0.013	0.013	0.014	0.013
0.019	0.013	0.002	0.012	0.014	0.015	0.017	0.014	0.014	0.014	0.013	0.014	0.014	0.013	0.012	0.012	0.016	0.013	0.013	0.014	0.012	0.000	0.015	0.013	0.012	0.012	0.013	0.002	0.012	0.013	0.016	0.013	0.012	0.013	0.014	0.013
0.019	0.013	0.000	0.012	0.014	0.015	0.016	0.014	0.014	0.013	0.013	0.014	0.014	0.013	0.012	0.012	0.015	0.013	0.013	0.014	0.012	0.002	0.015	0.012	0.012	0.012	0.013	0.002	0.012	0.013	0.016	0.013	0.012	0.013	0.014	0.013
0.018	0.014	0.012	0.000	0.015	0.015	0.016	0.014	0.014	0.014	0.013	0.014	0.014	0.014	0.011	0.010	0.013	0.013	0.011	0.009	0.010	0.012	0.013	0.010	0.010	0.009	0.014	0.012	0.009	0.014	0.016	0.011	0.008	0.007	0.014	0.010
0.018	0.012	0.011	0.010	0.014	0.015	0.016	0.014	0.013	0.013	0.013	0.014	0.014	0.013	0.012	0.007	0.010	0.013	0.011	0.009	0.004	0.011	0.013	0.010	0.004	0.004	0.012	0.011	0.004	0.012	0.015	0.009	0.008	0.010	0.014	0.005
0.019	0.013	0.012	0.010	0.014	0.015	0.016	0.015	0.013	0.013	0.013	0.014	0.015	0.013	0.012	0.007	0.010	0.013	0.011	0.009	0.004	0.012	0.014	0.011	0.004	0.005	0.013	0.012	0.005	0.013	0.015	0.009	0.008	0.010	0.014	0.006
0.018	0.013	0.012	0.010	0.014	0.015	0.016	0.014	0.014	0.013	0.013	0.014	0.014	0.013	0.012	0.007	0.011	0.013	0.011	0.010	0.003	0.012	0.013	0.010	0.003	0.005	0.013	0.012	0.005	0.013	0.015	0.009	0.008	0.011	0.014	0.006
0.018	0.013	0.012	0.010	0.014	0.015	0.016	0.014	0.014	0.013	0.013	0.014	0.014	0.013	0.012	0.007	0.010	0.013	0.011	0.009	0.002	0.012	0.013	0.010	0.003	0.005	0.013	0.012	0.005	0.013	0.015	0.009	0.008	0.011	0.014	0.006
0.018	0.013	0.012	0.010	0.015	0.015	0.016	0.014	0.014	0.013	0.013	0.014	0.014	0.013	0.012	0.007	0.011	0.013	0.011	0.009	0.003	0.012	0.013	0.010	0.003	0.005	0.013	0.012	0.006	0.013	0.015	0.009	0.008	0.011	0.014	0.006
0.018	0.013	0.012	0.010	0.015	0.015	0.016	0.014	0.014	0.014	0.014	0.014	0.015	0.013	0.012	0.007	0.011	0.013	0.011	0.009	0.003	0.012	0.013	0.010	0.003	0.005	0.013	0.012	0.006	0.013	0.015	0.009	0.008	0.011	0.014	0.006
0.018	0.012	0.012	0.010	0.015	0.015	0.017	0.014	0.013	0.013	0.014	0.014	0.014	0.013	0.012	0.007	0.011	0.013	0.011	0.009	0.006	0.012	0.013	0.010	0.006	0.003	0.012	0.012	0.003	0.012	0.015	0.009	0.008	0.010	0.014	0.004
0.020	0.014	0.013	0.010	0.015	0.017	0.017	0.015	0.014	0.014	0.015	0.015	0.016	0.014	0.013	0.008	0.012	0.015	0.012	0.009	0.006	0.014	0.015	0.011	0.006	0.002	0.014	0.013	0.002	0.014	0.016	0.010	0.008	0.011	0.015	0.003
0.018	0.012	0.012	0.009	0.014	0.015	0.016	0.014	0.013	0.013	0.013	0.014	0.014	0.013	0.011	0.007	0.011	0.013	0.011	0.009	0.005	0.012	0.013	0.010	0.006	0.002	0.012	0.012	0.002	0.012	0.015	0.009	0.008	0.010	0.014	0.003
0.018	0.013	0.012	0.010	0.014	0.015	0.016	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.013	0.012	0.007	0.011	0.013	0.012	0.009	0.006	0.012	0.014	0.010	0.006	0.003	0.013	0.012	0.002	0.013	0.015	0.010	0.008	0.010	0.014	0.004
0.018	0.013	0.012	0.010	0.014	0.015	0.016	0.014	0.013	0.014	0.014	0.014	0.014	0.014	0.013	0.012	0.007	0.011	0.013	0.012	0.009	0.006	0.012	0.013	0.010	0.006	0.003	0.013	0.012	0.003	0.013	0.015	0.010	0.008	0.010	0.014	0.002
0.018	0.013	0.012	0.010	0.014	0.015	0.016	0.014	0.014	0.013	0.014	0.014	0.014	0.014	0.013	0.012	0.007	0.010	0.013	0.011	0.009	0.005	0.012	0.013	0.010	0.006	0.002	0.012	0.012	0.000	0.012	0.015	0.009	0.008	0.010	0.014	0.003
0.018	0.013	0.012	0.010	0.014	0.015	0.016	0.014	0.014	0.013	0.014	0.014	0.014	0.014	0.013	0.012	0.007	0.010	0.013	0.011	0.009	0.005	0.012	0.013	0.010	0.006	0.003	0.013	0.012	0.002	0.013	0.015	0.010	0.008	0.010	0.014	0.003
0.018	0.012	0.012	0.009	0.014	0.015	0.016	0.014	0.013	0.013	0.013	0.014	0.014	0.013	0.011	0.007	0.011	0.013	0.011	0.009	0.005	0.012	0.013	0.009	0.005	0.000	0.012	0.012	0.002	0.012	0.015	0.009	0.008	0.010	0.014	0.003
0.018	0.012	0.012	0.010	0.014	0.015	0.016	0.014	0.013	0.013	0.013	0.014	0.014	0.013	0.011	0.007	0.011	0.013	0.011	0.009	0.005	0.012	0.013	0.010	0.006	0.002	0.012	0.012	0.003	0.012	0.015	0.009	0.008	0.010	0.013	0.004
0.018	0.012	0.012	0.009	0.014	0.015	0.016	0.014	0.013	0.013	0.013	0.014	0.014	0.013	0.011	0.007	0.011	0.013	0.011	0.009	0.005	0.012	0.013	0.010	0.006	0.002	0.012	0.012	0.003	0.012	0.015	0.009	0.008	0.010	0.014	0.003
0.327		0.013	0.014	0.012	0.014	0.013	0.015	0.016	0.012	0.012	0.014	0.015	0.008	0.013	0.013	0.016	0.011	0.013	0.014	0.013	0.013	0.014	0.012	0.013	0.012	0.004	0.013	0.013	0.004	0.014	0.014	0.013	0.015	0.014	0.013
0.332	0.140		0.012	0.014	0.015	0.016	0.014	0.014	0.013	0.013	0.014	0.014	0.013	0.012	0.011	0.015	0.013	0.013	0.014	0.012	0.002	0.015	0.013	0.012	0.012	0.013	0.002	0.012	0.013	0.015	0.013	0.012	0.013	0.014	0.013
0.325	0.136	0.099		0.015	0.015	0.016	0.014	0.014	0.014	0.013	0.014	0.014	0.014	0.012	0.010	0.013	0.013	0.011	0.009	0.010	0.012	0.013	0.010	0.010	0.009	0.014	0.012	0.010	0.014	0.016	0.011	0.008	0.007	0.015	0.010
0.337	0.101	0.142	0.153		0.016	0.015	0.017	0.016	0.013	0.013	0.015	0.015	0.013	0.015	0.014	0.018	0.010	0.015	0.015	0.015	0.014	0.014	0.014	0.015	0.014	0.012	0.014	0.014	0.012	0.015	0.015	0.014	0.015	0.015	0.014
0.313	0.172	0.185	0.185	0.175		0.016	0.014	0.018	0.014	0.015	0.014	0.014	0.015	0.014	0.015	0.019	0.014	0.015	0.017	0.015	0.015	0.014	0.015	0.015	0.015	0.014	0.015	0.015	0.015	0.015	0.016	0.016	0.016	0.016	0.016
0.309	0.109	0.153	0.143	0.128	0.174		0.017	0.017	0.014	0.014	0.016	0.016	0.014	0.016	0.015	0.018	0.013	0.014	0.016	0.016	0.017	0.016	0.016	0.016	0.016	0.013	0.016	0.016	0.013	0.016	0.015	0.015	0.016	0.014	0.016
0.319	0.185	0.156	0.161	0.197	0.169	0.187		0.018	0.015	0.015	0.013	0.013	0.015	0.015	0.014	0.019	0.016	0.015	0.017	0.014	0.014	0.014	0.014	0.014	0.014	0.015	0.014	0.014	0.015	0.015	0.016	0.015	0.015	0.017	0.015
0.326	0.150	0.112	0.112	0.152	0.199	0.163	0.186		0.016	0.016	0.017	0.016	0.016	0.012	0.013	0.016	0.016	0.013	0.013	0.014	0.014	0.017	0.013	0.014	0.013	0.016	0.014	0.014	0.016	0.017	0.013	0.013	0.013	0.014	0.014
0.317	0.110	0.145	0.140	0.111	0.180	0.109	0.192	0.152		0.007	0.014	0.014	0.012	0.013	0.013	0.017	0.012	0.014	0.015	0.013	0.014	0.014	0.013	0.014	0.013	0.012	0.013	0.013	0.012	0.014	0.014	0.014	0.014	0.014	0.014
0.317	0.112	0.144	0.144	0.123	0.181	0.113	0.192	0.154	0.041		0.015	0.014	0.012	0.014	0.013	0.017	0.013	0.014	0.014	0.014	0.013	0.014	0.014	0.014	0.013	0.012	0.013	0.014	0.012	0.015	0.014	0.014	0.014	0.014	0.014
0.326	0.155	0.153	0.150	0.170	0.154	0.153	0.137	0.169	0.161	0.169		0.012	0.013	0.014	0.014	0.018	0.014	0.014	0.015	0.014	0.014	0.012	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.015	0.015	0.014	0.015	0.015	0.015
0.326	0.179	0.166	0.156	0.173	0.149	0.181	0.151	0.163	0.172	0.178	0.110		0.014	0.014	0.014	0.019	0.014	0.014	0.016	0.014	0.014	0.012	0.013	0.015	0.014	0.014	0.014	0.014	0.014	0.015	0.015	0.014	0.015	0.015	0.015
0.331	0.045	0.145	0.147	0.114	0.178	0.128	0.196	0.148	0.117	0.114	0.158	0.188		0.013	0.013	0.017	0.012	0.014	0.014	0.013	0.013	0.014	0.013	0.013	0.013	0.008	0.013	0.013	0.008	0.015	0.014	0.013	0.015	0.014	0.014
0.330	0.144	0.105	0.096	0.164	0.188	0.153	0.175	0.089	0.156	0.161	0.169	0.169	0.148		0.012	0.015	0.014	0.012	0.012	0.012	0.012	0.015	0.010	0.012	0.011	0.013	0.012	0.012	0.013	0.015	0.012	0.011	0.012	0.012	0.012
0.333	0.125	0.094	0.060	0.139	0.187	0.141	0.163	0.095	0.135	0.142	0.151	0.159	0.134	0.101		0.011	0.013	0.011	0.008	0.007	0.012	0.013	0.009	0.007	0.007	0.013	0.011	0.007	0.013	0.015	0.008	0.007	0.010	0.013	0.008
0.338	0.113	0.105	0.078	0.152	0.195	0.136	0.179	0.117	0.150	0.148	0.164	0.177	0.129	0.103	0.045		0.017	0.014	0.012	0.010	0.016	0.017	0.013	0.011	0.011	0.016	0.015	0.010	0.016	0.018	0.012	0.010	0.013	0.016	0.011
0.326	0.085	0.140	0.134	0.081	0.161	0.105	0.188	0.161	0.098	0.106	0.161	0.172	0.099	0.153	0.135	0.140		0.014	0.014	0.013	0.013	0.014	0.013	0.013	0.013	0.011	0.013	0.013	0.011	0.015	0.014	0.013	0.014	0.014	0.014
0.315	0.132	0.107	0.080	0.151	0.181	0.126	0.167	0.099	0.140	0.145	0.155	0.162	0.144	0.093	0.077	0.079	0.147		0.012	0.011	0.013	0.014	0.011	0.011	0.011	0.013	0.013	0.011	0.013	0.015	0.011	0.011	0.012	0.013	0.012
0.333	0.115	0.105	0.040	0.139	0.185	0.139	0.175	0.089	0.129	0.133	0.147	0.155	0.127	0.085	0.034	0.051	0.117	0.075		0.009	0.014	0.015	0.009	0.009	0.009	0.013	0.014	0.009	0.013	0.017	0.009	0.006	0.008	0.015	0.009
0.330	0.132	0.099	0.067	0.152	0.183	0.149	0.166	0.114	0.139	0.145	0.155	0.166	0.144	0.104	0.034	0.047	0.139	0.088	0.052		0.012	0.013	0.010	0.002	0.005	0.013	0.012	0.005	0.013	0.015	0.009	0.008	0.011	0.014	0.006
0.330	0.142	0.002	0.100	0.145	0.186	0.155	0.155	0.114	0.148	0.145	0.153	0.166	0.147	0.107	0.097	0.108	0.142	0.109	0.107	0.101		0.015	0.013	0.012	0.012	0.013	0.002	0.012	0.013	0.016	0.013	0.012	0.013	0.014	0.013
0.328	0.164	0.150	0.145	0.156	0.156	0.155	0.151	0.165	0.170	0.164	0.103	0.114	0.186	0.175	0.148	0.145	0.158	0.151	0.143	0.148	0.150		0.013	0.013	0.013	0.014	0.014	0.013	0.014	0.015	0.015	0.014	0.014	0.015	0.014
0.322	0.121	0.108	0.069	0.154	0.180	0.134	0.169	0.101	0.140	0.150	0.155	0.151	0.136	0.084	0.060	0.074	0.137	0.077	0.044	0.074	0.110	0.147		0.010	0.009	0.012	0.012	0.010	0.012	0.014	0.011	0.008	0.009	0.013	0.010

| | | |

KD50	KD53	KD55	KE05	KE10	KE31	KJ65	KJ70	KJ73	L26	L8	nr5miwelld	pm01a	pt03	r3a 2b	wc17 1
0.014	0.014	0.016	0.013	0.014	0.013	0.013	0.013	0.013	0.014	0.015	0.015	0.014	0.016	0.015	0.016
0.014	0.014	0.016	0.013	0.014	0.013	0.013	0.013	0.013	0.014	0.015	0.015	0.014	0.016	0.015	0.016
0.014	0.014	0.017	0.014	0.014	0.014	0.014	0.014	0.014	0.015	0.015	0.015	0.013	0.017	0.016	0.016
0.015	0.015	0.018	0.014	0.015	0.015	0.015	0.014	0.014	0.015	0.016	0.017	0.016	0.017	0.017	0.018
0.013	0.013	0.017	0.014	0.013	0.012	0.013	0.012	0.013	0.015	0.014	0.014	0.016	0.014	0.015	0.013
0.012	0.012	0.014	0.011	0.011	0.012	0.012	0.012	0.011	0.016	0.013	0.014	0.016	0.016	0.014	0.017
0.012	0.012	0.014	0.011	0.011	0.012	0.012	0.012	0.011	0.016	0.013	0.014	0.016	0.016	0.014	0.017
0.012	0.013	0.014	0.013	0.002	0.012	0.012	0.013	0.012	0.015	0.014	0.015	0.016	0.016	0.015	0.015
0.012	0.013	0.014	0.012	0.002	0.012	0.012	0.013	0.012	0.015	0.014	0.015	0.016	0.016	0.015	0.015
0.012	0.012	0.014	0.012	0.002	0.012	0.012	0.012	0.012	0.015	0.014	0.015	0.016	0.016	0.015	0.015
0.008	0.010	0.008	0.000	0.012	0.009	0.010	0.010	0.006	0.014	0.012	0.012	0.016	0.015	0.011	0.016
0.006	0.010	0.011	0.010	0.011	0.005	0.004	0.010	0.009	0.015	0.011	0.012	0.016	0.015	0.006	0.016
0.006	0.011	0.012	0.010	0.012	0.006	0.004	0.011	0.010	0.015	0.011	0.012	0.016	0.015	0.006	0.016
0.007	0.010	0.012	0.010	0.012	0.005	0.002	0.011	0.010	0.015	0.011	0.013	0.016	0.015	0.007	0.016
0.007	0.010	0.011	0.010	0.012	0.005	0.002	0.010	0.010	0.015	0.011	0.012	0.016	0.015	0.006	0.016
0.006	0.010	0.012	0.010	0.012	0.006	0.002	0.010	0.010	0.015	0.011	0.012	0.016	0.015	0.006	0.016
0.006	0.010	0.012	0.010	0.012	0.005	0.002	0.010	0.010	0.015	0.011	0.012	0.016	0.015	0.006	0.016
0.007	0.010	0.011	0.010	0.012	0.004	0.006	0.010	0.009	0.015	0.012	0.011	0.016	0.016	0.004	0.017
0.007	0.011	0.012	0.010	0.013	0.003	0.006	0.011	0.010	0.016	0.012	0.012	0.016	0.016	0.002	0.017
0.007	0.010	0.011	0.009	0.012	0.002	0.005	0.010	0.009	0.015	0.012	0.012	0.016	0.015	0.003	0.016
0.007	0.010	0.011	0.010	0.012	0.003	0.005	0.010	0.009	0.015	0.011	0.012	0.016	0.015	0.004	0.016
0.007	0.010	0.011	0.010	0.012	0.004	0.005	0.010	0.009	0.015	0.012	0.012	0.016	0.015	0.004	0.016
0.007	0.010	0.011	0.009	0.012	0.003	0.006	0.010	0.009	0.015	0.011	0.012	0.016	0.015	0.004	0.016
0.007	0.010	0.011	0.010	0.012	0.004	0.005	0.010	0.009	0.015	0.012	0.012	0.016	0.015	0.004	0.016
0.007	0.010	0.011	0.009	0.012	0.003	0.006	0.010	0.009	0.015	0.011	0.012	0.016	0.015	0.004	0.016
0.006	0.010	0.010	0.009	0.012	0.002	0.005	0.010	0.009	0.015	0.011	0.011	0.016	0.015	0.002	0.016
0.007	0.010	0.011	0.009	0.012	0.002	0.006	0.010	0.009	0.015	0.011	0.012	0.015	0.016	0.003	0.016
0.007	0.010	0.010	0.009	0.012	0.002	0.006	0.010	0.009	0.015	0.011	0.011	0.016	0.015	0.002	0.016
0.013	0.013	0.017	0.014	0.013	0.012	0.013	0.012	0.013	0.015	0.014	0.014	0.016	0.014	0.015	0.013
0.012	0.012	0.014	0.012	0.002	0.012	0.012	0.013	0.012	0.015	0.014	0.015	0.016	0.016	0.015	0.015
0.008	0.010	0.008	0.000	0.012	0.009	0.010	0.010	0.005	0.014	0.012	0.012	0.016	0.015	0.011	0.016
0.014	0.014	0.017	0.015	0.014	0.014	0.015	0.015	0.014	0.016	0.015	0.016	0.017	0.014	0.016	0.008
0.016	0.015	0.019	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.016	0.018	0.016	0.017	0.018	0.017
0.015	0.016	0.017	0.016	0.016	0.016	0.016	0.016	0.015	0.017	0.015	0.016	0.017	0.011	0.016	0.014
0.015	0.015	0.017	0.014	0.014	0.014	0.014	0.014	0.014	0.007	0.015	0.017	0.015	0.017	0.016	0.018
0.013	0.013	0.015	0.014	0.014	0.013	0.014	0.013	0.013	0.017	0.012	0.013	0.016	0.016	0.013	0.016
0.014	0.014	0.016	0.014	0.013	0.013	0.013	0.013	0.013	0.016	0.015	0.015	0.016	0.014	0.016	0.013
0.014	0.014	0.016	0.013	0.013	0.013	0.013	0.014	0.013	0.016	0.015	0.015	0.016	0.014	0.016	0.012
0.014	0.014	0.017	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.016	0.013	0.017	0.016	0.016
0.015	0.014	0.018	0.014	0.014	0.014	0.014	0.013	0.014	0.015	0.014	0.015	0.014	0.017	0.017	0.016
0.013	0.014	0.017	0.014	0.013	0.013	0.013	0.013	0.013	0.016	0.014	0.016	0.016	0.014	0.015	0.014
0.012	0.010	0.014	0.011	0.012	0.011	0.012	0.010	0.012	0.015	0.013	0.012	0.015	0.016	0.013	0.016
0.006	0.009	0.010	0.010	0.011	0.007	0.007	0.009	0.008	0.015	0.011	0.011	0.015	0.014	0.008	0.015
0.011	0.013	0.012	0.013	0.015	0.011	0.011	0.013	0.012	0.020	0.013	0.014	0.018	0.017	0.012	0.019
0.013	0.013	0.016	0.013	0.013	0.013	0.013	0.013	0.012	0.016	0.014	0.015	0.016	0.013	0.015	0.011
0.011	0.011	0.013	0.011	0.013	0.011	0.011	0.011	0.011	0.015	0.011	0.013	0.016	0.015	0.013	0.016
0.006	0.009	0.010	0.009	0.014	0.009	0.010	0.009	0.006	0.016	0.012	0.010	0.016	0.015	0.009	0.016
0.007	0.010	0.011	0.010	0.012	0.005	0.003	0.010	0.010	0.015	0.011	0.012	0.016	0.016	0.007	0.016
0.012	0.013	0.014	0.012	0.002	0.012	0.012	0.013	0.012	0.015	0.014	0.015	0.016	0.016	0.015	0.015
0.014	0.014	0.016	0.013	0.014	0.013	0.013	0.013	0.013	0.014	0.015	0.015	0.014	0.016	0.015	0.016
0.009	0.000	0.011	0.010	0.012	0.010	0.011	0.002	0.009	0.015	0.011	0.002	0.015	0.015	0.011	0.016

0.007	0.011	0.012	0.010	0.012	0.006	0.003	0.010	0.010	0.015	0.011	0.012	0.016	0.016	0.007	0.016
0.006	0.010	0.010	0.009	0.012	0.002	0.005	0.010	0.009	0.015	0.011	0.011	0.016	0.015	0.002	0.016
0.013	0.013	0.016	0.014	0.013	0.012	0.013	0.012	0.013	0.015	0.014	0.014	0.016	0.014	0.015	0.013
0.012	0.012	0.014	0.012	0.000	0.012	0.011	0.012	0.012	0.015	0.013	0.014	0.016	0.016	0.014	0.015
0.007	0.010	0.011	0.009	0.012	0.003	0.006	0.010	0.009	0.015	0.011	0.012	0.016	0.015	0.004	0.016
0.013	0.013	0.017	0.014	0.013	0.012	0.013	0.012	0.013	0.015	0.014	0.014	0.016	0.014	0.015	0.013
0.015	0.014	0.018	0.016	0.015	0.015	0.015	0.014	0.015	0.015	0.015	0.015	0.016	0.016	0.017	0.016
0.008	0.011	0.012	0.011	0.013	0.009	0.009	0.011	0.009	0.016	0.011	0.012	0.016	0.015	0.010	0.016
0.005	0.008	0.009	0.008	0.012	0.008	0.008	0.008	0.007	0.015	0.010	0.010	0.016	0.014	0.008	0.015
0.009	0.009	0.007	0.007	0.013	0.010	0.011	0.009	0.007	0.015	0.012	0.010	0.016	0.015	0.011	0.015
0.014	0.013	0.015	0.014	0.014	0.014	0.014	0.013	0.014	0.016	0.013	0.014	0.016	0.015	0.015	0.014
0.007	0.010	0.011	0.010	0.013	0.004	0.006	0.011	0.009	0.015	0.012	0.012	0.016	0.016	0.004	0.016
	0.009	0.009	0.008	0.012	0.007	0.007	0.009	0.007	0.015	0.010	0.010	0.016	0.014	0.007	0.016
0.054		0.011	0.010	0.012	0.010	0.011	0.002	0.010	0.015	0.011	0.002	0.015	0.015	0.011	0.016
0.038	0.066		0.008	0.014	0.011	0.012	0.012	0.007	0.017	0.012	0.012	0.017	0.016	0.011	0.018
0.041	0.070	0.024		0.012	0.009	0.010	0.010	0.006	0.014	0.012	0.012	0.016	0.015	0.011	0.016
0.094	0.110	0.095	0.099		0.012	0.011	0.012	0.012	0.015	0.013	0.014	0.016	0.016	0.014	0.015
0.029	0.067	0.054	0.058	0.098		0.006	0.010	0.009	0.015	0.011	0.012	0.016	0.015	0.003	0.016
0.027	0.074	0.069	0.068	0.095	0.021		0.010	0.010	0.015	0.011	0.013	0.016	0.015	0.007	0.016
0.052	0.002	0.069	0.070	0.108	0.070	0.073		0.009	0.015	0.011	0.002	0.015	0.015	0.011	0.016
0.029	0.063	0.021	0.022	0.094	0.057	0.062	0.059		0.014	0.011	0.011	0.016	0.014	0.010	0.015
0.162	0.171	0.165	0.164	0.170	0.166	0.176	0.173	0.161		0.015	0.017	0.015	0.017	0.016	0.018
0.069	0.086	0.075	0.088	0.122	0.082	0.081	0.086	0.073	0.165		0.012	0.016	0.016	0.012	0.016
0.061	0.002	0.071	0.082	0.118	0.078	0.084	0.002	0.067	0.170	0.090		0.015	0.015	0.011	0.016
0.139	0.137	0.144	0.151	0.139	0.145	0.153	0.137	0.141	0.139	0.158	0.134		0.017	0.016	0.016
0.139	0.147	0.141	0.141	0.160	0.151	0.149	0.147	0.137	0.187	0.149	0.149	0.174		0.016	0.014
0.029	0.076	0.058	0.059	0.111	0.004	0.025	0.076	0.053	0.164	0.082	0.078	0.149	0.155		0.016
0.136	0.149	0.141	0.142	0.142	0.146	0.144	0.149	0.136	0.178	0.142	0.149	0.157	0.106	0.146	

Figure 1. Neighbour-joining analysis of specimens of Neoniphargidae and Paramelitidae from the present study to aid in the identification of unique haplotypes and lineages. Numbers on major nodes correspond to bootstrap support over 100 iterations; values <50% are not shown. Scale bar= genetic distance. Unique haplotypes used to represent each lineage in the model-based phylogenetic analysis are highlighted in yellow.

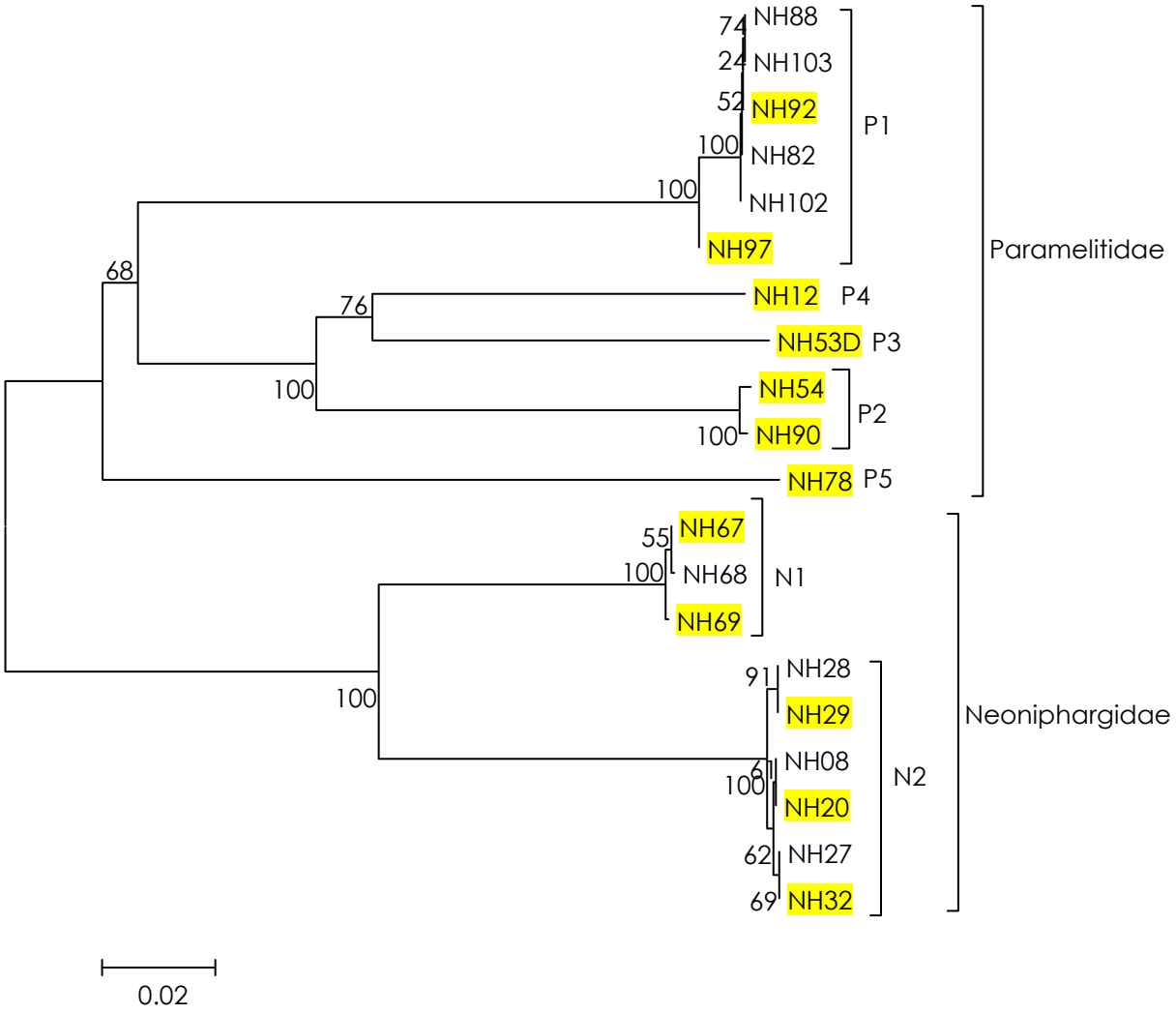


Figure 2. Neighbour-joining analysis of specimens of Melitidae/Eriopisidae from the present study, to aid in the identification of unique haplotypes and lineages. Numbers on major nodes correspond to bootstrap support over 100 iterations; values <50% are not shown. Scale bar= genetic distance. Unique haplotypes used to represent each lineage in the model-based phylogenetic analysis are highlighted in yellow.

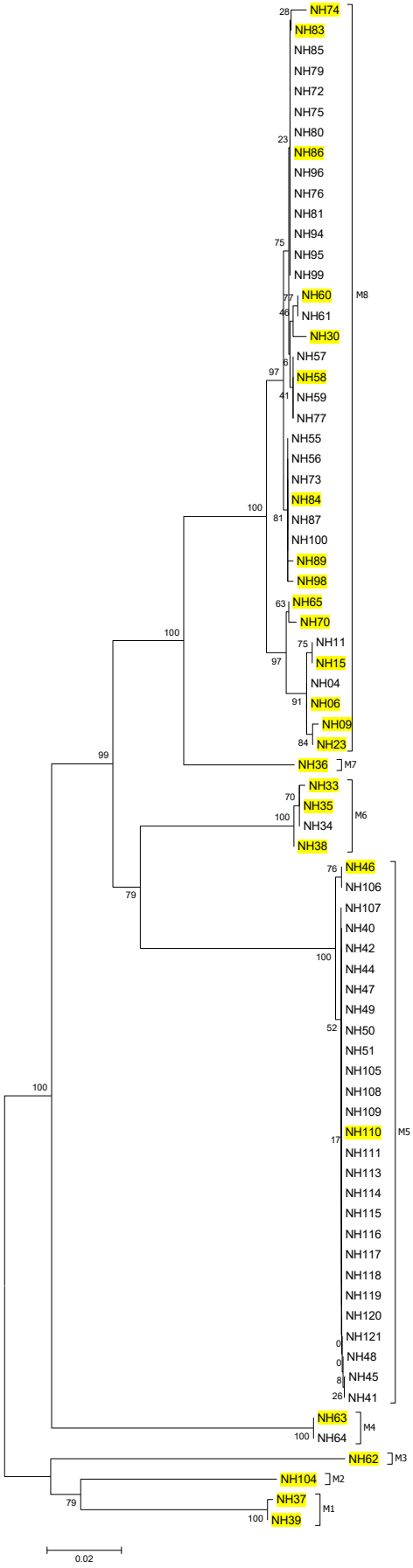


Figure 3. Bayesian analysis of COI haplotypes of Neonipharidae (Amphipoda) from the present study and reference specimens from Genbank and previous surveys in the Pilbara. Numbers on major nodes correspond to posterior probabilities; values <50% are not shown. Specimens from the present study are highlighted in yellow; GenBank voucher specimens highlighted in turquoise. Scale bar= number of substitutions per site. Red boxes enclose species with high confidence.

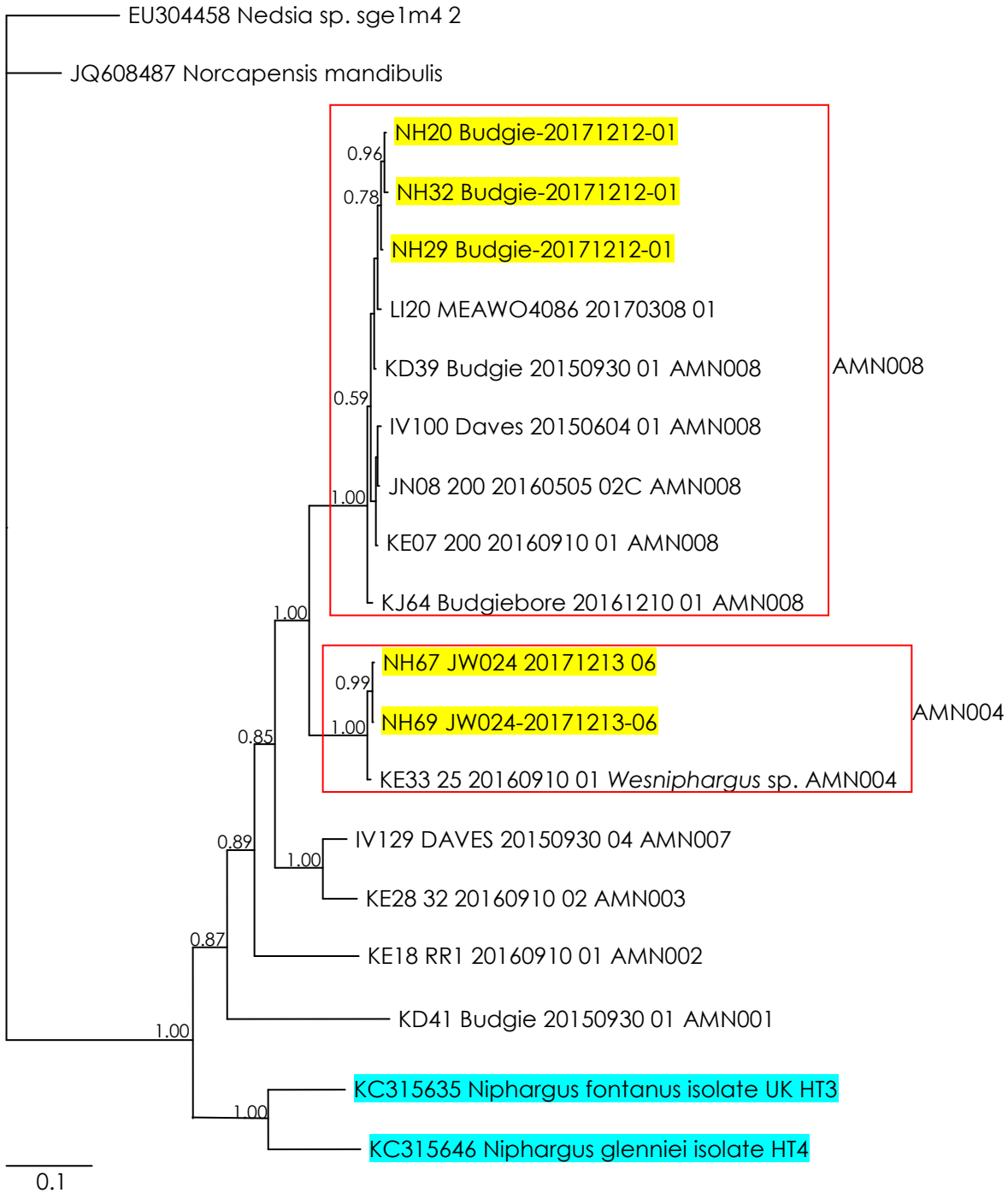


Figure 4. Bayesian analysis of COI haplotypes of Paramelitidae (Amphipoda) from the present study and reference specimens from Genbank and previous surveys in the Pilbara. Numbers on major nodes correspond to posterior probabilities; values <50% are not shown. Specimens from the present study are highlighted in yellow; GenBank voucher specimens highlighted in turquoise. Scale bar= number of substitutions per site. Red boxes enclose species with high confidence; dashed lines indicate groups that require further consideration.

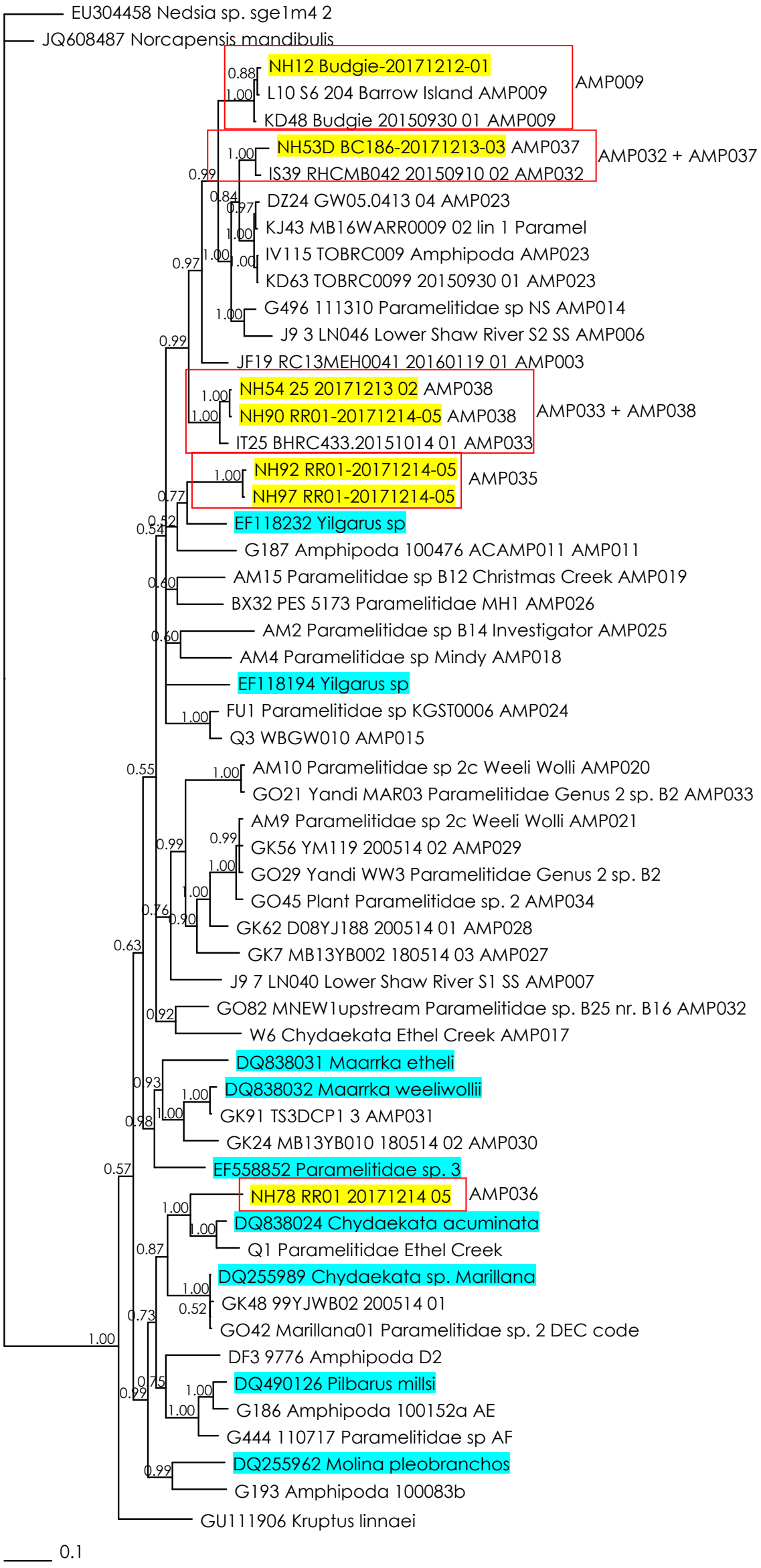
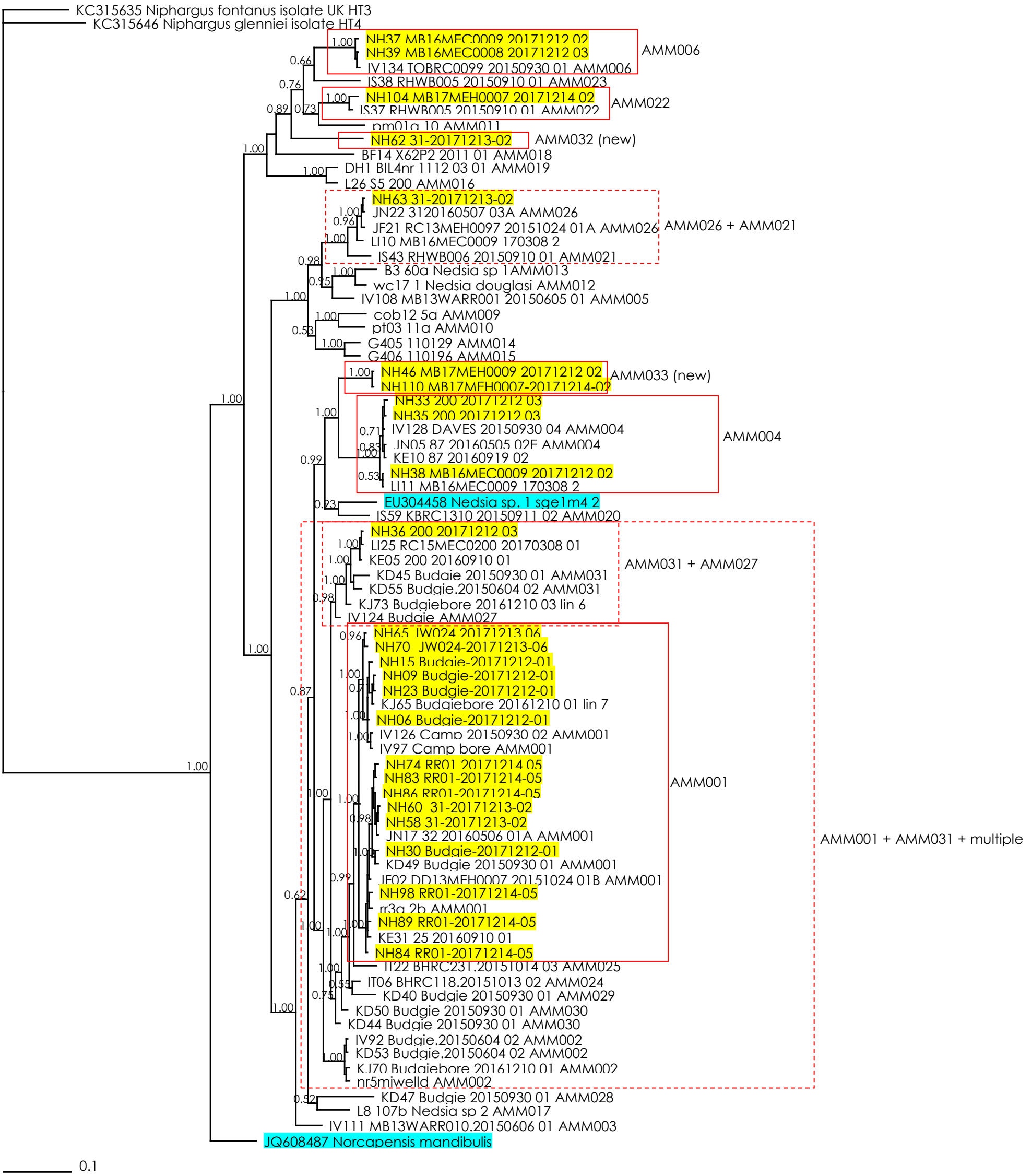


Figure 5. Bayesian analysis of COI haplotypes of Melitidae/Eriopisidae (Amphipoda) from the present study and reference specimens from Genbank and previous surveys in the Pilbara. Numbers on major nodes correspond to posterior probabilities; values <50% are not shown. Specimens from the present study are highlighted in yellow; GenBank voucher specimens highlighted in turquoise. Scale bar= number of substitutions per site. Red boxes enclose species with high confidence; dashed lines indicate groups that require further consideration.



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11 April 2017

Biota Environmental Sciences

Via email

Re. Report for the analysis of environmental water samples collected during December 2017 for the presence of blind eel DNA (Helix Job 484)

Executive Summary

- Eighty-nine samples from 17 sites were extracted and analysed using the *O. candidium* probe.
- Amplification was observed in seven samples from three sites. The control site (n=3), 25 site (n=1) and MB17MEH0015 site (n=3).
- All samples were run with the 16S mammal probe as an extraction positive control. Of the 89 samples only 59 samples amplified for the presence of mammal DNA.
- All samples that amplified with the *O. candidium* probe also amplified for the mammal probe

Methods

A modification to previous collections methods was in how filters were stored during transport. In previous collection filter papers were stored in 100% ethanol. A modification in this study was filter papers were stored in a sterile plastic bag at -20ºC for transport. Furthermore only half of the filter paper was sent for analysis. Upon reaching the lab all samples were stored at -80ºC.

Samples were extracted using the QIAGEN Blood and Tissue Kit (QIAGEN, Hilden, Germany) and as with previous studies all starting volumes were doubled to ensure that the filter was covered during incubation. All samples had two elutes of 50µl each.

The extracted DNA was run with the species diagnostic assay for *Ophisternon candidum* and the mammal control assay (16S) as per previous studies.

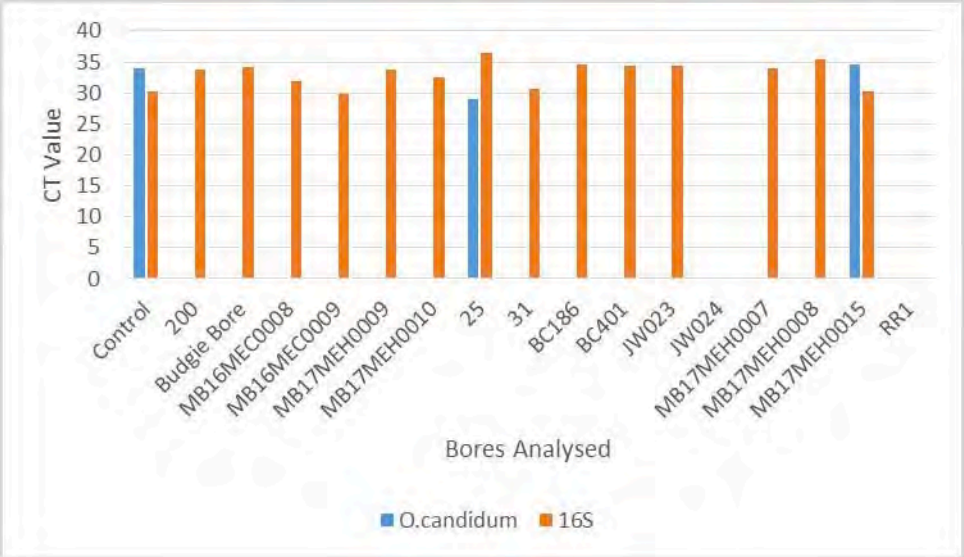
Results

Seventeen sites were sampled with three to six filters per site using two collection methods (bailer and pump) (Appendix 1). Of the 89 filters tested seven amplified from three different sites for the presence of *O. candidium* DNA (Figure 1). These sites were the control site, site 25 and site MB17MEH0015. For the control site three filters were collected all of which amplified for the presence of O. candidium. For site 25 only one of the five filters collected amplified, and for MB17MEH0015 three of the five filters amplified.

From the 89 filters sent for analysis, 59 filters amplified with the control probe. The 20 filters that failed to amplify may have been due to no mammal DNA present in the bore or the presence of only degraded DNA. Two sites were noted to have failed across all filters collected (JW024 and RR1).

All samples had three replicates for the O. candidium probe and one replicate for the control probe. Amplification of the *O. candidium* was noted in all replicates except NI84 in which the third replicate failed to amplify. This was most likely the result of degradation.

Figure 1: Sites sampled during the December 2017 collection and the results for *O. candidium* specific qPCR assay. No bar indicates no amplification.



Conclusion

In conclusion, we confirm that *O. candidium* DNA was observed in three sites. The control site (n=3), 25 site (n=1) and MB17MEH0015 site (n=3). Both sampling methods (bailer and pump) collected *O. candidium* DNA even though varying volumes of water were used (500-1000ml). The modified methods of storing filters at -20ºC for transport and -80ºC for storage appear to be affective in addition to using only half the filters.

Three replicates were done for each sample and a range of 5.09 - 7.68% increase in the CT value was noted between replicates. As expected eDNA is susceptible to degradation even via limited freezer thaw cycles. For future work it is suggested that freeze thaw cycles be limited as much as possible.

Reference

Helix_Job_258_Blind_eel_DNA_update_v1.2 report

Thank you once again for collaborating on this project with Helix. We hope we can continue to provide you with useful information, and feel free to contact us if you have any questions or would like to discuss the results in detail.

Sincerely,

Helix Molecular Solutions Pty Ltd

Site	Easting	Northing	Sampled date	Biota Code	Hole depth	Drilled	Notes	Post Notes	Stygo hauls	Type	Notes	eDNA	# EDNA filters	Lab ID	Extraction Notes	Positive	O. Candidium rep 1	O. Candidium rep 2	O. Candidium rep 3
Control	424478	7597147	2017-12-11	Control-20171211-1				eDNA only. Taken from surface water at the site of RRWS01	-			Yes		NI01		32.73	33.23	33.68	35.99
Control	424478	7597147	2017-12-11	Control-20171211-2				eDNA only. Taken from surface water at the site of RRWS01	-			Yes		NI02		32.91	30.94	33.41	33.77
Control	424478	7597147	2017-12-11	Control-20171211-3				eDNA only. Taken from surface water at the site of RRWS01	-			Yes	3	NI03		30	32.14	32.36	35.2
200	392512.0324	7607435.55	2017-12-12	200-20171212-B1			PSS089	Stygo net stuck and lost after 2 hauls	5	B1		Yes		NI04		-	-	-	-
200	392512.0324	7607435.55	2017-12-12	200-20171212-B2			PSS089	Stygo net stuck and lost after 2 hauls	5	B2		Yes		NI05		33.5	-	-	-
200	392512.0324	7607435.55	2017-12-12	200-20171212-B3			PSS089	Stygo net stuck and lost after 2 hauls	5	B3		Yes		NI06		34.55	-	-	-
200	392512.0324	7607435.55	2017-12-12	200-20171212-P4			PSS089	Stygo net stuck and lost after 2 hauls	5	P4		Yes		NI07		32.72	-	-	-
200	392512.0324	7607435.55	2017-12-12	200-20171212-P5			PSS089	Stygo net stuck and lost after 2 hauls	5	P5		Yes		NI08		33.44	-	-	-
200	392512.0324	7607435.55	2017-12-12	200-20171212-P6			PSS089	Stygo net stuck and lost after 2 hauls	5	P6		Yes	6	NI09		34.48	-	-	-
Budgie Bore	382494.7379	7615587.299	2017-12-12	Budgie Bore-20171212-B1					5	B1		Yes		NI10		-	-	-	-
Budgie Bore	382494.7379	7615587.299	2017-12-12	Budgie Bore-20171212-B2					5	B2	500ml	Yes		NI11	whole filter in bag, half used	-	-	-	-
Budgie Bore	382494.7379	7615587.299	2017-12-12	Budgie Bore-20171212-B3					5	B3		Yes		NI12		34.52	-	-	-
Budgie Bore	382494.7379	7615587.299	2017-12-12	Budgie Bore-20171212-P4					5	P4		Yes		NI13		34.84	-	-	-
Budgie Bore	382494.7379	7615587.299	2017-12-12	Budgie Bore-20171212-P5					5	P5		Yes		NI14		-	-	-	-
Budgie Bore	382494.7379	7615587.299	2017-12-12	Budgie Bore-20171212-P6					5	P6	500ml	Yes	6	NI15	whole filter in bag, half used	36	-	-	-
MB16MEC0008	393565	7600580	2017-12-12	MB16MEC0008-20171212-B1	36	Drilled 2016			5	B1		Yes		NI16		31.28	-	-	-
MB16MEC0008	393565	7600580	2017-12-12	MB16MEC0008-20171212-B2	36	Drilled 2016			5	B2		Yes		NI17		31.29	-	-	-
MB16MEC0008	393565	7600580	2017-12-12	MB16MEC0008-20171212-B3	36	Drilled 2016			5	B3		Yes		NI18		30.91	-	-	-
MB16MEC0008	393565	7600580	2017-12-12	MB16MEC0008-20171212-P4	36	Drilled 2016			5	P4		Yes		NI19		31.96	-	-	-
MB16MEC0008	393565	7600580	2017-12-12	MB16MEC0008-20171212-P5	36	Drilled 2016			5	P5		Yes		NI20		33.83	-	-	-
MB16MEC0008	393565	7600580	2017-12-12	MB16MEC0008-20171212-P6	36	Drilled 2016			5	P6		Yes	6	NI21		32.32	-	-	-
MB16MEC0009	393590.062	7601144.506	2017-12-12	MB16MEC0009-20171212-B1	43	Drilled 2016			5	B1		Yes		NI22		29.64	-	-	-
MB16MEC0009	393590.062	7601144.506	2017-12-12	MB16MEC0009-20171212-B2	43	Drilled 2016			5	B2		Yes		NI23		30.33	-	-	-
MB16MEC0009	393590.062	7601144.506	2017-12-12	MB16MEC0009-20171212-B3	43	Drilled 2016			5	B3		Yes		NI24		29.96	-	-	-
MB16MEC0009	393590.062	7601144.506	2017-12-12	MB16MEC0009-20171212-P4	43	Drilled 2016			5	P4		Yes		NI25		35.17	-	-	-
MB16MEC0009	393590.062	7601144.506	2017-12-12	MB16MEC0009-20171212-P5	43	Drilled 2016			5	P5		Yes		NI26		28.24	-	-	-
MB16MEC0009	393590.062	7601144.506	2017-12-12	MB16MEC0009-20171212-P6	43	Drilled 2016			5	P6	500ml	Yes	6	NI27	whole filter in bag, half used	29.26	-	-	-
MB17MEH0009	416435.8	7599848	2017-12-12	MB17MEH0009-20171212-B1	43	30-Aug-17			5	B1		Yes		NI28		34.48	-	-	-
MB17MEH0009	416435.8	7599848	2017-12-12	MB17MEH0009-20171212-B2	43	30-Aug-17			5	B2		Yes		NI29		35.79	-	-	-
MB17MEH0009	416435.8	7599848	2017-12-12	MB17MEH0009-20171212-B3	43	30-Aug-17			5	B3		Yes		NI30		33.94	-	-	-
MB17MEH0009	416435.8	7599848	2017-12-12	MB17MEH0009-20171212-P4	43	30-Aug-17			5	P4		Yes		NI31		-	-	-	-
MB17MEH0009	416435.8	7599848	2017-12-12	MB17MEH0009-20171212-P5	43	30-Aug-17			5	P5		Yes		NI32		-	-	-	-
MB17MEH0009	416435.8	7599848	2017-12-12	MB17MEH0009-20171212-P6	43	30-Aug-17			5	P6		Yes	6	NI33		35.28	-	-	-
MB17MEH0010	416440	7599848	2017-12-12	MB17MEH0010-20171212-B1	30	31-Aug-17			5	B1		Yes		NI34		30.36	-	-	-
MB17MEH0010	416440	7599848	2017-12-12	MB17MEH0010-20171212-B2	30	31-Aug-17			5	B2		Yes		NI35		31.1	-	-	-
MB17MEH0010	416440	7599848	2017-12-12	MB17MEH0010-20171212-B3	30	31-Aug-17			5	B3		Yes		NI36		32.22	-	-	-
MB17MEH0010	416440	7599848	2017-12-12	MB17MEH0010-20171212-P4	30	31-Aug-17			5	P4		Yes		NI37		33.8	-	-	-
MB17MEH0010	416440	7599848	2017-12-12	MB17MEH0010-20171212-P5	30	31-Aug-17			5	P5		Yes		NI38		35.6	-	-	-
MB17MEH0010	416440	7599848	2017-12-12	MB17MEH0010-20171212-P6	30	31-Aug-17			5	P6		Yes	6	NI39		34.09	-	-	-
25	432152	7602229	2017-12-13	25-20171213-B1				Site Locked - Needed key from utilities in Panna (near mess)	5	B1		Yes		NI40		34.91	-	-	-
25	432152	7602229	2017-12-13	25-20171213-B2				Site Locked - Needed key from utilities in Panna (near mess)	5	B2		Yes		NI41		-	-	-	-
25	432152	7602229	2017-12-13	25-20171213-P3				Site Locked - Needed key from utilities in Panna (near mess)	5	P3		Yes		NI42		-	-	-	-
25	432152	7602229	2017-12-13	25-20171213-P4				Site Locked - Needed key from utilities in Panna (near mess)	5	P4	500ml	Yes		NI43		35.32	28.35	28.79	29.87
25	432152	7602229	2017-12-13	25-20171213-P5				Site Locked - Needed key from utilities in Panna (near mess)	5	P5		Yes	5	NI44		-	-	-	-
31	432929	7603179	2017-12-13	31-20171213-B1				Site Locked - Needed key from utilities in Panna (near mess)	5	B1		Yes		NI45		29.37	-	-	-
31	432929	7603179	2017-12-13	31-20171213-B2				Site Locked - Needed key from utilities in Panna (near mess)	5	B2		Yes		NI46		32.71	-	-	-
31	432929	7603179	2017-12-13	31-20171213-P3				Site Locked - Needed key from utilities in Panna (near mess)	5	P3		Yes		NI47		-	-	-	-
31	432929	7603179	2017-12-13	31-20171213-P4				Site Locked - Needed key from utilities in Panna (near mess)	5	P4		Yes		NI48		-	-	-	-
31	432929	7603179	2017-12-13	31-20171213-P5				Site Locked - Needed key from utilities in Panna (near mess)	5	P5	500ml	Yes	5	NI49		-	-	-	-
BC186	429578	7587212	2017-12-13	BC186-20171213-B1			Confirmed eel record 2009		5	B1		Yes		NI50		-	-	-	-
BC186	429578	7587212	2017-12-13	BC186-20171213-B2			Confirmed eel record 2009		5	B2	500ml	Yes		NI51	whole filter in bag, half used	34.61	-	-	-
BC186	429578	7587212	2017-12-13	BC186-20171213-B3			Confirmed eel record 2009		5	B3		Yes		NI52		-	-	-	-
BC186	429578	7587212	2017-12-13	BC186-20171213-P4			Confirmed eel record 2009		5	P4	500ml	Yes		NI53	whole filter in bag, half used	-	-	-	-
BC186	429578	7587212	2017-12-13	BC186-20171213-P5			Confirmed eel record 2009		5	P5		Yes	5	NI54		-	-	-	-
BC401	443563	7574126	2017-12-13	BC401-20171213-B1					5	B1	500ml	Yes		NI55	whole filter in bag, half used	32.7	-	-	-
BC401	443563	7574126	2017-12-13	BC401-20171213-B2					5	B2		Yes		NI56		35.32	-	-	-
BC401	443563	7574126	2017-12-13	BC401-20171213-P3					5	P3	500ml	Yes		NI57	whole filter in bag, half used	-	-	-	-
BC401	443563	7574126	2017-12-13	BC401-20171213-P4					5	P4		Yes		NI58		34.74	-	-	-
BC401	443563	7574126	2017-12-13	BC401-20171213-P5					5	P5		Yes	5	NI59		37.06	-	-	-
JW023	426138	7590140	2017-12-13	JW023-20171213-B1			Confirmed Eel record 2016	Hydrocarbons	5	B1		Yes		NI60		35.34	-	-	-
JW023	426138	7590140	2017-12-13	JW023-20171213-B2			Confirmed Eel record 2016	Hydrocarbons	5	B2	500ml?	Yes		NI61		36.56	-	-	-
JW023	426138	7590140	2017-12-13	JW023-20171213-B3			Confirmed Eel record 2016	Hydrocarbons	5	B3		Yes		NI62		36.64	-	-	-
JW023	426138	7590140	2017-12-13	JW023-20171213-B4			Confirmed Eel record 2016	Hydrocarbons	5	B4		Yes		NI63		33.33	-	-	-
JW023	426138	7590140	2017-12-13	JW023-20171213-B5			Confirmed Eel record 2016	Hydrocarbons	5	B5	500ml	Yes	5	NI64	whole filter in bag, half used	35.01	-	-	-
JW024	427126	7590154	2017-12-13	JW024-20171213-B1			Confirmed Eel record 2017		5	B1		Yes		NI65		-	-	-	-
JW024	427126	7590154	2017-12-13	JW024-20171213-B2			Confirmed Eel record 2017		5	B2		Yes		NI66		-	-	-	-
JW024	427126	7590154	2017-12-13	JW024-20171213-P3			Confirmed Eel record 2017		5	P3		Yes		NI67		-	-	-	-
JW024	427126	7590154	2017-12-13	JW024-20171213-P4			Confirmed Eel record 2017		5	P4		Yes		NI68		-	-	-	-
JW024	427126	7590154	2017-12-13	JW024-20171213-P5			Confirmed Eel record 2017		5	P5	500ml	Yes	5	NI69		-	-	-	-
MB17MEH0007	417663.8	7600421	2017-12-14	MB17MEH0007-20171214-B1	30	29-Aug-17		Bailer only for eDNA, Pump stopped working	5	B1		Yes		NI70	whole filter in bag, half used	34.84	-	-	-
MB17MEH0007	417663.8	7600421	2017-12-14	MB17MEH0007-20171214-B2	30	29-Aug-17		Bailer only for eDNA, Pump stopped working	5	B2		Yes		NI71		-	-	-	-
MB17MEH0007	417663.8	7600421	2017-12-14	MB17MEH0007-20171214-B3	30	29-Aug-17		Bailer only for eDNA, Pump stopped working	5	B3		Yes		NI72		-	-	-	-
MB17MEH0007	417663.8	7600421	2017-12-14	MB17MEH0007-20171214-B4	30	29-Aug-17		Bailer only for eDNA, Pump stopped working	5	B4		Yes		NI73		34.16	-	-	-
MB17MEH0007	417663.8	7600421	2017-12-14	MB17MEH0007-20171214-B5	30	29-Aug-17		Bailer only for eDNA, Pump stopped working	5	B5		Yes	5	NI74		33.19	-	-	-
MB17MEH0008	417119.5	7600417	2017-12-14	MB17MEH0008-20171214-B1	18	29-Aug-17		Bailer only for eDNA, Pump stopped working	5	B1		Yes		NI75	whole filter in bag, half used	35.53	-	-	-
MB17MEH0008	417119.5	7600417	2017-12-14	MB17MEH0008-20171214-B2	18	29-Aug-17		Bailer only for eDNA, Pump stopped working	5	B2		Yes		NI76		-	-	-	-
MB17MEH0008	417119.5	7600417	2017-12-14	MB17MEH0008-20171214-B3	18	29-Aug-17		Bailer only for eDNA, Pump stopped working	5	B3		Yes		NI77		36.34	-	-	-
MB17MEH0008	417119.5	7600417	2017-12-14	MB17MEH0008-20171214-B4	18	29-Aug-17		Bailer only for eDNA, Pump stopped working	5	B4		Yes		NI78	whole filter in bag, half used	35.86	-	-	-
MB17MEH0008	417119.5	7600417	2017-12-14	MB17MEH0008-20171214-B5	18	29-Aug-17		Bailer only for eDNA, Pump stopped working	5	B5	500ml	Yes	5	NI79	whole filter in bag, half used	35.7	-	-	-
MB17MEH0015	416041	7597690	2017-12-14	MB17MEH0015-20171214-B1	37	3-Nov-17		Bailer only for eDNA, Pump stopped working	5	B1	750ml	Yes		NI80		30.63	-	-	-
MB17MEH0015	416041	7597690	2017-12-14	MB17MEH0015-20171214-B2	37	3-Nov-17		Bailer only for eDNA, Pump stopped working	5	B2	900ml	Yes		NI81		31.43	-	-	-
MB17MEH0015	416041	7597690	2017-12-14	MB17MEH0015-20171214-B3	37	3-Nov-17		Bailer only for eDNA, Pump stopped working	5	B3		Yes		NI82		30.41	33.88	36.43	36.7
MB17MEH0015	416041	7597690	2017-12-14	MB17MEH0015-20171214-B4	37	3-Nov-17		Bailer only for eDNA, Pump stopped working	5	B4	500ml	Yes		NI83	whole filter in bag, half used	31.2	34.12	33.97	37.07
MB17MEH0015	416041	7597690	2017-12-14	MB17MEH0015-20171214-B5	37	3-Nov-17		Bailer only for eDNA, Pump stopped working	5	B5		Yes	5	NI84		33.74	32.47	32.94	-
RR1	419176	7597904	2017-12-14	RR1-20171214-B1	17.2		depth to water 1.87	Bailer only, unable to drive close enough for pump	5	B1		Yes		NI85		-	-	-	-
RR1	419176	7597904	2017-12-14	RR1-20171214-B2	17.2		depth to water 1.87	Bailer only, unable to drive close enough for pump	5	B2	900ml	Yes		NI86		-	-	-	-
RR1	419176	7597904	2017-12-14	RR1-20171214-B3	17.2		depth to water 1.87	Bailer only, unable to drive close enough for pump	5	B3		Yes		NI87		-	-	-	-
RR1	419176	7597904	2017-12-14	RR1-20171214-B4	17.2		depth to water 1.87	Bailer only, unable to drive close enough for pump	5	B4		Yes		NI88		-	-	-	-
RR1	419176	7597904	2017-12-14	RR1-20171214-B5	17.2		depth to water 1.87	Bailer only, unable to drive close enough for pump	5	B5		Yes	5	NI89		-	-	-	-

Appendix 4

Curtin University eDNA Metabarcoding Report

eDNA Metabarcoding Preliminary Report: Blind Cave Eel survey in the Pilbara WA

Prepared for

Rio Tinto
Level 24, 152-158 St Georges Terrace
Perth, WA, 6000

Prepared by

Trace and Environmental DNA (TrEnD) Laboratory

Curtin University

21st March 2018

Report Authors: Dr Nicole White and Prof. Michael Bunce (TrEnD laboratory)

Signature:

(Dr Nicole White) **Date: 21st March 2018**

Disclaimer:
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Executive Summary:

Overall Project objective:

The aim of this pilot project was to use an environmental DNA (eDNA) metabarcoding approach to determine presence/absence of Blind Cave Eel (*Ophisternon candidum*) from within and outside the Mesa H project area in the Pilbara region of Western Australia. The data was to be incorporated into an environmental impact statement (EIS) by Rio Tinto. This interim report documents the results to date and will be superseded by the final report on the project which involves replication of data and design of new assays for eel detection.

Outputs:

- Two collection trips in 2017 were conducted (i) June 2017: 91 water samples from 18 bores were collected and filtered by Michelle Guzik (University of Adelaide. (ii) December 2017: 85 water samples were collected and filtered by Jason Alexander (Biota) from 16 bores and one open surface water sample from the Robe River (5x 1 liter replicates). The TrEnD lab at Curtin University successfully isolated DNA from 122 of these samples.
  .
- As a preliminary first-pass to determine the presence of Blind Cave Eel (*O. candidum*) from 122 water membranes the TrEnD labs Fish 16S assay was used. Although this DNA assay (Fish 16S) isn't specific for Blind Cave Eel our previous research has demonstrated successful amplification of eel DNA.

- The June 2017 water membranes detected the possibility of Blind Cave Eel (*O. candidum*) from bore JW021. The December 2017 water membranes detected the possibility of Blind Cave Eel (*Ophisternon candidum*) from bore 25 and bore RR1. This result is preliminary in nature – detections are currently un-replicated. Additional sites could yield eel signatures as assays are repeated and modified.

- Blind Cave Eel (*O.candidum*) tissue was sourced from the Western Australia Museum (WAM) for comparative purposes. We have sequenced the 16S barcode from this sample.

- Comparisons of the potential Blind Cave Eel (*O. candidum*) DNA sequences from bore JW021 with the National Centre for Biotechnology Information (NCBI) database showed an 85.9% match to *O. bengalense*, an eel-like fish found in northern Australia and 85.9% match to *Synbranchid* sp., a freshwater eel-like fish.

- Comparisons of the potential Blind Cave Eel (*O. candidum*) DNA sequences from bore 25 and RR1 with the NCBI database showed an 87.7%% match to *O. bengalense* and 87.1% match to *Synbranchid* sp.

- Comparisons of the potential Blind Cave Eel (*O. candidum*) DNA sequences from bore JW021, 25 and RR1 with the reference sample obtained from the WAM showed 100% match to the DNA sequences obtained from bore JW021 and 97% match to the DNA sequences from bore 25 and RR1. The genetic sequences in bores 25 and RR1 are 100% similar to each other but distinctly different from the WAM reference or the JW021 sequence. The significance of this genetic difference is unknown.

Recommendations:

- An eDNA approach using a Fish 16S assay has successfully detected Blind Cave Eel from three bores within and outside the Mesa H project area. The sensitivity and reproducibility of these findings still need to be confirmed by the ongoing research program. The successful detection of Blind eel from a non-invasive sample speaks to the promise of eDNA approaches for the detection of taxa in subterranean environments.

1. Introduction

eDNA refers to all genetic material that is recovered from environmental substrates (such as water or sediment). DNA directly from an organism (e.g. microorganisms) as well as trace amounts of DNA that are shed by all organisms is collectively termed eDNA. This preserved, but often degraded, genetic material provides a means to audit species composition and communities at a given location. When combined with recently developed DNA sequencing technologies (termed 'next generation' or 'high-throughput' sequencing), eDNA can provide a wealth of information for studies of introduced marine pests (IMP), biodiversity surveys, food web dynamics, and diet analysis.

Potential applications for monitoring using eDNA include:

- Biosecurity: to detect the presence/absence of introduced species
- Environmental Impact Assessment: baseline/ongoing monitoring and assessment; audit
- Conservation: to detect the presence/absence of threatened species

Rio Tinto has partnered with the Trace and Environmental DNA (TrEnD) Laboratory at Curtin University to develop eDNA tools for Blind Cave Eel (*Ophisternon candidum*) as a means to use DNA-based bio surveys in groundwater monitoring and management.

eDNA sampling has benefits over other traditional survey methods including:

- highly cost-effective monitoring compared to traditional survey methods
- rapid sample collection that is non destructive to habitats, flora and fauna
- non-reliance on individuals with taxonomic expertise, provision of consistent results between monitoring programs, independent of surveyors

The objectives of this project, albeit preliminary, were to use an environmental DNA (eDNA) metabarcoding approach to determine the presence/absence of Blind Cave Eel (*Ophisternon candidum*) a threatened species within the groundwater systems of the Pilbara in Western Australia, specifically the Mesa H area (Rio Tinto). The data was to be incorporated into an environmental impact statement.

2. Methods and Samples

Water samples were collected by Michelle Guzik (University of Adelaide; June 2017) and Jason Alexander (Biota; December 2017) and filtered using a Sentino pump (Pall corporation) as outlined in TrEnD standard operating procedures (available upon request). Turbidity in the water resulted in varying volumes of water that could be filtered between the bores and replicates (see table 1 below and attached electronic data file).

Table 1

Bore water collected by Michelle Guzik (June 2017)								
AWFS ID	**Bore Hole**	**Collection me**	**Date filtered**	**Sample 1 (A)**	**Sample 2 (B)**	**Sample 3 ©**	**Sample 4 (D)**	**Sample 5 (E)**
AWFS-I17-106 (A, B, C, D, E)	JIMWE003	Bailer	13/06/2017	250mL	750mL	1L	1L	650mL
AWFS-I17-107 (A, B, C, D, E)	JW021	Bailer	13/06/2017	700mL	700mL	600mL	600mL	800mL
AWFS-I17-108 (A, B, C, D, E)	BC186	Bailer	13/06/2017	1L	1L	1L	1L	1L
AWFS-I17-109 (A, B, C, D, E)	JW024	Bailer	13/06/2017	1L	1L	1L	700mL	1L
AWFS-I17-110 (A, B, C, D, E)	BC276	Bailer	14/06/2017	1L	500mL	500mL	500mL	250mL
AWFS-I17-111 (A, B, C, D, E)	BC667	Bailer	14/06/2017	250mL	250mL	250mL	1L	1L
AWFS-I17-112 (A, B, C, D, E)	BCP001	Bailer	14/06/2017	250mL (colle	250mL (colle	250mL	1L	1L
AWFS-I17-113 (A, B, C, D, E)	BC458	Bailer	15/06/2017	1L	1L	1L	1L	1L
AWFS-I17-114	Robe River	Container	14/06/2017	700mL	NA	NA	NA	NA
AWFS-I17-115 (A, B, C, D, E)	BUNWO1108	Bailer	15/05/2017	700mL	1L	1L	1L	500mL
AWFS-I17-116 (A, B, C, D)	BUNWB13	Bailer	15/05/2017	1L	750mL	750mL	750mL	NA
AWFS-I17-117 (A, B, C, D, E)	BUNWB09	Bailer	15/06/2017	1L	800mL	800mL	800mL	1L
AWFS-I17-118 (A, B, C, D, E)	BC401	Bailer	16/06/2017	1L	600mL	500mL (colle	1L	1L
AWFS-I17-119 (A, B, C, D, E)	BUNWB08	Bailer	16/06/2017	1L	1L	1L	1L	1L
AWFS-I17-120 (A, B, C, D, E)	BC225	Bailer	15/06/2017	1L	1L	1L	1L	1L
AWFS-I17-121 (A, B, C, D, E)	JIMWE004	Bailer	16/06/2017	1L	1L	1L	800mL	800mL
AWFS-I17-122 (A, B, C, D, E)	BC292	Bailer	16/06/2017	250mL	1L	1L	1L	1L
AWFS-I17-123 (A, B, C, D, E)	BUNWO0773	Bailer	16/06/2017	500mL	500mL	500mL	1L	1L
AWFS-I17-124 (A, B, C, D, E)	PZ11BUN008	Bailer	16/06/2017	600mL	250mL	250mL	250mL	250mL

Bore water collected by Jason Alexander (Biota; December 2017)							
AWFS ID	**Site**	**Easting**	**Northing**	**Date**	**Hole depth**	**Drilled**	**Notes**
AWFS-I18-001 (A,B,C,D,E)	25	432152	7602229	2017-12-13			
AWFS-I18-002 (A,B,C,D,E)	31	432929	7603179	2017-12-13			
AWFS-I18-003 (A,B,C,D,E)	200/Dave Bore	392512.032	7607435.55	2017-12-12			PSS089
AWFS-I18-004 (A,B,C,D,E)	BC186	429578	7587212	2017-12-13			Confirmed eel record 200
AWFS-I18-005 (A,B,C,D,E)	BC401	443563	7574126	2017-12-13			
AWFS-I18-006 (A,B,C,D,E)	Budgie Bore	382494.738	7615587.3	2017-12-12			
AWFS-I18-007 (A,B,C,D,E)	JW023	426138	7590140	2017-12-13			Confirmed Eel record 201
AWFS-I18-008 (A,B,C,D,E)	JW024	427126	7590154	2017-12-13			Confirmed Eel record 201
AWFS-I18-009 (A,B,C,D,E)	MB16MEC0009	393590.062	7601144.51	2017-12-12	43	Drilled 2016	
AWFS-I18-010 (A,B,C,D,E)	MB17MEH0008	417119.5	7600417	2017-12-14	18	29-Aug-17	
AWFS-I18-011 (A,B,C,D,E)	MB17MEH0010	416440	7599848	2017-12-12	30	31-Aug-17	
AWFS-I18-012 (A,B,C,D,E)	MB17MEH0015	416041	7597690	2017-12-14	37	3-Nov-17	
AWFS-I18-013 (A,B,C,D,E)	RR1	419176	7597904	2017-12-14	17.2		depth to water 1.87
AWFS-I18-014 (A,B,C,D,E)	MB16MEC0008	393565	7600580	2017-12-12	36	Drilled 2016	
AWFS-I18-015 (A,B,C,D,E)	MB17MEH0007	417663.8	7600421	2017-12-14	30	29-Aug-17	
AWFS-I18-016 (A,B,C,D,E)	MB17MEH0009	416435.8	7599848	2017-12-12	43	30-Aug-17	
AWFS-I18-017 (A,B,C,D,E)	Control	424478	7597147	2017-12-11			

eDNA was extracted using Qiagen Blood & Tissue DNeasy kits in the TrEnD laboratory at Curtin University in dedicated facilities (inclusive of laboratory clean rooms) suited for eDNA workflows. eDNA derived from the Fish 16S assay was amplified using PCR, followed by sequencing on an Illumina MiSeq in the TrEnD Laboratory. Negative laboratory controls were included (and sequenced if identified as positive) to control for environmental laboratory contamination.

The 16S DNA sequences recovered were compared to the National Centre for Biotechnology Information (NCBI) database for taxonomic identification and to reference Blind Cave Eel (*Ophisternon candidum*) obtained from the WAM (P.34817-001).

3. Results and Discussion

The following table outlines the taxonomic assignments from each bore water sample for which suspected Blind Cave Eel (*Ophisternon candidum*) was amplified and sequenced. Taxonomic assignments are to genera and species with the per cent match genetic similarity to the DNA sequences contained on the reference database (NCBI). At the time of this report, the taxonomic assignments for the DNA sequences obtained from the bore water samples (i.e. DNA 'barcodes') are listed in the table below and the electronic file accompanying this report. The environmental laboratory controls for this work were identified as negative and not included in the Table.

Table 2

Taxonomic Assignments			
AWFS ID	**Bore**	**% match (NCBI)**	**Species**
AWFS-I17-107B	JW021	85.9	Synbranchid sp. VietNam-TC-2002 haplotype 1
		85.9	Ophisternon bengalense voucher MRS haplotype OB1
AWFS-I18-001A	25	87.1	Synbranchid sp. VietNam-TC-2002 haplotype 1
		87.1	Ophisternon bengalense voucher MRS haplotype OB1
AWFS-I18-013A	RR1	87.1	Synbranchid sp. VietNam-TC-2002 haplotype 1
		87.1	Ophisternon bengalense voucher MRS haplotype OB1
AWFS-I18-013C	RR1	87.1	Synbranchid sp. VietNam-TC-2002 haplotype 1
		87.1	Ophisternon bengalense voucher MRS haplotype OB1
AWFS-F18-005 BlindEel_WAM P.34817-001		85.9	Synbranchid sp. VietNam-TC-2002 haplotype 1
		85.9	Ophisternon bengalense voucher MRS haplotype OB1

Fish DNA was detected in a number of sampling locations. This preliminary report is only reporting on, and presenting data from, those bores that yielded eel DNA.

Comparisons of the potential Blind Cave Eel (*O. candidum*) DNA sequences from bore JW021 with the NCBI database showed an 85.9% match to *O. bengalense*, an eel-like fish found in northern Australia and 85.9% match to *Synbranchid* sp., a freshwater eel-like fish (see Table 2). The DNA barcode recovered from JW021 was a 100% match to the reference DNA sequence from the WAM Blind Cave Eel (*O. candidum*) sample. Eel DNA was recovered in one of two replicates from bore JW021

Comparisons of the potential Blind Cave Eel (*O. candidum*) DNA sequences from bore 25 and RR1 with the NCBI database showed an 87.7%% match to *O. bengalense* and 87.1% match to Synbranchid sp. (see table 2). The DNA barcode recovered from bore RR1 and bore 25 was a 97% match to the reference DNA sequence from the WAM Blind Cave Eel (*O. candidum*) sample. Eel DNA was recovered in two of the five replicates from bore RR1 and one of five replicates from bore 25.

The genetic sequences in bores 25 and RR1 are 100% similar to each other but distinctly different from the WAM reference or the JW021 sequence. The significance of this genetic difference is

unknown it may represent variation within the species or a distinct lineage. There is a distinctive DNA 'insertion' in the sequences obtained from JW021 and the WAM reference that is the major distinguishing feature (see Figure 1)

Figure 1: 16S DNA sequences from bore JW021, RR1, 25 and *O. candidum* (WAM P.34817-001)

4. Findings, Recommendations and Concluding remarks

The Fish 16S metabarcoding assay utilised on the bore water samples collected in June and December 2017 detected the potential Blind Cave Eel (*O. candidum*) in three of 34 bores. To our knowledge this represents the first time an eDNA based approach has been used in the ground water system(s) in the Pilbara for the detection of a restricted species. The gaps in the reference databases often prevent definitive assignments to genus and/or species at the time of this report. Although comparisons of the suspected Blind Cave Eel (*O. candidum*) DNA sequences with the DNA sequences obtained from a tissue sample of Blind Cave Eel (*O. candidum*) from the WAM indicate the strong likelihood of Blind Cave Eel (*O. candidum*). Current laboratory work is underway to sequence the complete mitochondrial genome from the WAM reference sample and develop a metabarcoding assay specific for Blind Cave Eel (*O. candidum*). Once completed, the Blind Cave Eel (*Ophisternon candidum*) metabarcoding assay will be used to re-screen the 122 water samples to validate the findings from the Fish 16S assay and potentially find additional bores that may contain Blind Cave Eel (*O. candidum*).

The DNA yields recovered from the bores was low and, as expected, not every replicate from positive wells yielded a positive detection. The sensitivity of the assays and the level of replication appropriate is yet to be determined for bores in the Pilbara. The development of additional assays and optimisation of existing assays (and sampling protocols) is ongoing and will likely enhance the likelihood of detections.

5. Appendices and additional information

- An electronic file titled; Appendix_BlindCaveEel_March2018.xlsx is attached to this report.

- Additional information on sampling and methods are available from TrEnD upon request however the exact nature of the assays and workflow are proprietary.

- Below is a list of acronyms, abbreviations and definitions that may apply to aspects of this report.

% value in data	Represents the percentage similarity of a DNA sequence recovered from a sample compared to reference sequences in a database (e.g. compared to DNA databases such as GenBank or references generated in-house)
(x) value in data	Represents the frequency the % value was recorded in the dataset
16S rRNA	The 16S rRNA refers to a conserved gene region of mitochondrial DNA, which codes for a subunit of the ribosome. 16S rRNA is found in all eukaryotes making it a good candidate for DNA barcoding and is used extensively to detect vertebrate taxa such as fish and mammals.
18S rRNA	The 18S rRNA refers to a conserved gene region of nuclear DNA, which codes for a subunit of the ribosome. 18S rRNA is found in all eukaryotes making it a good candidate for DNA barcoding
18S IMS reference database	Reference 18S rRNA sequences of invasive marine species that are available in DNA databases
Assay	In the context of metabarcoding an assay is a molecular test (using PCR) that is implemented to target a group of taxa within a mixed biological substrate. It is akin to using a magnet to selective enrich for needles (the target) in the context of a haystack (the total DNA from a sample).
COI	The gene region that is being used as the standard barcode for almost all animal groups is a 648 base-pair region of the mitochondrial cytochrome c oxidase 1 gene ("CO1"). COI is proving highly effective in identifying birds, butterflies, fish, flies and many other animal groups. COI is not an effective barcode region in plants because it evolves too slowly, but two gene regions in the chloroplast, matK and rbcL, have been approved as the barcode regions for plants
CO1 IMS reference database	Reference COI sequences of invasive marine species that are available in DNA databases
DNA	Deoxyribonucleic Acid (DNA) is the hereditary material that contains the genetic information of an organism
DNA metabarcoding	Is a genetic technique that simultaneously amplifies and sequences barcode regions

	(e.g. COI, 18S, 16S) of many different species in parallel
eDNA	Environmental DNA (eDNA) refers to genetic material that is recovered from an environmental substrate (e.g. water, sediment, air)
eukaryotes	An organism where cells contain a nucleus surrounded by a membrane and has the DNA bound together by proteins (histones) into chromosomes. The cells of eukaryotes also contain an endoplasmic reticulum and numerous specialised organelles not present in prokaryotes, especially mitochondria, golgi bodies, and lysosomes
Fisheries	Department of Primary Industries and Regional Development, Fisheries Division, Aquatic Biosecurity Section
GenBank	Publically available repository of genetic information. Contains the barcode information of genes that have previously been sequenced
Genome	A genome is all the genetic material of an organism. It consists of DNA (or RNA in RNA viruses). The genome includes both the genes (the coding regions) and the noncoding DNA. In eukaryotes it refers to the genomes of the nucleus, mitochondria and chloroplasts. In prokaryotes, there is a single genome (as they do not contain mitochondria or chloroplasts)
Illumina MiSeq	Next generation sequencing platform developed by the company Illumina
IMP	Introduced marine pests
IMS	Introduced marine species
Metabarcoding assay	A PCR reaction using a specific set of primers that simultaneously amplifies the same gene target from multiple species
Mitochondria	The mitochondrion (plural mitochondria) is a double membrane-bound organelle found in all eukaryotic organisms, although some cells in some organisms may lack them (e.g. Red blood cells). It contains its own genome
Mitogenomes	Refers to the mitochondrial genome
NGS	Next generation sequencing or second generation sequencing refers to massively parallel sequencing technology, as opposed to first generation sequencing or sanger sequencing where only a single template is sequenced at one time
Nucleotide	A compound consisting of a nucleoside linked to a phosphate group. Nucleotides form the basic structural unit of nucleic acids such as DNA
PCR	Polymerase chain reaction (PCR) is the technique that is used to amplify (akin to photocopying DNA) specific regions of the genome from specific groups of taxa
Primer	A short DNA strand (≈20bp in size) used in PCR to target particular groups of organisms and genes. Two of them are required for PCR (a forward and a reverse)
Primer binding site	A primer-binding site is the target region of a genome where the primer attaches to start replication. The primer binding site is on one of the two complementary strands of a double-stranded nucleotide polymer, in the strand which is to be copied, or is within a single-stranded nucleotide polymer sequence
prokaryote	Any of the typically unicellular microorganisms that lack a distinct nucleus and

	membrane-bound organelles and that are classified as a kingdom (Prokaryotae syn. Monera) or into two domains (Bacteria and Archaea)
RNA	Ribonucleic acid (RNA) is a polymeric molecule implicated in various biological roles in coding, decoding, regulation, and expression of genes
rRNA	ribosomal ribonucleic acid is the RNA component of the ribosome, and is essential for protein synthesis in all living organisms
Sequence	DNA sequencing is the process of determining the precise order of nucleotides within a DNA molecule. It includes any method or technology that is used to determine the order of the four bases—adenine, guanine, cytosine, and thymine—in a strand of DNA
Shotgun sequencing	Refers to randomly sequencing short pieces of DNA (≈150bp in size) after shearing or cutting DNA (e.g. fragmenting a genome)
TrEnD	Trace and Environmental DNA laboratory, Curtin University

Follow-up Report: eDNA metabarcoding for Blind Cave Eel survey in the Pilbara WA

Prepared for

Rio Tinto
Level 24, 152-158 St Georges Terrace
Perth, WA, 6000

Prepared by

Trace and Environmental DNA (TrEnD) Laboratory

Curtin University

13th August 2018

Report Authors: Dr Nicole White (TrEnD laboratory)

Signature:

Dr Nicole White **Date:** **13 August 2018**

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Executive Summary:

Overall Project objective:

The aim of this pilot project was to use an environmental DNA (eDNA) metabarcoding approach to determine presence/absence of Blind Cave Eel (*Ophisternon candidum*) from within and outside the Mesa H project area in the Pilbara region of Western Australia. The data was to be incorporated into an environmental impact statement (EIS) by Rio Tinto.

Outputs:

- This report is a follow-up of the results from the EelFishCOI 'molecular magnet' designed for Blind Cave Eel (*Ophisternon candidum*) detection. This report presents the eDNA results following on from the report issued to RioTinto on the 13th July 2018 by the TrEnD lab.

- The presence of Blind Cave Eel (*Ophisternon candidum*) DNA was confirmed from two sample sites of the Robe River and bores JW021, JW024, BC186, 25, RR1 and MB17MEH0015. Blind Cave Eel DNA was not previously detected from MB17MEH0015 with the EelFish16S assay reported on 13th July 2018. Re-screening all 122 eDNA water membranes collected in June and December 2017 with Fish16S and EelFishCOI 'molecular magnets' confirms the presence of *O. candidum* from this additional bore.

Recommendations:

- This is the first time eDNA metabarcoding methods have been implemented in the Pilbara groundwater systems. The Fish16S, EelFish16S and EelFishCOI metabarcoding assays designed by the TrEnD lab indicates that an eDNA approach is able to detected Blind Cave Eel (*Ophisternon candidum*) from the survey area as a non-invasive method. Blind Cave Eel (*Ophisternon candidum*) DNA was isolated and DNA sequenced from 6 bores sampled, in addition to two open surface water samples collected from the Robe River, which indicates eDNA metabarcoding is capable of detecting threatened species. Finally it is worth noting that these eDNA assays are performing at the limits of detection and further gains in sensitivity may be achievable with optimised sampling.
-

1. Introduction

eDNA refers to all genetic material that is recovered from environmental substrates (such as water or sediment). DNA directly from an organism (e.g. microorganisms) as well as trace amounts of DNA that are shed by all organisms is collectively termed eDNA. This preserved, but often degraded, genetic material provides a means to audit species composition and communities at a given location. When combined with recently developed DNA sequencing technologies (termed 'next generation' or 'high-throughput' sequencing), eDNA can provide a wealth of information for studies of introduced marine pests (IMP), biodiversity surveys, food web dynamics, and diet analysis.

Potential applications for monitoring using eDNA include:

- Biosecurity: to detect the presence/absence of introduced species
- Environmental Impact Assessment: baseline/ongoing monitoring and assessment; audit
- Conservation: to detect the presence/absence of threatened species

Rio Tinto has partnered with the Trace and Environmental DNA (TrEnD) Laboratory at Curtin University to develop eDNA tools for Blind Cave Eel (*Ophisternon candidum*) as a means to use DNA-based bio surveys in groundwater monitoring and management.

eDNA sampling has benefits over other traditional survey methods including:

- highly cost-effective monitoring compared to traditional survey methods
- rapid sample collection that is non destructive to habitats, flora and fauna
- non-reliance on individuals with taxonomic expertise, provision of consistent results between monitoring programs, independent of surveyors

The objectives of this project were to use an environmental DNA (eDNA) metabarcoding approach to determine the presence/absence of Blind Cave Eel (*Ophisternon candidum*) a threatened species within the groundwater systems of the Pilbara in Western Australia, specifically the Mesa H area (Rio Tinto). The data is to be incorporated into an environmental impact statement.

2. Methods and Samples

Please refer to report "**eDNA Metabarcoding Report: Blind Cave Eel survey in the Pilbara WA**" issued to RioTinto by the TrEnD lab on 13th July 2018.

3. Results and Discussion

Table 1 list the water samples from each bore and those for which Blind Cave Eel (*Ophisternon candidum*) were detected with the Fish16S, EelFish16S and EelFishCOI metabarcoding assays. DNA sequences obtained for *O. candidum* can be found in the Supplementary Information accompanying this report.

Table 1: Results of eDNA metabarcoding (Fish16S, EelFish16S, EelFishCOI) from groundwater for Blind Cave Eel (*Ophisternon candidum*) detection.

TrEnD Sample ID	Site (bore code)	Field Trip	Ophisternon candidum DNA detected?
AWFS-I17-106	JIMWE003	Jun-17	No
AWFS-I17-107	JW021	Jun-17	Yes
AWFS-I17-108	BC186	Jun-17	No
AWFS-I17-109	JW024	Jun-17	No
AWFS-I17-110	BC276	Jun-17	No
AWFS-I17-111	BC667	Jun-17	No
AWFS-I17-112	BCP001	Jun-17	No
AWFS-I17-113	BC458	Jun-17	No
AWFS-I17-114	Robe River (RR)	Jun-17	Yes
AWFS-I17-115	BUNWO1108	Jun-17	No
AWFS-I17-116	BUNWB13	Jun-17	No
AWFS-I17-117	BUNWB09	Jun-17	No
AWFS-I17-118	BC401	Jun-17	No
AWFS-I17-119	BUNWB08	Jun-17	No
AWFS-I17-120	BC225	Jun-17	No
AWFS-I17-121	JIMWE004	Jun-17	No
AWFS-I17-122	BC292	Jun-17	No
AWFS-I17-123	BUNWO0773	Jun-17	No
AWFS-I17-124	PZ11BUN008	Jun-17	No
AWFS-I18-001	25	Dec-17	Yes
AWFS-I18-002	31	Dec-17	No
AWFS-I18-003	200/Dave Bore	Dec-17	No
AWFS-I18-004	BC186	Dec-17	Yes
AWFS-I18-005	BC401	Dec-17	No
AWFS-I18-006	Budgie Bore	Dec-17	No
AWFS-I18-007	JW023	Dec-17	No
AWFS-I18-008	JW024	Dec-17	Yes
AWFS-I18-009	MB16MEC0009	Dec-17	No
AWFS-I18-010	MB17MEH0008	Dec-17	No
AWFS-I18-011	MB17MEH0010	Dec-17	No
AWFS-I18-012	MB17MEH0015	Dec-17	Yes
AWFS-I18-013	RR1	Dec-17	Yes

AWFS-I18-014	MB16MEC0008	Dec-17	No
AWFS-I18-015	MB17MEH0007	Dec-17	No
AWFS-I18-016	MB17MEH0009	Dec-17	No
AWFS-I18-017	Control (RR)	Dec-17	Yes

4. Findings, Recommendations and Concluding remarks

At the time of report "**eDNA Metabarcoding Report: Blind Cave Eel survey in the Pilbara WA**" issued to RioTinto by the TrEnD lab on 13th July 2018, the water samples identified as positive from the EelFishCOI and Fish16S metabarcoding assays had not been DNA sequenced and bioinformatically processed.

The Fish16S, EelFish16S and EelFishCOI assays utilised on bore water samples collected in June and December 2017 detected Blind Cave Eel (*Ophisternon candidum*) from two sample locations of the Robe River, in addition to bores JW021, JW024, BC186, 25, RR1 and MB17MEH0015. To our knowledge this represents the first time an eDNA based metabarcoding approach, specific for *Ophisternon candidum*, has been applied to samples from ground water system(s) in the Pilbara, Western Australia. Sequencing the mitochondrial genome of *Ophisternon candidum* (WAM P.34817-001) has provided definitive assignments of DNA sequences from eDNA groundwater samples to genus and species.

5. Appendices and additional information

- An electronic file titled; SupplementaryInformation_EelFish16SandCOI_August2018.xlsx is attached to this report.

- Additional information on sampling and methods are available from TrEnD upon request however the exact nature of the assays and workflow are proprietary.

- Below is a list of acronyms, abbreviations and definitions that may apply to aspects of this report.

% value in data	Represents the percentage similarity of a DNA sequence recovered from a sample compared to reference sequences in a database (e.g. compared to DNA databases such as GenBank or references generated in-house)
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18S rRNA	The 18S rRNA refers to a conserved gene region of nuclear DNA, which codes for a subunit of the ribosome. 18S rRNA is found in all eukaryotes making it a good candidate for DNA barcoding
18S IMS reference database	Reference 18S rRNA sequences of invasive marine species that are available in DNA databases
Assay	In the context of metabarcoding an assay is a molecular test (using PCR) that is implemented to target a group of taxa within a mixed biological substrate. It is akin to using a magnet to selective enrich for needles (the target) in the context of a haystack (the total DNA from a sample).
COI	The gene region that is being used as the standard barcode for almost all animal groups is a 648 base-pair region of the mitochondrial cytochrome c oxidase 1 gene ("CO1"). COI is proving highly effective in identifying birds, butterflies, fish, flies and many other animal groups. COI is not an effective barcode region in plants because it evolves too slowly, but two gene regions in the chloroplast, matK and rbcL, have been approved as the barcode regions for plants
CO1 IMS reference database	Reference COI sequences of invasive marine species that are available in DNA databases
DNA	Deoxyribonucleic Acid (DNA) is the hereditary material that contains the genetic information of an organism
DNA metabarcoding	Is a genetic technique that simultaneously amplifies and sequences barcode regions (e.g. COI, 18S, 16S) of many different species in parallel
eDNA	Environmental DNA (eDNA) refers to genetic material that is recovered from an environmental substrate (e.g. water, sediment, air)

eukaryotes	An organism where cells contain a nucleus surrounded by a membrane and has the DNA bound together by proteins (histones) into chromosomes. The cells of eukaryotes also contain an endoplasmic reticulum and numerous specialised organelles not present in prokaryotes, especially mitochondria, golgi bodies, and lysosomes
Fisheries	Department of Primary Industries and Regional Development, Fisheries Division, Aquatic Biosecurity Section
GenBank	Publically available repository of genetic information. Contains the barcode information of genes that have previously been sequenced
Genome	A genome is all the genetic material of an organism. It consists of DNA (or RNA in RNA viruses). The genome includes both the genes (the coding regions) and the noncoding DNA. In eukaryotes it refers to the genomes of the nucleus, mitochondria and chloroplasts. In prokaryotes, there is a single genome (as they do not contain mitochondria or chloroplasts)
Illumina MiSeq	Next generation sequencing platform developed by the company Illumina
IMP	Introduced marine pests
IMS	Introduced marine species
Metabarcoding assay	A PCR reaction using a specific set of primers that simultaneously amplifies the same gene target from multiple species
Mitochondria	The mitochondrion (plural mitochondria) is a double membrane-bound organelle found in all eukaryotic organisms, although some cells in some organisms may lack them (e.g. Red blood cells). It contains its own genome
Mitogenomes	Refers to the mitochondrial genome
NGS	Next generation sequencing or second generation sequencing refers to massively parallel sequencing technology, as opposed to first generation sequencing or sanger sequencing where only a single template is sequenced at one time
Nucleotide	A compound consisting of a nucleoside linked to a phosphate group. Nucleotides form the basic structural unit of nucleic acids such as DNA
PCR	Polymerase chain reaction (PCR) is the technique that is used to amplify (akin to photocopying DNA) specific regions of the genome from specific groups of taxa
Primer	A short DNA strand (≈20bp in size) used in PCR to target particular groups of organisms and genes. Two of them are required for PCR (a forward and a reverse)
Primer binding site	A primer-binding site is the target region of a genome where the primer attaches to start replication. The primer binding site is on one of the two complementary strands of a double-stranded nucleotide polymer, in the strand which is to be copied, or is within a single-stranded nucleotide polymer sequence
prokaryote	Any of the typically unicellular microorganisms that lack a distinct nucleus and membrane-bound organelles and that are classified as a kingdom (Prokaryotae syn. Monera) or into two domains (Bacteria and Archaea)
RNA	Ribonucleic acid (RNA) is a polymeric molecule implicated in various biological roles in coding, decoding, regulation, and expression of genes

rRNA	ribosomal ribonucleic acid is the RNA component of the ribosome, and is essential for protein synthesis in all living organisms
Sequence	DNA sequencing is the process of determining the precise order of nucleotides within a DNA molecule. It includes any method or technology that is used to determine the order of the four bases—adenine, guanine, cytosine, and thymine—in a strand of DNA
Shotgun sequencing	Refers to randomly sequencing short pieces of DNA (≈150bp in size) after shearing or cutting DNA (e.g. fragmenting a genome)
TrEnD	Trace and Environmental DNA laboratory, Curtin University

Appendix 5

WAM Morphological Identification of Troglobitic Spiders

WAM Report

Troglobitic Spiders from Mesa H, Robe Valley, Western Australia

(Project *Mesa H Troglobitic Spiders*)

Report to Biota

16 Mar 2017

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Although identifications in this report were consistent with the best available information and current scientific thinking at the time of identification the use of this report is at the risk of the user. Any liability to users of this report for loss of any kind arising out of the use of this report or the information and identifications it contains is expressly disclaimed.

SUMMARY

Specimens were submitted to the Western Australian Museum on the 13th March 2017. The project contained: A Spider from the family Oonopidae (n=1) and a spider from the family Gnaphosidae (n=1). A summary of specimen identifications together with their SRE status may be found in Table 1. A full explanation of the SRE categories used by the Western Australian Museum may be found in Appendix 1.

Table 1. Summary of specimen identifications and SRE status.

ORDER	FAMILY	GENUS	SPECIES	# OF SPECIMENS	SRE STATUS	SRE SUB-CATEGORY
Araneae	Oonopidae	*Prethopalpus*	`ARA052`	1	Potential SRE	(E) Research and experience
Araneae	Gnaphosidae	Genus indet.	`sp. indet. (juv.)`	1	Potential SRE	(A) Juvenile

SHORT-RANGE ENDEMISM

The terrestrial invertebrate fauna of inland Australia contains a plethora of species, and just the arthropods were recently estimated to consist of more than 250,000 species (Yeates, Harvey et al. 2004; Chapman 2009). The vast majority of these are found within the Insecta and Arachnida, although significant numbers of millipedes are to be expected. For many years, the prospect of including invertebrates in assessments of biological systems subject to modification proved daunting because of the large numbers of unknown species. These animals were largely ignored, as they were too diverse and their taxonomy too little known for them to be considered in environmental surveys that require a rapid turn-around time.

In a recent publication, the issue of Short-Range Endemism in the Australian invertebrate fauna was examined (Harvey 2002). Species that could be defined as Short-Range Endemics (SRE) were those that had a naturally small range of less than 10,000 km^2. Harvey (2002) found that those species possessed a series of distinct ecological and life-history traits that contributed to their limited distributions, including:

- poor powers of dispersal;
- confinement to discontinuous habitats;
- usually highly seasonal, only active during cooler, wetter periods; and
- low levels of fecundity.

A number of major invertebrate groups have a high proportion of individual species that show these traits and can be considered SRE's. The Western Australian fauna contains a number of SRE taxa, including millipedes, land snails, trap-door spiders, some pseudoscorpions, slaters, and onychophorans and these represent focal groups in Environmental Impact Assessment studies in the state (EPA 2009). The south coast region is relatively well known compared with other regions of the state (Framenau, Moir et al. 2008), but there are many poorly known species and gaps in our understanding of the distributions of many species.

METHODS

Specimens collected by Biota were submitted to the Western Australian Museum on the 13th March 2017. The specimens were examined at the WA museum using Leica dissecting microscopes (MZ6, MZ16). The SRE status of the taxonomic group was given using the SRE categorisation system developed and implemented by the Western Australian Museum. A full explanation of the WAM SRE categories is available in Appendix 1.

SIGNIFICANT OUTCOMES

This project has found one species that may have significant SRE outcomes.

The significant findings are summarised below.

ARACHNIDA

ORDER ARANEAE

Family Oonopidae

1. *Prethopalpus `ARA052`*
    - **SRE Category: Potential SRE; (B) Habitat indicators; (E) Research and experience.**
    - Examination of the adult male morphology, specifically the shape of the male pedipalp and abdominal scutae, combined with the locality would indicate that it is likely an undescribed species within *Prethopalpus* and has been allocated the WAM species code 'ARA052'.

      Baehr *et al*. (2014) described 14 troglobitic *Prethopalpus* species from the arid zone of Western Australia, all of which are SREs and many known only from a single bore. Two species have been recorded from the Robe River Valley, *Prethopalpus scanloni* from bore DBRC089 and the other *P*. `ARA051` from bore MEBRC0073, Mesa B. No specimens of this genus have yet been collected from Mesa H. This species is similar to that of *P. scanloni* in having a bulging epigastric plate in lateral view, but differs by having a dorsal scute, whereas *P. scanloni* does not. Further, given the limited distributional ability of this taxa, and its location within an isolated mesa (Mesa H), makes this species likely to be an SRE. Collections of adult troglobitic spiders are patchy and occur rarely, so this find is particularly significant.

APPENDIX 1. WAM SHORT-RANGE ENDEMIC CATEGORIES

	Taxonomic Certainty	Taxonomic Uncertainty
Distribution < 10 000km^2	**Confirmed SRE** • *A known distribution of < 10 000km².* • *The taxonomy is well known.* • *The group is well represented in collections and/ or via comprehensive sampling.*	**Potential SRE** • *Patchy sampling has resulted in incomplete knowledge of the geographic distribution of the group.* • *We have incomplete taxonomic knowledge.* • *The group is not well represented in collections.* • *This category is most applicable to situations where there are gaps in our knowledge of the taxon.* **Sub-categories for this SRE designation are outlined below**
Distribution > 10 000km^2	**Widespread (not an SRE)** • *A known distribution of > 10 000km².* • *The taxonomy is well known.* • *The group is well represented in collections and/ or via comprehensive sampling.*	

SRE SUB-CATEGORIES

If a taxon is determined to be a "Potential SRE", the following sub-categories will further elucidate this status.

A. *Data Deficient:*
- There is insufficient data available to determine SRE status.
- Factors that fall under this category include:
  - New species.
  - Lack of geographic information.
  - Lack of taxonomic information.
  - The group may be poorly represented in collections.
  - The individuals sampled (e.g. juveniles) may prevent identification to species level.

B. *Habitat Indicators:*
- It is becoming increasingly clear that habitat data can elucidate SRE status.
- Where habitat is known to be associated with SRE taxa and vice versa, it will be noted here.

C. *Morphology Indicators:*
- A suite of morphological characters are characteristic of SRE taxa.
- Where morphological characters are known to be associated with SRE taxa and vice-versa, it will be noted here.

D. *Molecular Evidence:*
- If molecular work has been done on this taxon (or a close relative), it may reveal patterns congruent or incongruent with SRE status.

E. *Research & Expertise:*
- Previous research and/ or WAM expertise elucidates taxon SRE status.
- This category takes into account the expert knowledge held within the WAM.

APPENDIX 2. SPECIMEN DATA FOR [TAXA] COLLECTED FROM [GEOGRAPHIC LOCATION]

REGNO	FLDNO	ORDER	INFRAORDER	FAMILY	GENUS	SPECIES	AUTHORITY	STATE	SITE	LATITUDE	LONGITUDE	M	F	JUV	TOT
142823	RC16JIM0019.20161027-01	Araneae	Araneomorphae	Oonopidae	*Prethopalpus*	*`ARA052`*		W.A.	Mesa H, ca. 18 km SSE. Pannawonica	21°47'22"S	116°15'18"E	1			1
142824	RC14MEH0270.20161212.T4-02	Araneae	Araneomorphae	Gnaphosidae		`sp. indet. (juv.)`		W.A.	Mesa H, ca. 18 km SE. Pannawonica	21°45'50"S	116°12'38"E			1	1

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Appendix 6

Fauna Recorded

Site	Phase	Easting	Northing	Date	Phylum	Class	Order	Family	Genus	Species	n	Field code	WAM registration	Preservation	Identifier	Identification method	Lineage
DD13MEH0007	Phase 1	419635.017	7593002.209	24/10/15	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	DD13MEH0007-20151024-01B	C60931	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
DD13MEH0007	Phase 1	419635.017	7593002.209	24/10/15	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	DD13MEH0007-20151024-01C	C60932	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
DD13MEH0007	Phase 1	419635.017	7593002.209	24/10/15	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	DD13MEH0007-20151024-01D	C60933	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
DD13MEH0007	Phase 1	419635.017	7593002.209	24/10/15	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	DD13MEH0007-20151024-01E	C60934	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
DD13MEH0007	Phase 1	419635.017	7593002.209	24/10/15	Arthropoda	Maxillopoda	Cyclopoida	Cyclopidae	Diacyclops	humphreysi	10	DD13MEH000720151024-02			Stuart Halse	Morphologic	
DD13MEH0007	Phase 1	419635.017	7593002.209	24/10/15	Arthropoda	Maxillopoda	Calanoida	Ridgewayiidae	Stygoridgewayia	trispinosa	10	DD13MEH000720151024-02			Jane McRae	Morphologic	
DD13MEH0007	Phase 1	419635.017	7593002.209	24/10/15	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	DD13MEH0007-20151024-01A	C60930	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
RC13MEH0007	Phase 1	419641.545	7592602.94	24/10/15	Arthropoda	Maxillopoda	Cyclopoida	Cyclopidae	Diacyclops	humphreysi	10	RC13MEH000720151024-01			Stuart Halse	Morphologic	
RC13MEH0007	Phase 1	419641.545	7592602.94	24/10/15	Arthropoda	Maxillopoda	Calanoida	Ridgewayiidae	Stygoridgewayia	trispinosa	14	RC13MEH000720151024-02			Jane McRae	Morphologic	
RC13MEH0007	Phase 1	419641.545	7592602.94	24/10/15	Arthropoda	Malacostraca	Amphipoda	Paramelitidae		sp. 'AMP035'	1	RC13MEH0007-20151024-03	C60949	100% Ethanol	Terrie Finston	Molecular	HelixAMP035
RC13MEH0041	Phase 1	419940.332	7592705.239	24/10/15	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	RC13MEH0041-20151024-01	C60951	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
RC13MEH0097	Phase 1	420085.762	7592803.224	24/10/15	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	RC13MEH0097-20151024-01C	C60954	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
RC13MEH0097	Phase 1	420085.762	7592803.224	24/10/15	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM026'	1	RC13MEH0097-20151024-01A	C60952	100% Ethanol	Terrie Finston	Molecular	HelixAMM026
RC13MEH0097	Phase 1	420085.762	7592803.224	24/10/15	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	RC13MEH0097-20151024-01B	C60953	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
RC14MEH0018	Phase 1	419087.88	7593298.882	25/10/15	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	RC14MEH0018-20151025-01	C60955	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
RC14MEH0053	Phase 1	419091.838	7592752.187	24/10/15	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	RC14MEH0053-20151024-01B	C60963	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
RC14MEH0053	Phase 1	419091.838	7592752.187	24/10/15	Arthropoda	Maxillopoda	Calanoida	Ridgewayiidae	Stygoridgewayia	trispinosa	9	RC14MEH005320151024-02			Jane McRae	Morphologic	
RC14MEH0053	Phase 1	419091.838	7592752.187	24/10/15	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	RC14MEH0053-20151024-01A	C60962	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
DD13MEH0007	Phase 2	419635.017	7593002.209	19/1/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	DD13MEH0007-20160119-01B	C60937	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
DD13MEH0007	Phase 2	419635.017	7593002.209	19/1/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	DD13MEH0007-20160119-01C	C60938	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
DD13MEH0007	Phase 2	419635.017	7593002.209	19/1/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	DD13MEH0007-20160119-01D	C60939	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
DD13MEH0007	Phase 2	419635.017	7593002.209	19/1/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	DD13MEH0007-20160119-01E	C60940	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
DD13MEH0007	Phase 2	419635.017	7593002.209	19/1/16	Nematoda					sp.	1		C8560	100% Ethanol	Penny Brooshooft	Morphologic	
DD13MEH0007	Phase 2	419635.017	7593002.209	19/1/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	DD13MEH0007-20160119-01A	C60936	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
RC12JIM0019	Phase 2	421395.839	7591472.302	19/1/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	RC12JIM0019-20160119-01B	C60943	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
RC12JIM0019	Phase 2	421395.839	7591472.302	19/1/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	RC12JIM0019-20160119-01D	C60945	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
RC12JIM0019	Phase 2	421395.839	7591472.302	19/1/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	RC12JIM0019-20160119-01E	C60946	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
RC12JIM0019	Phase 2	421395.839	7591472.302	19/1/16	Arthropoda	Malacostraca	Amphipoda			sp.	1	RC12JIM0019-20160119-01C	C60944	100% Ethanol	Nicola Watson	Morphologic	Failed
RC12JIM0019	Phase 2	421395.839	7591472.302	19/1/16	Nematoda					sp.	1		C8661	100% Ethanol	Penny Brooshooft	Morphologic	
RC12JIM0019	Phase 2	421395.839	7591472.302	19/1/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	RC12JIM0019-20160119-01A	C60942	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
RC13MEH0040	Phase 2	419892.868	7592704.088	19/1/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	RC13MEH0040-20160119-01B	C60948	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
RC13MEH0040	Phase 2	419892.868	7592704.088	19/1/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	RC13MEH0040-20160119-01A	C60947	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
RC13MEH0041	Phase 2	419940.332	7592705.239	19/1/16	Arthropoda	Malacostraca	Amphipoda	Paramelitidae		sp. 'AMP003'	1	RC13MEH0041-20160119-01	C60950	100% Ethanol	Terrie Finston	Molecular	HelixAMP003
RC14MEH0018	Phase 2	419087.88	7593298.882	19/1/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	RC14MEH0018-20160119-01B	C60958	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
RC14MEH0018	Phase 2	419087.88	7593298.882	19/1/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	RC14MEH0018-20160119-01C	C60959	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
RC14MEH0018	Phase 2	419087.88	7593298.882	19/1/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	RC14MEH0018-20160119-01D	C60960	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
RC14MEH0018	Phase 2	419087.88	7593298.882	19/1/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	RC14MEH0018-20160119-01E	C60961	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
RC14MEH0018	Phase 2	419087.88	7593298.882	19/1/16	Arthropoda	Maxillopoda	Calanoida	Ridgewayiidae	Stygoridgewayia	trispinosa	1	RC14MEH0018.20160119-02			Jane McRae	Morphologic	
RC14MEH0018	Phase 2	419087.88	7593298.882	19/1/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	RC14MEH0018-20160119-01A	C60957	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
RC14MEH0053	Phase 2	419091.838	7592752.187	19/1/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	RC14MEH0053-20160119-01B	C60966	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
RC14MEH0053	Phase 2	419091.838	7592752.187	19/1/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	RC14MEH0053-20160119-01C	C60967	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
RC14MEH0053	Phase 2	419091.838	7592752.187	19/1/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	RC14MEH0053-20160119-01D	C60968	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
RC14MEH0053	Phase 2	419091.838	7592752.187	19/1/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	RC14MEH0053-20160119-01E	C60969	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
RC14MEH0053	Phase 2	419091.838	7592752.187	19/1/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	RC14MEH0053-20160119-01A	C60965	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
Dave Bore	Phase 3	392512	7607436	5/5/16	Arthropoda	Malacostraca	Amphipoda	Neoniphargidae		sp. 'AMN008'	1	200-20160505-02B	C70336	100% Ethanol	Terrie Finston	Molecular	HelixAMN008
Dave Bore	Phase 3	392512	7607436	5/5/16	Arthropoda	Malacostraca	Amphipoda	Neoniphargidae		sp. 'AMN008'	1	200-20160505-02C	C70337	100% Ethanol	Terrie Finston	Molecular	HelixAMN008
Dave Bore	Phase 3	392512	7607436	5/5/16	Arthropoda	Malacostraca	Amphipoda	Neoniphargidae		sp. 'AMN008'	1	200-20160505-02D	C70338	100% Ethanol	Terrie Finston	Molecular	HelixAMN008
Dave Bore	Phase 3	392512	7607436	5/5/16	Arthropoda	Malacostraca	Amphipoda	Neoniphargidae		sp. 'AMN008'	1	200-20160505-02E	C70339	100% Ethanol	Terrie Finston	Molecular	HelixAMN008
Dave Bore	Phase 3	392512	7607436	5/5/16	Arthropoda	Ostracoda	Podocopida	Candonidae	Pilbaracandona	sp. 'BOS526'	1	200-20160505-01	C70410	100% Ethanol	Stuart Halse	Morphologic	
Dave Bore	Phase 3	392512	7607436	5/5/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM004'	1	200-20160505-02A	C70335	100% Ethanol	Terrie Finston	Molecular	HelixAMM004
31	Phase 3	432924.921	7603180.965	7/5/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	3120160507-03B	C70326	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
31	Phase 3	432924.921	7603180.965	7/5/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	3120160507-03C	C70327	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
31	Phase 3	432924.921	7603180.965	7/5/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	3120160507-03D	C70328	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
31	Phase 3	432924.921	7603180.965	7/5/16	Arthropoda	Maxillopoda	Cyclopoida	Cyclopidae	Halicyclops	rochai	2	3120160507-01			Jane McRae	Morphologic	
31	Phase 3	432924.921	7603180.965	7/5/16	Arthropoda	Maxillopoda	Calanoida	Ridgewayiidae	Stygoridgewayia	trispinosa	4	3120160507-01			Jane McRae	Morphologic	
31	Phase 3	432924.921	7603180.965	7/5/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM026'	1	3120160507-03A	C70325	100% Ethanol	Terrie Finston	Molecular	HelixAMM026
32	Phase 3	432449.703	7602669.071	6/5/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	32-20160506-01B	C70341	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
32	Phase 3	432449.703	7602669.071	6/5/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	32-20160506-01C	C70342	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
32	Phase 3	432449.703	7602669.071	6/5/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	32-20160506-01D	C70343	100% Ethanol	Terrie Finston	Molecular	HelixAMM001

Site	Phase	Easting	Northing	Date	Phylum	Class	Order	Family	Genus	Species	n	Field code	WAM registration	Preservation	Identifier	Identification method	Lineage
32	Phase 3	432449.703	7602669.071	6/5/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	32-20160506-01E	C70344	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
32	Phase 3	432449.703	7602669.071	6/5/16	Arthropoda	Malacostraca	Amphipoda	Neoniphargidae		sp. B02	1	32-20160506-02			Jane McRae	Morphologic	
32	Phase 3	432449.703	7602669.071	6/5/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	32-20160506-01A	C70340	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
34	Phase 3	432417.972	7602437.654	6/5/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	34-20160506-01	C70324	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
87	Phase 3	410739	7604138	5/5/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM004'	1	87-20160505-02B	C70330	100% Ethanol	Terrie Finston	Molecular	HelixAMM004
87	Phase 3	410739	7604138	5/5/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM004'	1	87-20160505-02C	C70331	100% Ethanol	Terrie Finston	Molecular	HelixAMM004
87	Phase 3	410739	7604138	5/5/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM004'	1	87-20160505-02D	C70332	100% Ethanol	Terrie Finston	Molecular	HelixAMM004
87	Phase 3	410739	7604138	5/5/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM004'	1	87-20160505-02E	C70333	100% Ethanol	Terrie Finston	Molecular	HelixAMM004
87	Phase 3	410739	7604138	5/5/16	Arthropoda	Ostracoda	Podocopida	Candonidae	Humphreyscandona	imperfecta	1	87-20160505-01	C70409	100% Ethanol	Staurt Halse	Morphologic	
87	Phase 3	410739	7604138	5/5/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM004'	1	87-20160505-02A	C70329	100% Ethanol	Terrie Finston	Molecular	HelixAMM004
RR1	Phase 3	419178.96	7597902.88	5/5/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	RR120160505-01B	C70346	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
RR1	Phase 3	419178.96	7597902.88	5/5/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	RR120160505-01C	C70347	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
RR1	Phase 3	419178.96	7597902.88	5/5/16	Arthropoda	Malacostraca	Amphipoda			sp.	1	RR120160505-01D	C70348	100% Ethanol	Nicola Watson	Morphologic	Failed
RR1	Phase 3	419178.96	7597902.88	5/5/16	Arthropoda	Malacostraca	Amphipoda			sp.	1	RR120160505-01E	C70394	100% Ethanol	Nicola Watson	Morphologic	Failed
RR1	Phase 3	419178.96	7597902.88	5/5/16	Arthropoda	Ostracoda	Podocopida	Candonidae	Pierrecandona	sp. 'BOS576'	1	RR1201605-06B	C70408	100% Ethanol	Stuart Halse	Morphologic	
RR1	Phase 3	419178.96	7597902.88	5/5/16	Arthropoda	Malacostraca	Isopoda	Cirolanidae	Haptolana	yarraloola	1	RR120160505-04			Jane McRae	Morphologic	
RR1	Phase 3	419178.96	7597902.88	5/5/16	Arthropoda	Malacostraca	Isopoda	Cirolanidae	Kagalana	tonde	1	RR120160505-04			Jane McRae	Morphologic	
RR1	Phase 3	419178.96	7597902.88	5/5/16	Arthropoda	Maxillopoda	Calanoida	Ridgewayiidae	Stygoridgewayia	trispinosa	10	RR120160505-05			Jane McRae	Morphologic	
RR1	Phase 3	419178.96	7597902.88	5/5/16	Arthropoda	Maxillopoda	Cyclopoida	Cyclopidae	Halicyclops	rochai	2	RR120160505-05			Jane McRae	Morphologic	
RR1	Phase 3	419178.96	7597902.88	5/5/16	Arthropoda	Maxillopoda	Cyclopoida	Cyclopidae	Diacyclops	cockingi	1	RR120160505-05	C70412	100% Ethanol	Jane McRae	Morphologic	
RR1	Phase 3	419178.96	7597902.88	5/5/16	Arthropoda	Ostracoda	Podocopida	Candonidae		sp. 'BOS577'	3	RR120160505-06A	C70407	100% Ethanol	Stuart Halse	Morphologic	
RR1	Phase 3	419178.96	7597902.88	5/5/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	RR120160505-01A	C70345	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
Dave Bore	Phase 4	392512	7607436	10/9/16	Arthropoda	Ostracoda	Podocopida	Candonidae	Pilbaracandona	sp. 'BOS526'	1	200-20160910-02	C70415	100% Ethanol	Stuart Halse	Morphologic	
Dave Bore	Phase 4	392512	7607436	10/9/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM031'	1	200-20160910-01A	C70360	100% Ethanol	Terrie Finston	Molecular	HelixAMM031
Dave Bore	Phase 4	392512	7607436	10/9/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM004'	1	200-20160910-01B	C70361	100% Ethanol	Terrie Finston	Molecular	HelixAMM004
Dave Bore	Phase 4	392512	7607436	10/9/16	Arthropoda	Malacostraca	Amphipoda	Neoniphargidae		sp. 'AMN008'	1	200-20160910-01C	C70362	100% Ethanol	Terrie Finston	Molecular	HelixAMN008
Dave Bore	Phase 4	392512	7607436	10/9/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM031'	1	200-20160910-01D			Terrie Finston	Molecular	HelixAMM031
25	Phase 4	432150.74	7602224.467	10/9/16	Arthropoda	Malacostraca	Thermosbaenacea	Halosbaenidae	Halosbaena	tulki	1	25-20160910-02	C70349	100% Ethanol	Jane McRae	Morphologic	
25	Phase 4	432150.74	7602224.467	10/9/16	Arthropoda	Maxillopoda	Calanoida	Ridgewayiidae	Stygoridgewayia	trispinosa	1	25-20160910-03	C70398	100% Ethanol	Jane McRae	Morphologic	
25	Phase 4	432150.74	7602224.467	10/9/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	25-20160910-01A	C70371	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
25	Phase 4	432150.74	7602224.467	10/9/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	25-20160910-01B	C70372	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
25	Phase 4	432150.74	7602224.467	10/9/16	Arthropoda	Malacostraca	Amphipoda	Neoniphargidae	Wesniphargus	sp. 'AMN004'	1	25-20160910-01C			Terrie Finston	Molecular	HelixAMN004
31	Phase 4	432924.921	7603180.965	10/9/16	Arthropoda	Maxillopoda	Calanoida	Ridgewayiidae	Stygoridgewayia	trispinosa	18	31-20160910-02	C70401	100% Ethanol	Jane McRae	Morphologic	
31	Phase 4	432924.921	7603180.965	10/9/16	Arthropoda	Malacostraca	Thermosbaenacea	Halosbaenidae	Halosbaena	tulki	16	31-20160910-03	C70351	100% Ethanol	Jane McRae	Morphologic	
31	Phase 4	432924.921	7603180.965	10/9/16	Arthropoda	Malacostraca	Amphipoda			sp.	17	31-20160910-04			Penny Brooshooft	Morphologic	
31	Phase 4	432924.921	7603180.965	10/9/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	31-20160910-04A	C70363	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
31	Phase 4	432924.921	7603180.965	10/9/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	31-20160910-04B	C70364	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
31	Phase 4	432924.921	7603180.965	10/9/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	31-20160910-04C	C70365	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
31	Phase 4	432924.921	7603180.965	10/9/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	31-20160910-04D	C70366	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
31	Phase 4	432924.921	7603180.965	10/9/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	31-20160910-04E	C70367	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
31	Phase 4	432924.921	7603180.965	10/9/16	Platyhelminthes					sp.	8	31-20160910-01	V9010	100% Ethanol	Penny Brooshooft	Morphologic	
32	Phase 4	432449.703	7602669.071	10/9/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	32-20160910-02A	C70379	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
32	Phase 4	432449.703	7602669.071	10/9/16	Arthropoda	Malacostraca	Amphipoda	Neoniphargidae		sp. 'AMN003'	1	32-20160910-02B	C70380	100% Ethanol	Terrie Finston	Molecular	HelixAMN003
32	Phase 4	432449.703	7602669.071	10/9/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	32-20160910-02C			Terrie Finston	Molecular	HelixAMM001
32	Phase 4	432449.703	7602669.071	10/9/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	32-20160910-02D			Terrie Finston	Molecular	HelixAMM001
32	Phase 4	432449.703	7602669.071	10/9/16	Platyhelminthes					sp.	1	32-20160910-03	V9009	100% Ethanol	Penny Brooshooft	Morphologic	
32	Phase 4	432449.703	7602669.071	10/9/16	Arthropoda	Maxillopoda	Calanoida	Ridgewayiidae	Stygoridgewayia	trispinosa	5	32-20160910-01	C70399	100% Ethanol	Jane McRae	Morphologic	
34	Phase 4	432417.972	7602437.654	10/9/16	Arthropoda	Maxillopoda	Cyclopoida	Cyclopidae	Diacyclops	sp.	2	34-20160910-02A	C70402	100% Ethanol	Jane McRae	Morphologic	
34	Phase 4	432417.972	7602437.654	10/9/16	Arthropoda	Maxillopoda	Calanoida	Ridgewayiidae	Stygoridgewayia	trispinosa	2	34-20160910-02B	C70403	100% Ethanol	Jane McRae	Morphologic	
34	Phase 4	432417.972	7602437.654	10/9/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	34-20160910-01A	C70368	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
34	Phase 4	432417.972	7602437.654	10/9/16	Arthropoda	Malacostraca	Amphipoda			sp.	1	34-20160910-01B	C70369	100% Ethanol	Nicola Watson	Morphologic	Failed
34	Phase 4	432417.972	7602437.654	10/9/16	Arthropoda	Malacostraca	Amphipoda			sp.	1	34-20160910-01C	C70370	100% Ethanol	Nicola Watson	Morphologic	Failed
87	Phase 4	410739	7604138	19/9/16	Arthropoda	Malacostraca	Amphipoda			sp.	14	87-20160919-02			Penny Brooshooft	Morphologic	
87	Phase 4	410739	7604138	19/9/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM004'	1	87-20160919-02A	C70355	100% Ethanol	Terrie Finston	Molecular	HelixAMM004
87	Phase 4	410739	7604138	19/9/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM004'	1	87-20160919-02B	C70356	100% Ethanol	Terrie Finston	Molecular	HelixAMM004
87	Phase 4	410739	7604138	19/9/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM004'	1	87-20160919-02C	C70357	100% Ethanol	Terrie Finston	Molecular	HelixAMM004
87	Phase 4	410739	7604138	19/9/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM004'	1	87-20160919-02D	C70358	100% Ethanol	Terrie Finston	Molecular	HelixAMM004
87	Phase 4	410739	7604138	19/9/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM004'	1	87-20160919-02E	C70359	100% Ethanol	Terrie Finston	Molecular	HelixAMM004
87	Phase 4	410739	7604138	19/9/16	Arthropoda	Ostracoda	Podocopida	Candonidae	Humphreyscandona	imperfecta	2	87-20160919-03	C70414	100% Ethanol	Stuart Halse	Morphologic	

Site	Phase	Easting	Northing	Date	Phylum	Class	Order	Family	Genus	Species	n	Field code	WAM registration	Preservation	Identifier	Identification method	Lineage
87	Phase 4	410739	7604138	19/9/16	Arthropoda	Maxillopoda	Cyclopoida	Cyclopidae	Diacyclops	humphreysi	2	87-20160919-01	C70413	100% Ethanol	Jane McRae	Morphologic	
DD13MEH0007	Phase 4	419635.017	7593002.209	14/9/16	Arthropoda	Maxillopoda	Calanoida	Ridgewayiidae	Stygoridgewayia	trispinosa	7	DD13MEH0007-20160914-03	C70404	100% Ethanol	Jane McRae	Morphologic	
DD13MEH0007	Phase 4	419635.017	7593002.209	14/9/16	Arthropoda	Malacostraca	Amphipoda			sp.	2	DD13MEH0007-20160914-02	C70353	100% Ethanol	Nicola Watson	Morphologic	
DD13MEH0007	Phase 4	419635.017	7593002.209	14/9/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	DD13MEH0007-20160914-02A	C70374	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
DD13MEH0007	Phase 4	419635.017	7593002.209	14/9/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	DD13MEH0007-20160914-02B	C70375	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
DD13MEH0007	Phase 4	419635.017	7593002.209	14/9/16	Arthropoda	Malacostraca	Amphipoda			sp.	1	DD13MEH0007-20160914-02C			Nicola Watson	Morphologic	Failed
DD13MEH0007	Phase 4	419635.017	7593002.209	14/9/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	DD13MEH0007-20160914-02D			Terrie Finston	Molecular	HelixAMM001
DD13MEH0007	Phase 4	419635.017	7593002.209	14/9/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	DD13MEH0007-20160914-02E			Terrie Finston	Molecular	HelixAMM001
RC13MEH0007	Phase 4	419641.545	7592602.94	14/9/16	Arthropoda	Maxillopoda	Calanoida	Ridgewayiidae	Stygoridgewayia	trispinosa	27	RC13MEH0007.20160914-01	C70406	100% Ethanol	Jane McRae	Morphologic	
RC13MEH0040	Phase 4	419892.868	7592704.088	14/9/16	Arthropoda	Maxillopoda	Calanoida	Ridgewayiidae	Stygoridgewayia	trispinosa	1	RC13MEH0040.20160914-02	C70405	100% Ethanol	Jane McRae	Morphologic	
RC13MEH0040	Phase 4	419892.868	7592704.088	14/9/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	RC13MEH0040.20160914-01A	C70376	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
RC13MEH0040	Phase 4	419892.868	7592704.088	14/9/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	RC13MEH0040.20160914-01B	C70377	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
RC13MEH0040	Phase 4	419892.868	7592704.088	14/9/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	RC13MEH0040.20160914-01C	C70378	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
RC16JIM0019	Phase 4	423026.712	7590287.794	12/9/16	Arthropoda	Malacostraca	Amphipoda			sp.	14	RC16JIM0019.20160912-01	C70352	100% Ethanol	Penny Brooshooft	Morphologic	
RC16JIM0019	Phase 4	423026.712	7590287.794	12/9/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	RC16JIM0019.20160912-01A	C70373	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
RC16JIM0019	Phase 4	423026.712	7590287.794	12/9/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	RC16JIM0019.20160912-01B			Terrie Finston	Molecular	HelixAMM001
RC16JIM0019	Phase 4	423026.712	7590287.794	12/9/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	RC16JIM0019.20160912-01C			Terrie Finston	Molecular	HelixAMM001
RC16JIM0019	Phase 4	423026.712	7590287.794	12/9/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	RC16JIM0019.20160912-01D			Terrie Finston	Molecular	HelixAMM001
RC16JIM0019	Phase 4	423026.712	7590287.794	12/9/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	RC16JIM0019.20160912-01E			Terrie Finston	Molecular	HelixAMM001
RR1	Phase 4	419178.96	7597902.88	10/9/16	Arthropoda	Ostracoda	Podocopida	Candonidae	Pierrecandona	sp. 'BOS576'	1	RR1-20160910-02	C70413	100% Ethanol	Stuart Halse	Morphologic	
RR1	Phase 4	419178.96	7597902.88	10/9/16	Arthropoda	Ostracoda	Podocopida	Limnocytheridae	Gomphodella	sp.	3	RR1-20160910-02B	C70412	100% Ethanol	Stuart Halse	Morphologic	
RR1	Phase 4	419178.96	7597902.88	10/9/16	Arthropoda	Ostracoda	Podocopida	Cyprididae		sp.	1	RR1-20160910-02A	C70411	100% Ethanol	Stuart Halse	Morphologic	
RR1	Phase 4	419178.96	7597902.88	10/9/16	Arthropoda	Malacostraca	Amphipoda			sp.	4	RR1-20160910-01	C70350	100% Ethanol	Nicola Watson	Morphologic	
RR1	Phase 4	419178.96	7597902.88	10/9/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	RR1-20160910-01A	C70381	100% Ethanol	Terrie Finston	Molecular	HelixAMM001
RR1	Phase 4	419178.96	7597902.88	10/9/16	Arthropoda	Malacostraca	Amphipoda			sp.	1	RR1-20160910-01B	C70382	100% Ethanol	Nicola Watson	Morphologic	Failed
RR1	Phase 4	419178.96	7597902.88	10/9/16	Arthropoda	Malacostraca	Amphipoda	Paramelitidae		sp. 'AMP035'	1	RR1-20160910-01C			Terrie Finston	Molecular	HelixAMP035
RR1	Phase 4	419178.96	7597902.88	10/9/16	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	RR1-20160910-01D			Nicola Watson	Molecular	HelixAMM001
RR1	Phase 4	419178.96	7597902.88	10/9/16	Arthropoda	Malacostraca	Amphipoda	Neonyphargidae		sp. 'AMN002'	1	RR1-20160910-01E			Terrie Finston	Molecular	HelixAMN002
25	Phase 5	432150.74	7602224.467	13/12/17	Arthropoda	Malacostraca	Amphipoda	Paramelitidae		sp. 'AMP038'	1	25-20171213-02			Terrie Finston	Molecular	HelixAMP038
25	Phase 5	432150.74	7602224.467	13/12/17	Arthropoda	Maxillopoda	Cyclopoida	Cyclopidae	Diacyclops	sp.	1	25-20171213-01			J Alexander	Morphologic	
25	Phase 5	432150.74	7602224.467	13/12/17	Arthropoda	Maxillopoda	Cyclopoida	Cyclopidae	Halicyclops	rochai	1	25-20171213-01			J Alexander	Morphologic	
31	Phase 5	432924.921	7603180.965	13/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	7	31-20171213-02			Terrie Finston	Molecular	HelixAMM001
31	Phase 5	432924.921	7603180.965	13/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	7	31-20171213-02			Terrie Finston	Molecular	HelixAMM001
31	Phase 5	432924.921	7603180.965	13/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	7	31-20171213-02			Terrie Finston	Molecular	HelixAMM001
31	Phase 5	432924.921	7603180.965	13/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	7	31-20171213-02			Terrie Finston	Molecular	HelixAMM001
31	Phase 5	432924.921	7603180.965	13/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	7	31-20171213-02			Terrie Finston	Molecular	HelixAMM001
31	Phase 5	432924.921	7603180.965	13/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	7	31-20171213-02			Terrie Finston	Molecular	HelixAMM001
31	Phase 5	432924.921	7603180.965	13/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM026'	2	31-20171213-02			Terrie Finston	Molecular	HelixAMM026
31	Phase 5	432924.921	7603180.965	13/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM026'	2	31-20171213-02			Terrie Finston	Molecular	HelixAMM026
31	Phase 5	432924.921	7603180.965	13/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM032'	1	31-20171213-02			Terrie Finston	Molecular	HelixAMM032
31	Phase 5	432924.921	7603180.965	13/12/17	Arthropoda	Malacostraca	Isopoda	Cirolanidae	Kagalana	tonde	1	31-20171213-03			J Alexander	Morphologic	
31	Phase 5	432924.921	7603180.965	13/12/17	Arthropoda	Maxillopoda	Calanoida	Ridgewayiidae	Stygoridgewayia	trispinosa	36	31-20171213-01			J Alexander	Morphologic	
31	Phase 5	432924.921	7603180.965	13/12/17	Arthropoda	Maxillopoda	Cyclopoida	Cyclopidae	Diacyclops	humphreysi	3	31-20171213-01			J Alexander	Morphologic	
31	Phase 5	432924.921	7603180.965	13/12/17	Arthropoda	Maxillopoda	Cyclopoida	Cyclopidae	Halicyclops	rochai	1	31-20171213-01			J Alexander	Morphologic	
31	Phase 5	432924.921	7603180.965	13/12/17	Arthropoda	Ostracoda	Podocopida	Candonidae	Areacandona	sp. 'BOS1039'	3	31-20171213-05			J Alexander	Morphologic	
BC186	Phase 5	429577.919	7587211.514	13/12/17	Annelida	Oligochaeta	Tubificida	Enchytraeidae	Enchytraeus	sp. 'AP PSS1'	1	BC186-20171213-04			J Alexander	Morphologic	
BC186	Phase 5	429577.919	7587211.514	13/12/17	Arthropoda	Malacostraca	Amphipoda	Paramelitidae		sp. 'AMP037'	1	BC186-20171213-03			Terrie Finston	Molecular	HelixAMP037
BC186	Phase 5	429577.919	7587211.514	13/12/17	Arthropoda	Malacostraca	Amphipoda			sp.	1	BC186-20171213-03			J Alexander	Morphologic	Failed
BC186	Phase 5	429577.919	7587211.514	13/12/17	Arthropoda	Maxillopoda	Calanoida	Ridgewayiidae	Stygoridgewayia	trispinosa	3	BC186-20171213-01			J Alexander	Morphologic	
BC186	Phase 5	429577.919	7587211.514	13/12/17	Arthropoda	Ostracoda	Podocopida	Candonidae	Areacandona	sp. 'BOS1039'	6	BC186-20171213-02			J Alexander	Morphologic	
BC186	Phase 5	429577.919	7587211.514	13/12/17	Arthropoda	Ostracoda	Podocopida	Candonidae	Areacandona	triangulum	4	BC186-20171213-02			J Alexander	Morphologic	
Budgie Bore	Phase 5	382495	7615587	12/12/17	Arthropoda	Arachnida	Trombidiformes	Mideopsidae	Tiramideopsis	lictus	2	Budgie-20171212-03			J Alexander	Morphologic	
Budgie Bore	Phase 5	382495	7615587	12/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	Budgie-20171212-01			Terrie Finston	Molecular	HelixAMM001
Budgie Bore	Phase 5	382495	7615587	12/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	Budgie-20171212-01			Terrie Finston	Molecular	HelixAMM001
Budgie Bore	Phase 5	382495	7615587	12/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	Budgie-20171212-01			Terrie Finston	Molecular	HelixAMM001
Budgie Bore	Phase 5	382495	7615587	12/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	Budgie-20171212-01			Terrie Finston	Molecular	HelixAMM001
Budgie Bore	Phase 5	382495	7615587	12/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	Budgie-20171212-01			Terrie Finston	Molecular	HelixAMM001
Budgie Bore	Phase 5	382495	7615587	12/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	Budgie-20171212-01			Terrie Finston	Molecular	HelixAMM001

Site	Phase	Easting	Northing	Date	Phylum	Class	Order	Family	Genus	Species	n	Field code	WAM registration	Preservation	Identifier	Identification method	Lineage
Budgie Bore	Phase 5	382495	7615587	12/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	Budgie-20171212-01			Terrie Finston	Molecular	HelixAMM001
Budgie Bore	Phase 5	382495	7615587	12/12/17	Arthropoda	Malacostraca	Amphipoda	Neoniphargidae		sp. 'AMN008'	1	Budgie-20171212-01			Terrie Finston	Molecular	HelixAMN008
Budgie Bore	Phase 5	382495	7615587	12/12/17	Arthropoda	Malacostraca	Amphipoda	Neoniphargidae		sp. 'AMN008'	1	Budgie-20171212-01			Terrie Finston	Molecular	HelixAMN008
Budgie Bore	Phase 5	382495	7615587	12/12/17	Arthropoda	Malacostraca	Amphipoda	Neoniphargidae		sp. 'AMN008'	1	Budgie-20171212-01			Terrie Finston	Molecular	HelixAMN008
Budgie Bore	Phase 5	382495	7615587	12/12/17	Arthropoda	Malacostraca	Amphipoda	Neoniphargidae		sp. 'AMN008'	1	Budgie-20171212-01			Terrie Finston	Molecular	HelixAMN008
Budgie Bore	Phase 5	382495	7615587	12/12/17	Arthropoda	Malacostraca	Amphipoda	Neoniphargidae		sp. 'AMN008'	1	Budgie-20171212-01			Terrie Finston	Molecular	HelixAMN008
Budgie Bore	Phase 5	382495	7615587	12/12/17	Arthropoda	Malacostraca	Amphipoda	Neoniphargidae		sp. 'AMN008'	1	Budgie-20171212-01			Terrie Finston	Molecular	HelixAMN008
Budgie Bore	Phase 5	382495	7615587	12/12/17	Arthropoda	Malacostraca	Amphipoda	Paramelitidae		sp. 'AMP009'	1	Budgie-20171212-01			Terrie Finston	Molecular	HelixAMN009
Budgie Bore	Phase 5	382495	7615587	12/12/17	Arthropoda	Malacostraca	Amphipoda			sp.	1	Budgie-20171212-01			J Alexander	Morphologic	Failed
Budgie Bore	Phase 5	382495	7615587	12/12/17	Arthropoda	Malacostraca	Amphipoda			sp.	1	Budgie-20171212-01			J Alexander	Morphologic	Failed
Budgie Bore	Phase 5	382495	7615587	12/12/17	Arthropoda	Malacostraca	Amphipoda			sp.	1	Budgie-20171212-01			J Alexander	Morphologic	Failed
Budgie Bore	Phase 5	382495	7615587	12/12/17	Arthropoda	Malacostraca	Amphipoda			sp.	1	Budgie-20171212-01			J Alexander	Morphologic	Failed
Budgie Bore	Phase 5	382495	7615587	12/12/17	Arthropoda	Malacostraca	Amphipoda			sp.	1	Budgie-20171212-01			J Alexander	Morphologic	Failed
Budgie Bore	Phase 5	382495	7615587	12/12/17	Arthropoda	Malacostraca	Amphipoda			sp.	1	Budgie-20171212-01			J Alexander	Morphologic	Failed
Budgie Bore	Phase 5	382495	7615587	12/12/17	Arthropoda	Malacostraca	Amphipoda			sp.	1	Budgie-20171212-01			J Alexander	Morphologic	Failed
Budgie Bore	Phase 5	382495	7615587	12/12/17	Arthropoda	Malacostraca	Amphipoda			sp.	1	Budgie-20171212-01			J Alexander	Morphologic	Failed
Budgie Bore	Phase 5	382495	7615587	12/12/17	Arthropoda	Malacostraca	Amphipoda			sp.	1	Budgie-20171212-01			J Alexander	Morphologic	Failed
Budgie Bore	Phase 5	382495	7615587	12/12/17	Arthropoda	Malacostraca	Amphipoda			sp.	1	Budgie-20171212-01			J Alexander	Morphologic	Failed
Budgie Bore	Phase 5	382495	7615587	12/12/17	Arthropoda	Malacostraca	Amphipoda			sp.	1	Budgie-20171212-01			J Alexander	Morphologic	Failed
Budgie Bore	Phase 5	382495	7615587	12/12/17	Arthropoda	Malacostraca	Amphipoda			sp.	1	Budgie-20171212-01			J Alexander	Morphologic	Failed
Budgie Bore	Phase 5	382495	7615587	12/12/17	Arthropoda	Malacostraca	Amphipoda			sp.	1	Budgie-20171212-01			J Alexander	Morphologic	Failed
Budgie Bore	Phase 5	382495	7615587	12/12/17	Arthropoda	Malacostraca	Amphipoda			sp.	1	Budgie-20171212-01			J Alexander	Morphologic	Failed
Budgie Bore	Phase 5	382495	7615587	12/12/17	Arthropoda	Malacostraca	Amphipoda			sp.	1	Budgie-20171212-01			J Alexander	Morphologic	Failed
Budgie Bore	Phase 5	382495	7615587	12/12/17	Arthropoda	Malacostraca	Amphipoda			sp.	1	Budgie-20171212-01			J Alexander	Morphologic	Failed
Budgie Bore	Phase 5	382495	7615587	12/12/17	Arthropoda	Maxillopoda	Calanoida	Ridgewayiidae	Stygoridgewayia	trispinosa	9	Budgie-20171212-04			J Alexander	Morphologic	
Budgie Bore	Phase 5	382495	7615587	12/12/17	Arthropoda	Maxillopoda	Cyclopoida	Cyclopidae	Microcyclops	varicans	8	Budgie-20171212-04			J Alexander	Morphologic	
Dave Bore	Phase 5	392512	7607436	12/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM004'	1	200-20171212-03			Terrie Finston	Molecular	HelixAMM004
Dave Bore	Phase 5	392512	7607436	12/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM004'	1	200-20171212-03			Terrie Finston	Molecular	HelixAMM004
Dave Bore	Phase 5	392512	7607436	12/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM004'	1	200-20171212-03			Terrie Finston	Molecular	HelixAMM004
Dave Bore	Phase 5	392512	7607436	12/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM031'	1	200-20171212-03			Terrie Finston	Molecular	HelixAMM031
Dave Bore	Phase 5	392512	7607436	12/12/17	Arthropoda	Maxillopoda	Calanoida	Ridgewayiidae	Stygoridgewayia	trispinosa	26	200-20171212-01			J Alexander	Morphologic	
JW023	Phase 5	426138.471	7590140.642	13/12/17	Arthropoda	Maxillopoda	Cyclopoida	Cyclopidae	Diacyclops	sp.	12	JW024-20171213-05			J Alexander	Morphologic	
JW024	Phase 5	427126.621	7590154.159	13/12/17	Arthropoda	Arachnida	Trombidiformes	Limnesiidae	Limnesia	sp.	1	JW024-20171213-02			J Alexander	Morphologic	
JW024	Phase 5	427126.621	7590154.159	13/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	JW024-20171213-06			Terrie Finston	Molecular	HelixAMM001
JW024	Phase 5	427126.621	7590154.159	13/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	JW024-20171213-06			Terrie Finston	Molecular	HelixAMM001
JW024	Phase 5	427126.621	7590154.159	13/12/17	Arthropoda	Malacostraca	Amphipoda	Neoniphargidae	Wesniphargus	sp. 'AMN004'	1	JW024-20171213-06			Terrie Finston	Molecular	HelixAMN004
JW024	Phase 5	427126.621	7590154.159	13/12/17	Arthropoda	Malacostraca	Amphipoda	Neoniphargidae	Wesniphargus	sp. 'AMN004'	1	JW024-20171213-06			Terrie Finston	Molecular	HelixAMN004
JW024	Phase 5	427126.621	7590154.159	13/12/17	Arthropoda	Malacostraca	Amphipoda	Neoniphargidae	Wesniphargus	sp. 'AMN004'	1	JW024-20171213-06			Terrie Finston	Molecular	HelixAMN004
JW024	Phase 5	427126.621	7590154.159	13/12/17	Arthropoda	Malacostraca	Amphipoda			sp.	1	JW024-20171213-06			J Alexander	Morphologic	Failed
JW024	Phase 5	427126.621	7590154.159	13/12/17	Arthropoda	Malacostraca	Thermosbaenacea	Halosbaenidae	Halosbaena	tulki	3	JW024-20171213-05			J Alexander	Morphologic	
JW024	Phase 5	427126.621	7590154.159	13/12/17	Arthropoda	Maxillopoda	Calanoida	Ridgewayiidae	Stygoridgewayia	trispinosa	1	JW024-20171213-04			J Alexander	Morphologic	
JW024	Phase 5	427126.621	7590154.159	13/12/17	Arthropoda	Maxillopoda	Cyclopoida	Cyclopidae	Diacyclops	humphreysi	1	JW024-20171213-04			J Alexander	Morphologic	
JW024	Phase 5	427126.621	7590154.159	13/12/17	Arthropoda	Ostracoda	Podocopida	Candonidae	Pilbaracandona	sp. 'BOS526'	3	JW024-20171213-01			J Alexander	Morphologic	
MB16MEC0008	Phase 5	393565.012	7600580.184	12/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM006'	1	MB16MEC0008-20171212-03			Terrie Finston	Molecular	HelixAMM006
MB16MEC0008	Phase 5	393565.012	7600580.184	12/12/17	Arthropoda	Maxillopoda	Calanoida	Ridgewayiidae	Stygoridgewayia	trispinosa	19	MB16MEC0008-20171212-02			J Alexander	Morphologic	
MB16MEC0008	Phase 5	393565.012	7600580.184	12/12/17	Arthropoda	Maxillopoda	Cyclopoida	Cyclopidae	Diacyclops	humphreysi	4	MB16MEC0008-20171212-02			J Alexander	Morphologic	
MB16MEC0008	Phase 5	393565.012	7600580.184	12/12/17	Arthropoda	Maxillopoda	Cyclopoida	Cyclopidae	Halicyclops	rochai	10	MB16MEC0008-20171212-02			J Alexander	Morphologic	
MB16MEC0008	Phase 5	393565.012	7600580.184	12/12/17	Arthropoda	Ostracoda	Podocopida	Candonidae	Areacandona	triangulum	20	MB16MEC0008-20171212-04			J Alexander	Morphologic	
MB16MEC0009	Phase 5	393590.062	7601144.506	12/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM004'	1	MB16MEC0009-20171212-02			Terrie Finston	Molecular	HelixAMM004
MB16MEC0009	Phase 5	393590.062	7601144.506	12/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM006'	1	MB16MEC0009-20171212-02			Terrie Finston	Molecular	HelixAMM006
MB16MEC0009	Phase 5	393590.062	7601144.506	12/12/17	Arthropoda	Maxillopoda	Calanoida	Ridgewayiidae	Stygoridgewayia	trispinosa	7	MB16MEC0009-20171212-04			J Alexander	Morphologic	
MB16MEC0009	Phase 5	393590.062	7601144.506	12/12/17	Arthropoda	Maxillopoda	Cyclopoida	Cyclopidae	Diacyclops	humphreysi	19	MB16MEC0009-20171212-04			J Alexander	Morphologic	
MB16MEC0009	Phase 5	393590.062	7601144.506	12/12/17	Arthropoda	Maxillopoda	Cyclopoida	Cyclopidae	Halicyclops	rochai	2	MB16MEC0009-20171212-04			J Alexander	Morphologic	
MB16MEC0009	Phase 5	393590.062	7601144.506	12/12/17	Arthropoda	Ostracoda	Podocopida	Candonidae	Areacandona	triangulum	3	MB16MEC0009-20171212-03			J Alexander	Morphologic	
MB17MEH0007	Phase 5	417658.827	7600422.641	14/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM022'	1	MB17MEH0007-20171214-02			Terrie Finston	Molecular	HelixAMM022
MB17MEH0007	Phase 5	417658.827	7600422.641	14/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM033'	1	MB17MEH0007-20171214-02			Terrie Finston	Molecular	HelixAMM033
MB17MEH0007	Phase 5	417658.827	7600422.641	14/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM033'	1	MB17MEH0007-20171214-02			Terrie Finston	Molecular	HelixAMM033

Site	Phase	Easting	Northing	Date	Phylum	Class	Order	Family	Genus	Species	n	Field code	WAM registration	Preservation	Identifier	Identification method	Lineage
MB17MEH0007	Phase 5	417658.827	7600422.641	14/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM033'	1	MB17MEH0007-20171214-02			Terrie Finston	Molecular	HelixAMM033
MB17MEH0007	Phase 5	417658.827	7600422.641	14/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM033'	1	MB17MEH0007-20171214-02			Terrie Finston	Molecular	HelixAMM033
MB17MEH0007	Phase 5	417658.827	7600422.641	14/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM033'	1	MB17MEH0007-20171214-02			Terrie Finston	Molecular	HelixAMM033
MB17MEH0007	Phase 5	417658.827	7600422.641	14/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM033'	1	MB17MEH0007-20171214-02			Terrie Finston	Molecular	HelixAMM033
MB17MEH0007	Phase 5	417658.827	7600422.641	14/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM033'	1	MB17MEH0007-20171214-02			Terrie Finston	Molecular	HelixAMM033
MB17MEH0007	Phase 5	417658.827	7600422.641	14/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM033'	1	MB17MEH0007-20171214-02			Terrie Finston	Molecular	HelixAMM033
MB17MEH0007	Phase 5	417658.827	7600422.641	14/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM033'	1	MB17MEH0007-20171214-02			Terrie Finston	Molecular	HelixAMM033
MB17MEH0007	Phase 5	417658.827	7600422.641	14/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM033'	1	MB17MEH0007-20171214-02			Terrie Finston	Molecular	HelixAMM033
MB17MEH0007	Phase 5	417658.827	7600422.641	14/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM033'	1	MB17MEH0007-20171214-02			Terrie Finston	Molecular	HelixAMM033
MB17MEH0007	Phase 5	417658.827	7600422.641	14/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM033'	1	MB17MEH0007-20171214-02			Terrie Finston	Molecular	HelixAMM033
MB17MEH0007	Phase 5	417658.827	7600422.641	14/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM033'	1	MB17MEH0007-20171214-02			Terrie Finston	Molecular	HelixAMM033
MB17MEH0007	Phase 5	417658.827	7600422.641	14/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM033'	1	MB17MEH0007-20171214-02			Terrie Finston	Molecular	HelixAMM033
MB17MEH0007	Phase 5	417658.827	7600422.641	14/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM033'	1	MB17MEH0007-20171214-02			Terrie Finston	Molecular	HelixAMM033
MB17MEH0007	Phase 5	417658.827	7600422.641	14/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM033'	1	MB17MEH0007-20171214-02			Terrie Finston	Molecular	HelixAMM033
MB17MEH0007	Phase 5	417658.827	7600422.641	14/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM033'	1	MB17MEH0007-20171214-02			Terrie Finston	Molecular	HelixAMM033
MB17MEH0007	Phase 5	417658.827	7600422.641	14/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM033'	1	MB17MEH0007-20171214-02			Terrie Finston	Molecular	HelixAMM033
MB17MEH0007	Phase 5	417658.827	7600422.641	14/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM033'	1	MB17MEH0007-20171214-02			Terrie Finston	Molecular	HelixAMM033
MB17MEH0007	Phase 5	417658.827	7600422.641	14/12/17	Arthropoda	Malacostraca	Amphipoda			sp.	1	MB17MEH0007-20171214-02			J Alexander	Morphologic	Failed
MB17MEH0007	Phase 5	417658.827	7600422.641	14/12/17	Arthropoda	Maxillopoda	Calanoida	Ridgewayiidae	Stygoridgewayia	trispinosa	11	MB17MEH0007-20171214-01			J Alexander	Morphologic	
MB17MEH0007	Phase 5	417658.827	7600422.641	14/12/17	Arthropoda	Maxillopoda	Cyclopoida	Cyclopidae	Diacyclops	cockingi	23	MB17MEH0007-20171214-01			J Alexander	Morphologic	
MB17MEH0007	Phase 5	417658.827	7600422.641	14/12/17	Arthropoda	Maxillopoda	Cyclopoida	Cyclopidae	Diacyclops	sp. 'B03'	1	MB17MEH0007-20171214-01			J Alexander	Morphologic	
MB17MEH0007	Phase 5	417658.827	7600422.641	14/12/17	Arthropoda	Maxillopoda	Harpacticoida	Ameiridae	Abnitocrella	halsei	1	MB17MEH0007-20171214-01			J Alexander	Morphologic	
MB17MEH0007	Phase 5	417658.827	7600422.641	14/12/17	Arthropoda	Maxillopoda	Harpacticoida	Canthocamptidae	Elaphoidella	humphreysi	29	MB17MEH0007-20171214-01			J Alexander	Morphologic	
MB17MEH0007	Phase 5	417658.827	7600422.641	14/12/17	Arthropoda	Ostracoda	Podocopida	Candonidae	Gen. nov.	sp. 'BOS1037'	25	MB17MEH0007-20171214-03			J Alexander	Morphologic	
MB17MEH0007	Phase 5	417658.827	7600422.641	14/12/17	Arthropoda	Ostracoda	Podocopida	Candonidae	Pilbaracandona	sp. 'BOS526'	5	MB17MEH0007-20171214-03			J Alexander	Morphologic	
MB17MEH0007	Phase 5	417658.827	7600422.641	14/12/17	Mollusca	Gastropoda	Hypsogastropoda	Hydrobiidae		sp. B09	2	MB17MEH0007-20171214-04			J Alexander	Morphologic	
MB17MEH0009	Phase 5	416434.642	7599847.256	12/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM033'	1	MB17MEH0009-20171212-02			Terrie Finston	Molecular	HelixAMM033
MB17MEH0009	Phase 5	416434.642	7599847.256	12/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM033'	1	MB17MEH0009-20171212-02			Terrie Finston	Molecular	HelixAMM033
MB17MEH0009	Phase 5	416434.642	7599847.256	12/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM033'	1	MB17MEH0009-20171212-02			Terrie Finston	Molecular	HelixAMM033
MB17MEH0009	Phase 5	416434.642	7599847.256	12/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM033'	1	MB17MEH0009-20171212-02			Terrie Finston	Molecular	HelixAMM033
MB17MEH0009	Phase 5	416434.642	7599847.256	12/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM033'	1	MB17MEH0009-20171212-02			Terrie Finston	Molecular	HelixAMM033
MB17MEH0009	Phase 5	416434.642	7599847.256	12/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM033'	1	MB17MEH0009-20171212-02			Terrie Finston	Molecular	HelixAMM033
MB17MEH0009	Phase 5	416434.642	7599847.256	12/12/17	Arthropoda	Maxillopoda	Calanoida	Ridgewayiidae	Stygoridgewayia	trispinosa	13	MB17MEH0009-20171212-01			J Alexander	Morphologic	
MB17MEH0009	Phase 5	416434.642	7599847.256	12/12/17	Arthropoda	Maxillopoda	Cyclopoida	Cyclopidae	Diacyclops	humphreysi	3	MB17MEH0009-20171212-01			J Alexander	Morphologic	
MB17MEH0010	Phase 5	416447.194	7599849.354	12/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM033'	1	MB17MEH0010-20171212-01			Terrie Finston	Molecular	HelixAMM033
MB17MEH0010	Phase 5	416447.194	7599849.354	12/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM033'	1	MB17MEH0010-20171212-01			Terrie Finston	Molecular	HelixAMM033
MB17MEH0010	Phase 5	416447.194	7599849.354	12/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM033'	1	MB17MEH0010-20171212-01			Terrie Finston	Molecular	HelixAMM033
MB17MEH0010	Phase 5	416447.194	7599849.354	12/12/17	Arthropoda	Malacostraca	Amphipoda			sp.	1	MB17MEH0010-20171212-01			J Alexander	Morphologic	Failed
MB17MEH0010	Phase 5	416447.194	7599849.354	12/12/17	Arthropoda	Maxillopoda	Calanoida	Ridgewayiidae	Stygoridgewayia	trispinosa	1	MB17MEH0010-20171212-02			J Alexander	Morphologic	
MB17MEH0010	Phase 5	416447.194	7599849.354	12/12/17	Arthropoda	Maxillopoda	Cyclopoida	Cyclopidae	Diacyclops	humphreysi	14	MB17MEH0010-20171212-02			J Alexander	Morphologic	
MB17MEH0010	Phase 5	416447.194	7599849.354	12/12/17	Arthropoda	Maxillopoda	Harpacticoida	Canthocamptidae	Elaphoidella	humphreysi	4	MB17MEH0010-20171212-02			J Alexander	Morphologic	
MB17MEH0015	Phase 5	416044.945	7597712.125	14/12/17	Arthropoda	Maxillopoda	Cyclopoida	Cyclopidae	Diacyclops	humphreysi	1	MB17MEH0015-20171214-01			J Alexander	Morphologic	
MB17MEH0015	Phase 5	416044.945	7597712.125	14/12/17	Arthropoda	Maxillopoda	Harpacticoida	Ameiridae	Megastygonitocrella	unispinosa	2	MB17MEH0015-20171214-01			J Alexander	Morphologic	
RR1	Phase 5	419178.96	7597902.88	14/12/17	Arthropoda	Arachnida	Trombidiformes	Unionicolidae		sp.	1	RR01-20171214-03			J Alexander	Morphologic	
RR1	Phase 5	419178.96	7597902.88	14/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	RR01-20171214-05			Terrie Finston	Molecular	HelixAMM001
RR1	Phase 5	419178.96	7597902.88	14/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	RR01-20171214-05			Terrie Finston	Molecular	HelixAMM001
RR1	Phase 5	419178.96	7597902.88	14/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	RR01-20171214-05			Terrie Finston	Molecular	HelixAMM001
RR1	Phase 5	419178.96	7597902.88	14/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	RR01-20171214-05			Terrie Finston	Molecular	HelixAMM001
RR1	Phase 5	419178.96	7597902.88	14/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	RR01-20171214-05			Terrie Finston	Molecular	HelixAMM001
RR1	Phase 5	419178.96	7597902.88	14/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	RR01-20171214-05			Terrie Finston	Molecular	HelixAMM001
RR1	Phase 5	419178.96	7597902.88	14/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	RR01-20171214-05			Terrie Finston	Molecular	HelixAMM001
RR1	Phase 5	419178.96	7597902.88	14/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	RR01-20171214-05			Terrie Finston	Molecular	HelixAMM001
RR1	Phase 5	419178.96	7597902.88	14/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	RR01-20171214-05			Terrie Finston	Molecular	HelixAMM001
RR1	Phase 5	419178.96	7597902.88	14/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	RR01-20171214-05			Terrie Finston	Molecular	HelixAMM001
RR1	Phase 5	419178.96	7597902.88	14/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	RR01-20171214-05			Terrie Finston	Molecular	HelixAMM001
RR1	Phase 5	419178.96	7597902.88	14/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	RR01-20171214-05			Terrie Finston	Molecular	HelixAMM001
RR1	Phase 5	419178.96	7597902.88	14/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	RR01-20171214-05			Terrie Finston	Molecular	HelixAMM001
RR1	Phase 5	419178.96	7597902.88	14/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	RR01-20171214-05			Terrie Finston	Molecular	HelixAMM001
RR1	Phase 5	419178.96	7597902.88	14/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	RR01-20171214-05			Terrie Finston	Molecular	HelixAMM001

Site	Phase	Easting	Northing	Date	Phylum	Class	Order	Family	Genus	Species	n	Field code	WAM registration	Preservation	Identifier	Identification method	Lineage
RR1	Phase 5	419178.96	7597902.88	14/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	RR01-20171214-05			Terrie Finston	Molecular	HelixAMM001
RR1	Phase 5	419178.96	7597902.88	14/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	RR01-20171214-05			Terrie Finston	Molecular	HelixAMM001
RR1	Phase 5	419178.96	7597902.88	14/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	RR01-20171214-05			Terrie Finston	Molecular	HelixAMM001
RR1	Phase 5	419178.96	7597902.88	14/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	RR01-20171214-05			Terrie Finston	Molecular	HelixAMM001
RR1	Phase 5	419178.96	7597902.88	14/12/17	Arthropoda	Malacostraca	Amphipoda	Eriopisidae	Nedsia	sp. 'AMM001'	1	RR01-20171214-05			Terrie Finston	Molecular	HelixAMM001
RR1	Phase 5	419178.96	7597902.88	14/12/17	Arthropoda	Malacostraca	Amphipoda	Paramelitidae		sp. 'AMP035'	1	RR01-20171214-05			Terrie Finston	Molecular	HelixAMP035
RR1	Phase 5	419178.96	7597902.88	14/12/17	Arthropoda	Malacostraca	Amphipoda	Paramelitidae		sp. 'AMP035'	1	RR01-20171214-05			Terrie Finston	Molecular	HelixAMP035
RR1	Phase 5	419178.96	7597902.88	14/12/17	Arthropoda	Malacostraca	Amphipoda	Paramelitidae		sp. 'AMP035'	1	RR01-20171214-05			Terrie Finston	Molecular	HelixAMP035
RR1	Phase 5	419178.96	7597902.88	14/12/17	Arthropoda	Malacostraca	Amphipoda	Paramelitidae		sp. 'AMP035'	1	RR01-20171214-05			Terrie Finston	Molecular	HelixAMP035
RR1	Phase 5	419178.96	7597902.88	14/12/17	Arthropoda	Malacostraca	Amphipoda	Paramelitidae		sp. 'AMP035'	1	RR01-20171214-05			Terrie Finston	Molecular	HelixAMP035
RR1	Phase 5	419178.96	7597902.88	14/12/17	Arthropoda	Malacostraca	Amphipoda	Paramelitidae		sp. 'AMP035'	1	RR01-20171214-05			Terrie Finston	Molecular	HelixAMP035
RR1	Phase 5	419178.96	7597902.88	14/12/17	Arthropoda	Malacostraca	Amphipoda	Paramelitidae	Chydaekata	sp. 'AMP036'	1	RR01-20171214-05			Terrie Finston	Molecular	HelixAMP036
RR1	Phase 5	419178.96	7597902.88	14/12/17	Arthropoda	Malacostraca	Amphipoda	Paramelitidae		sp. 'AMP038'	1	RR01-20171214-05			Terrie Finston	Molecular	HelixAMP038
RR1	Phase 5	419178.96	7597902.88	14/12/17	Arthropoda	Malacostraca	Amphipoda			sp.	1	RR01-20171214-05			J Alexander	Morphologic	Failed
RR1	Phase 5	419178.96	7597902.88	14/12/17	Arthropoda	Malacostraca	Amphipoda			sp.	1	RR01-20171214-05			J Alexander	Morphologic	Failed
RR1	Phase 5	419178.96	7597902.88	14/12/17	Arthropoda	Malacostraca	Amphipoda			sp.	1	RR01-20171214-05			J Alexander	Morphologic	Failed
RR1	Phase 5	419178.96	7597902.88	14/12/17	Arthropoda	Malacostraca	Amphipoda			sp.	1	RR01-20171214-05			J Alexander	Morphologic	Failed
RR1	Phase 5	419178.96	7597902.88	14/12/17	Arthropoda	Malacostraca	Isopoda	Cirolanidae	Kagalana	tonde	1	RR01-20171214-04			J Alexander	Morphologic	
RR1	Phase 5	419178.96	7597902.88	14/12/17	Arthropoda	Maxillopoda	Calanoida	Ridgewayiidae	Stygoridgewayia	trispinosa	1	RR01-20171214-01			J Alexander	Morphologic	
RR1	Phase 5	419178.96	7597902.88	14/12/17	Arthropoda	Maxillopoda	Cyclopoida	Cyclopidae	Diacyclops	humphreysi	1	RR01-20171214-01			J Alexander	Morphologic	
RR1	Phase 5	419178.96	7597902.88	14/12/17	Arthropoda	Maxillopoda	Cyclopoida	Cyclopidae	Diacyclops	sp.	2	RR01-20171214-01			J Alexander	Morphologic	
RR1	Phase 5	419178.96	7597902.88	14/12/17	Arthropoda	Maxillopoda	Cyclopoida	Cyclopidae	Halicyclops	rochai	2	RR01-20171214-01			J Alexander	Morphologic	

Site	Phase	Eastin	Northing	Date	Phylum	Class	Order	Family	Genus	Species	n	Field code	WAM registration	Preservation	Identifier	Identification method	Lineage
MEHRD0577	Phase 6	417838.1501	7593854.922	20170130	Arthropoda	Malacostraca	Isopoda	Armadillidae		sp 'ISA056/ISA057'	1	MEHRD0577.20170130.T2-01	C70386	100% Ethanol	Terrie Finston	Molecular	HelixISA057
MEHRD0577	Phase 6	417838.1501	7593854.922	20170130	Arthropoda	Malacostraca	Isopoda	Armadillidae		sp 'ISA056/ISA057'	1	MEHRD0577.20170130.T2-01			Terrie Finston	Molecular	HelixISA057
MEHRD0577	Phase 6	417838.1501	7593854.922	20170130	Arthropoda	Malacostraca	Isopoda	Armadillidae		sp 'ISA056/ISA057'	1	MEHRD0577.20170130.T3-01			Terrie Finston	Molecular	HelixISA057
MEHRD0577	Phase 6	417838.1501	7593854.922	20170130	Arthropoda	Malacostraca	Isopoda	Armadillidae		sp 'ISA056/ISA057'	1	MEHRD0577.20170130.T3-01			Terrie Finston	Molecular	HelixISA057
MEHRD0834	Phase 6	418837.0531	7592555.134	20170130	Arthropoda	Malacostraca	Isopoda	Armadillidae		sp 'ISA056/ISA057'	1	MEHRD0834.20170130.T1-01	C70391	100% Ethanol	Terrie Finston	Molecular	HelixISA057
MEHRD0834	Phase 6	418837.0531	7592555.134	20170130	Arthropoda	Malacostraca	Isopoda	Armadillidae		sp 'ISA056/ISA057'	1	MEHRD0834.20170130.T1-01	C70392	100% Ethanol	Terrie Finston	Molecular	HelixISA057
MEHRD0834	Phase 6	418837.0531	7592555.134	20170130	Arthropoda	Malacostraca	Isopoda	Armadillidae		sp 'ISA056/ISA057'	1	MEHRD0834.20170130.T1-01			Terrie Finston	Molecular	HelixISA057
MEHRD0834	Phase 6	418837.0531	7592555.134	20170130	Arthropoda	Malacostraca	Isopoda	Armadillidae		sp 'ISA056/ISA057'	1	MEHRD0834.20170130.T1-01			Terrie Finston	Molecular	HelixISA057
MEHRD0834	Phase 6	418837.0531	7592555.134	20170130	Arthropoda	Malacostraca	Isopoda	Armadillidae		sp 'ISA056/ISA057'	1	MEHRD0834.20170130.T2-01	C70393	100% Ethanol	Terrie Finston	Molecular	HelixISA057
RC15MEH0329	Phase 1	415438.227	7596951.285	20151210	Arthropoda	Arachnida	Pseudoscorpiones	Atemnidae		sp. 'PA004'	1	RC15MEH0329-20151210-T3-03	T143625	100% Ethanol	Terrie Finston	Molecular	HelixPA004
RC16JIM0026	Phase 5	420040.245	7591853.293	20161212	Arthropoda	Arachnida	Pseudoscorpiones	Olpiidae	Beierolpium	sp. 'PO014'	1	RC16JIM0026.20161212.T2-01	T142827	100% Ethanol	Terrie Finston	Molecular	HelixPO014
RC16MEH0433	Phase 5	415439.259	7597649.364	20161212	Arthropoda	Arachnida	Pseudoscorpiones	Olpiidae	Beierolpium	sp. 'PO015'	1	RC16MEH0433.20161211.T1-02	T142828	100% Ethanol	Terrie Finston	Molecular	HelixPO015
GR15MEH0032	Phase 3	419071.543	7594646.228	20160628	Arthropoda	Entognatha	Diplura	Campodeidae		sp. 'DCA005'	1	GR15MEH0032.20160628.T3-2	E84290	100% Ethanol	Terrie Finston	Molecular	HelixDCA005
MEHRD0834	Phase 6	418837.0531	7592555.134	20170130	Arthropoda	Arachnida	Pseudoscorpiones	Chthoniidae		sp. 'PC055'	1	MEHRD0834.20170130.T2-02	TT142829	100% Ethanol	Terrie Finston	Molecular	HelixPC055
GR15MEH0015	Phase 3	416033.7	7596749.003	20160627	Arthropoda	Arachnida	Pseudoscorpiones	Chthoniidae		sp.'PC014/PC015'	1	GR15MEH0015.20160627.T2-03	T142833	100% Ethanol	Terrie Finston	Molecular	HelixPC014
RC15MEH0315	Phase 3	415737.557	7596649.798	20160627	Arthropoda	Arachnida	Pseudoscorpiones	Chthoniidae		sp.'PC014/PC015'	1	RC15MEH0315.20160627.T2-02	T143809	100% Ethanol	Terrie Finston	Molecular	HelixPC015
RC15MEH0315	Phase 3	415737.557	7596649.798	20160627	Arthropoda	Arachnida	Pseudoscorpiones	Chthoniidae		sp.'PC014/PC015'	1	RC15MEH0315.20160627.T3-02	T143810	100% Ethanol	Terrie Finston	Molecular	HelixPC015
RC15MEH0335	Phase 3	415234.691	7597151.756	20160627	Arthropoda	Arachnida	Pseudoscorpiones	Chthoniidae		sp.'PC014/PC015'	1	RC15MEH0335.20160627.T1-01	T143811	100% Ethanol	Terrie Finston	Molecular	HelixPC015
RC14MEH0388	Phase 3	418087.615	7593503.838	20160628	Arthropoda	Chilopoda	Scolopendromorpha	Cryptopidae		sp. 'SC18'	1	RC14MEH0388.20160628.T2-2	T143812	100% Ethanol	Terrie Finston	Molecular	HelixSC18
RC15MEH0114	Phase 2	416434.05	7594352.361	20160118	Arthropoda	Entognatha	Diplura			sp.	1	RC15MEH0114-20160118-T2-03	E84292	100% Ethanol	Penny Brooshooft	Morphological	Failed
RC16MEH0264	Phase 6	417476.021	7594964.208	20170130	Arthropoda	Entognatha	Diplura			sp.	1	RC16MEH0264.20170130.T3-01	E84288	100% Ethanol	Nicola Watson	Morphological	Failed
RC14MEH0270	Phase 5	418380.862	7593101.951	20161212	Arthropoda	Arachnida	Araneae	Gnaphosidae		sp.	1	RC14MEH0270.20161212.T4-02	T142824	100% Ethanol	Karen Cullen	Morphological	
DD13MEH0007	Phase 1	419635.017	7593002.209	20151023	Arthropoda	Arachnida	Schizomida	Hubbardiidae		sp. 'SCH015/SCH016'	1	DD13MEH0007-20160119-03	T143628	100% Ethanol	Terrie Finston	Molecular	HelixSCH015
RC12MEH0221	Phase 2	419349.389	7593104.572	20160120	Arthropoda	Arachnida	Schizomida	Hubbardiidae		sp. 'SCH015/SCH016'	1	RC12MEH0221-20160120-T3-03A	T143618	100% Ethanol	Terrie Finston	Molecular	HelixSCH015
RC12MEH0221	Phase 2	419349.389	7593104.572	20160120	Arthropoda	Arachnida	Schizomida	Hubbardiidae		sp. 'SCH015/SCH016'	1	RC12MEH0221-20160120-T3-03B	TT143619	100% Ethanol	Terrie Finston	Molecular	HelixSCH015
RC14MEH0252	Phase 2	418788.505	7593304.312	20160120	Arthropoda	Arachnida	Schizomida	Hubbardiidae		sp. 'SCH015/SCH016'	1	RC14MEH0252-20160120-T3-02	T143621	100% Ethanol	Terrie Finston	Molecular	HelixSCH015
RC15MEH0306	Phase 3	416430.841	7596647.612	20160627	Arthropoda	Arachnida	Schizomida	Hubbardiidae		sp. 'SCH015/SCH016'	1	RC15MEH0306.20160627.T3-03	T133452	100% Ethanol	Terrie Finston	Molecular	HelixSCH016
RC16JIM0026	Phase 5	420040.245	7591853.293	20161212	Arthropoda	Arachnida	Schizomida	Hubbardiidae		sp. 'SCH015/SCH016'	1	RC16JIM0026.20161212.T1-01	T133453	100% Ethanol	Terrie Finston	Molecular	HelixSCH015
RC16JIM0031	Phase 5	419780.264	7591698.526	20161212	Arthropoda	Arachnida	Schizomida	Hubbardiidae		sp. 'SCH015/SCH016'	1	RC16JIM0031.20161212.T2-01	T133454	100% Ethanol	Terrie Finston	Molecular	HelixSCH015
RC15MEH0329	Phase 2	415438.227	7596951.285	20160118	Arthropoda	Arachnida	Schizomida	Hubbardiidae		sp.	1	RC15MEH0329-20160118T3-01B	T143627	100% Ethanol	Penny Brooshooft	Morphological	Failed
RC16MEH0436	Phase 4	415708.444	7597253.62	20161026	Arthropoda	Arachnida	Pseudoscorpiones	Hyidae		sp. 'PH026'	1	RC16MEH0436.20161026.T2-01	T142826	100% Ethanol	Terrie Finston	Molecular	HelixPH026
RC16MEH0264	Phase 6	417476.021	7594964.208	20170130	Arthropoda	Arachnida	Pseudoscorpiones	Hyidae		sp. 'PH017/PH027'	1	RC16MEH0264.20170130.T3-03	T142832	100% Ethanol	Terrie Finston	Molecular	HelixPC027
RC14MEH0252	Phase 2	418788.505	7593304.312	20160120	Arthropoda	Arachnida	Pseudoscorpiones	Hyidae		sp. 'PH017/PH027'	1	RC14MEH0252-20160120-T1-04	T143620	100% Ethanol	Terrie Finston	Molecular	HelixPC017
MEHRD0577	Phase 6	417838.1501	7593854.922	20170130	Arthropoda	Malacostraca	Isopoda			sp.	1	MEHRD0577.20170130.T1-02	C70383	100% Ethanol	Nicola Watson	Morphological	Failed
MEHRD0577	Phase 6	417838.1501	7593854.922	20170130	Arthropoda	Malacostraca	Isopoda			sp.	1	MEHRD0577.20170130.T1-02	C70384	100% Ethanol	Nicola Watson	Morphological	Failed
MEHRD0577	Phase 6	417838.1501	7593854.922	20170130	Arthropoda	Malacostraca	Isopoda			sp.	1	MEHRD0577.20170130.T1-02	C70385	100% Ethanol	Nicola Watson	Morphological	Failed
MEHRD0577	Phase 6	417838.1501	7593854.922	20170130	Arthropoda	Malacostraca	Isopoda			sp.	1	MEHRD0577.20170130.T2-01	C70387	100% Ethanol	Nicola Watson	Morphological	Failed
MEHRD0577	Phase 6	417838.1501	7593854.922	20170130	Arthropoda	Malacostraca	Isopoda			sp.	1	MEHRD0577.20170130.T3-01	C70388	100% Ethanol	Nicola Watson	Morphological	Failed
MEHRD0577	Phase 6	417838.1501	7593854.922	20170130	Arthropoda	Malacostraca	Isopoda			sp.	1	MEHRD0577.20170130.T3-01	C70389	100% Ethanol	Nicola Watson	Morphological	Failed
MEHRD0577	Phase 6	417838.1501	7593854.922	20170130	Arthropoda	Malacostraca	Isopoda			sp.	1	MEHRD0577.20170130.T3-01	C70390	100% Ethanol	Nicola Watson	Morphological	Failed
MEHRD0577	Phase 6	417838.1501	7593854.922	20170130	Arthropoda	Malacostraca	Isopoda			sp.	1	MEHRD0577.20170130.T3-01			Nicola Watson	Morphological	Failed
MEHRD0577	Phase 6	417838.1501	7593854.922	20170130	Arthropoda	Malacostraca	Isopoda			sp.	1	MEHRD0577.20170130.T3-01			Nicola Watson	Morphological	Failed
MEHRD0834	Phase 6	418837.0531	7592555.134	20170130	Arthropoda	Malacostraca	Isopoda			sp.	1	MEHRD0834.20170130.T1-01			Nicola Watson	Morphological	Failed
RC14MEH0388	Phase 3	418087.615	7593503.838	20160628	Arthropoda	Entognatha	Diplura	Japygidae		sp. 'DJA003'	1	RC14MEH0388.20160628.T3-1	E84289	100% Ethanol	Terrie Finston	Molecular	HelixDJA003
DD13MEH0007	Phase 4	419635.017	7593002.209	20160914	Arthropoda	Entognatha	Diplura	Japygidae		sp. 'DJA011'	1	DD13MEH0007-20160914-01	E84284	100% Ethanol	Terrie Finston	Molecular	HelixDJA011
RC15MEH0302	Phase 1	416333.034	7596351.403	20151210	Arthropoda	Arachnida	Pseudoscorpiones	Olpiidae		sp. 'PO008'	1	RC15MEH0302-20151210-T1-03	T143624	100% Ethanol	Terrie Finston	Molecular	HelixPO008
MEHRC0957	Phase 2	415437.8502	7596554.182	20160118	Arthropoda	Arachnida	Schizomida	Hubbardiidae	Paradraculoides	sp. 'SCH038'	1	MEHRC157-20160118-T1-02A	T143615	100% Ethanol	Terrie Finston	Molecular	HelixSCH038
MEHRC0957	Phase 2	415437.8502	7596554.182	20160118	Arthropoda	Arachnida	Schizomida	Hubbardiidae	Paradraculoides	sp. 'SCH038'	1	MEHRC157-20160118-T1-02B	T143616	100% Ethanol	Terrie Finston	Molecular	HelixSCH038
RC15MEH0329	Phase 2	415438.227	7596951.285	20160118	Arthropoda	Arachnida	Schizomida	Hubbardiidae	Paradraculoides	sp. 'SCH038'	1	RC15MEH0329-20160118T3-01A	T143626	100% Ethanol	Terrie Finston	Molecular	HelixSCH038
RC16MEH0264	Phase 6	417476.021	7594964.208	20170130	Arthropoda	Arachnida	Schizomida	Hubbardiidae	Paradraculoides	sp. 'SCH038'	1	RC16MEH0264.20170130.T3-02	T142831	100% Ethanol	Terrie Finston	Molecular	HelixSCH038
RC16MEH0433	Phase 4	415439.259	7597649.364	20161026	Arthropoda	Arachnida	Schizomida	Hubbardiidae	Paradraculoides	sp. 'SCH038'	1	RC16MEH0433.20161026.T2-01	T142825	100% Ethanol	Terrie Finston	Molecular	HelixSCH038
RC15MEJ0019	Phase 6	419263.833	7592144.266	20170130	Arthropoda	Arachnida	Schizomida	Hubbardiidae	Paradraculoides	sp. 'SCH039'	1	RC15MEJ0019.20170130.T1-01	T142830	100% Ethanol	Terrie Finston	Molecular	HelixSCH039
RC14MEH0308	Phase 2	418986.673	7592555.537	20160120	Arthropoda	Entognatha	Diplura	Parajapygidae		sp. 'DPA001'	1	RC14MEH0308-20160120-T2-02	E84291	100% Ethanol	Terrie Finston	Molecular	HelixDPA001
MEHRD0758	Phase 6	414937.0889	7595953.467	20170130	Arthropoda	Entognatha	Diplura	Parajapygidae		sp. 'DPA009'	1	MEHRD0758.20170130.T3-01	E84287	100% Ethanol	Terrie Finston	Molecular	HelixDPA009
RC15MEH0382	Phase 2	418994.937	7594660.173	20160120	Arthropoda	Malacostraca	Isopoda	Philosciidae		sp. 'ISP047'	1	RC15MEH0382-20160120-T1-03A	C60922	100% Ethanol	Terrie Finston	Molecular	HelixISP047
RC15MEH0382	Phase 2	418994.937	7594660.173	20160120	Arthropoda	Malacostraca	Isopoda	Philosciidae		sp. 'ISP047'	1	RC15MEH0382-20160120-T1-03B	C60923	100% Ethanol	Terrie Finston	Molecular	HelixISP047
RC15MEH0382	Phase 2	418994.937	7594660.173	20160120	Arthropoda	Malacostraca	Isopoda	Philosciidae		sp. 'ISP047'	1	RC15MEH0382-20160120-T1-03C	C60924	100% Ethanol	Terrie Finston	Molecular	HelixISP047
RC15MEH0382	Phase 2	418994.937	7594660.173	20160120	Arthropoda	Malacostraca	Isopoda	Philosciidae		sp. 'ISP047'	1	RC15MEH0382-20160120-T1-03D	C60925	100% Ethanol	Terrie Finston	Molecular	HelixISP047
RC15MEH0382	Phase 2	418994.937	7594660.173	20160120	Arthropoda	Malacostraca	Isopoda	Philosciidae		sp. 'ISP047'	1	RC15MEH0382-20160120-T1-03E	C60926	100% Ethanol	Terrie Finston	Molecular	HelixISP047
RC15MEH0382	Phase 2	418994.937	7594660.173	20160120	Arthropoda	Malacostraca	Isopoda	Philosciidae		sp. 'ISP047'	1	RC15MEH0382-20160120-T2-03	C60927	100% Ethanol	Terrie Finston	Molecular	HelixISP047
RC16MEH0427	Phase 4	415130.678	7597112.585	20161026	Arthropoda	Malacostraca	Isopoda	Philosciidae		sp. 'ISP055'	1	RC16MEH0427.20161026.T3-01	C70354	100% Ethanol	Terrie Finston	Molecular	HelixISP055
RC16JIM0019	Phase 4	423026.712	7590287.794	20161027	Arthropoda	Arachnida	Araneae	Oonopidae	Prethopalpus	sp. 'ARA052'	1	RC16JIM0019.20161027-01	T142823	100% Ethanol	Karen Cullen	Morphological	

Site	Phase	Eastin	Northing	Date	Phylum	Class	Order	Family	Genus	Species	n	Field code	WAM registration	Preservation	Identifier	Identification method	Lineage
RC15MEH0175	Phase 1	416434.343	7594944.106	20151210	Arthropoda	Entognatha	Diplura	Projapygidae		sp. 'DPR008/DPR009/DPR011'	1	RC15MEH0175-20151210-T1-01	E84294	100% Ethanol	Terrie Finston	Molecular	HelixDPR008
RC15MEH0166	Phase 2	416932.656	7594851.369	20160118	Arthropoda	Entognatha	Diplura	Projapygidae		sp. 'DPR008/DPR009/DPR011'	1	RC15MEH0166-20160118-T3-03	E84293	100% Ethanol	Terrie Finston	Molecular	HelixDPR008
RC15MEH0261	Phase 2	418437.926	7595598.632	20160120	Arthropoda	Entognatha	Diplura	Projapygidae		sp. 'DPR008/DPR009/DPR011'	1	RC15MEH0261-20160120-T3-02	E84295	100% Ethanol	Terrie Finston	Molecular	HelixDPR009
RC16JIM0005	Phase 5	421202.357	7591531.346	20161212	Arthropoda	Entognatha	Diplura	Projapygidae		sp. 'DPR010'	1	RC16JIM0005.20161212.T1-01	E84285	100% Ethanol	Terrie Finston	Molecular	HelixDPR010
RC16JIM0005	Phase 5	421202.357	7591531.346	20161212	Arthropoda	Entognatha	Diplura	Projapygidae		sp. 'DPR008/DPR009/DPR011'	1	RC16JIM0005.20161212.T3-01	E84286	100% Ethanol	Terrie Finston	Molecular	HelixDPR011
RC12MEH0120	Phase 1	419988.44	7592306.75	20151211	Arthropoda	Arachnida	Pseudoscorpiones			sp.	1	RC12MEH0120-20151211-T1-01B	T143623	100% Ethanol	Nicola Watson	Morphological	Failed
RC12MEH0120	Phase 1	419988.44	7592306.75	20151211	Arthropoda	Arachnida	Pseudoscorpiones			sp.	1	RC12MEH0120-20151211-T1-01A	T143622	100% Ethanol	Nicola Watson	Morphological	Failed
RC15MEH0382	Phase 2	418994.937	7594660.173	20160120	Arthropoda	Malacostraca	Isopoda	Armadillidae	Troglarmadillo	sp. 'ISA046'	1	RC15MEH0382-20160120-T3-03	C60928	100% Ethanol	Terrie Finston	Molecular	HelixISA046
MEHRD0577	Phase 6	417838.1501	7593854.922	20170130	Arthropoda	Malacostraca	Isopoda			sp.	3	MEHRD0577.20170130.T3-01			Nicola Watson	Morphological	
RC12MEH0221	Phase 1	419349.389	7593104.572	20151210	Arthropoda	Insecta	Coleoptera	Curculionidae		sp. 'CCU014'	2	RC12MEH022120151210-T2-04A	E34038	100% Ethanol	Terrie Finston	Molecular	HelixCCU014
RC12MEH0221	Phase 1	419349.389	7593104.572	20151210	Arthropoda	Insecta	Coleoptera	Curculionidae		sp. 'CCU014'	2	RC12MEH022120151210-T2-04B	E34039	100% Ethanol	Terrie Finston	Molecular	HelixCCU014
RC14MEH0252	Phase 1	418788.505	7593304.312	20151210	Arthropoda	Insecta	Coleoptera	Curculionidae		sp. 'CCU014'	1	RC14MEH025220151210-T1-04	E34042	100% Ethanol	Terrie Finston	Molecular	HelixCCU014
RC15MEH0302	Phase 1	416333.034	7596351.403	20151210	Arthropoda	Insecta	Coleoptera	Curculionidae		sp. 'CCU014'	1	RC15MEH030220151210-T2-02	E34043	100% Ethanol	Terrie Finston	Molecular	HelixCCU014
RC12MEH0221	Phase 4	419349.389	7593104.572	20161026	Arthropoda	Insecta	Coleoptera	Ptiliidae		sp. 1/ 'CP003'	25	RC12MEH0221.20161026.T1-01	E34040	100% Ethanol	Nicola Watson	Morphological	
RC14MEH0238	Phase 1	418845.591	7592802.363	20151211	Arthropoda	Insecta	Coleoptera	Ptiliidae		sp. 'Robe Valley'/'CP002'	5	RC14MEH023820151211-T1-03	E34041	100% Ethanol	Nicola Watson	Morphological	
RC16MEH0264	Phase 6	417476.021	7594964.208	20170130	Arthropoda	Insecta	Coleoptera	Ptiliidae		sp. 1/ 'CP003'	1	RC16MEH0264.20170130.T3-04			Terrie Finston	Molecular	HelixCP003
RC16MEH0427	Phase 5	415130.678	7597112.585	20161211	Arthropoda	Insecta	Blattodea	Nocticolionidae	?Nocticola	sp. 'West Pilbara Complex'	1	RC16MEH0427.20161211.T2	E34037	100% Ethanol	Terrie Finston	Molecular	HelixBN021
RC12MEH0221	Phase 1	419349.389	7593104.572	20151210	Arthropoda	Insecta	Blattodea	Nocticolionidae	?Nocticola	sp. 'West Pilbara Complex'	1	RC12MEH022120151210-T2-01	E34036	100% Ethanol	Terrie Finston	Molecular	HelixBN020
RC16JIM0006	Phase 2	421366.083	7591828.359	20160120	Arthropoda	Entognatha	Zygentoma	Nicoletiidae		sp. 'TN019'	1	RC12JIM0006201601197T2-02	E34044	100% Ethanol	Terrie Finston	Molecular	HelixTN019
RC14MEH0252	Phase 1	418788.505	7593304.312	20151210	Arthropoda	Entognatha	Zygentoma	Nicoletiidae		sp. 'TN020'	1	RC14MEH025220151210-T1-03	E34045	100% Ethanol	Terrie Finston	Molecular	HelixTN020
RC16MEH0264	Phase 6	417476.021	7594964.208	20170130	Arthropoda	Insecta	Coleoptera	Ptiliidae		sp. 1/ 'CP003'	1	RC16MEH0264.20170130.T3-04			Terrie Finston	Molecular	HelixCP003
RC16MEH0264	Phase 6	417476.021	7594964.208	20170130	Arthropoda	Insecta	Coleoptera	Ptiliidae		sp. 1/ 'CP003'	1	RC16MEH0264.20170130.T3-04			Terrie Finston	Molecular	HelixCP003
RC16MEH0264	Phase 6	417476.021	7594964.208	20170130	Arthropoda	Insecta	Coleoptera	Ptiliidae		sp. 1/ 'CP003'	1	RC16MEH0264.20170130.T3-04			Terrie Finston	Molecular	HelixCP003
RC12MEH0221	Phase 4	419349.389	7593104.572	20161026	Arthropoda	Insecta	Coleoptera	Ptiliidae		sp. 1/ 'CP003'	1	RC12MEH0221.20161026.T1-01			Terrie Finston	Molecular	HelixCP003
RC12MEH0221	Phase 4	419349.389	7593104.572	20161026	Arthropoda	Insecta	Coleoptera	Ptiliidae		sp. 1/ 'CP003'	1	RC12MEH0221.20161026.T1-01			Terrie Finston	Molecular	HelixCP003
RC12MEH0221	Phase 4	419349.389	7593104.572	20161026	Arthropoda	Insecta	Coleoptera	Ptiliidae		sp. 1/ 'CP003'	1	RC12MEH0221.20161026.T1-01			Terrie Finston	Molecular	HelixCP003
RC12MEH0221	Phase 4	419349.389	7593104.572	20161026	Arthropoda	Insecta	Coleoptera	Ptiliidae		sp. 1/ 'CP003'	1	RC12MEH0221.20161026.T1-01			Terrie Finston	Molecular	HelixCP003
RC12MEH0221	Phase 4	419349.389	7593104.572	20161026	Arthropoda	Insecta	Coleoptera	Ptiliidae		sp. 1/ 'CP003'	1	RC12MEH0221.20161026.T1-01			Terrie Finston	Molecular	HelixCP003
RC14MEH0238	Phase 1	418845.591	7592802.363	20151211	Arthropoda	Insecta	Coleoptera	Ptiliidae		sp. 'Robe Valley'/'CP002'	1	RC14MEH023820151211-T1-03			Terrie Finston	Molecular	HelixCP002
RC14MEH0238	Phase 1	418845.591	7592802.363	20151211	Arthropoda	Insecta	Coleoptera	Ptiliidae		sp. 'Robe Valley'/'CP002'	1	RC14MEH023820151211-T1-03			Terrie Finston	Molecular	HelixCP002
RC14MEH0238	Phase 1	418845.591	7592802.363	20151211	Arthropoda	Insecta	Coleoptera	Ptiliidae		sp. 'Robe Valley'/'CP002'	1	RC14MEH023820151211-T1-03			Terrie Finston	Molecular	HelixCP002
RC14MEH0238	Phase 1	418845.591	7592802.363	20151211	Arthropoda	Insecta	Coleoptera	Ptiliidae		sp. 'Robe Valley'/'CP002'	1	RC14MEH023820151211-T1-03			Terrie Finston	Molecular	HelixCP002
RC14MEH0238	Phase 1	418845.591	7592802.363	20151211	Arthropoda	Insecta	Coleoptera	Ptiliidae		sp. 'Robe Valley'/'CP002'	1	RC14MEH023820151211-T1-03			Terrie Finston	Molecular	HelixCP002
J0866	Phase 1	422437.97	7596054.499	20080710	Arthropoda	Arachnida	Schizomida	Hubbardiidae		sp. 'SCH011'	1	J0866P2T1-3	T96T161	100% Ethanol	Terrie Finston	Molecular	HelixSCH011
J0866	Phase 2	422437.97	7596054.499	20081202	Arthropoda	Arachnida	Schizomida	Hubbardiidae		sp. 'SCH011'	1	J0866P2T2-1	T96160	100% Ethanol	Terrie Finston	Molecular	HelixSCH011
J0866	Phase 1	422437.97	7596054.499	20080710	Arthropoda	Arachnida	Schizomida	Hubbardiidae		sp.	1	J0866P1T2-1	T92212	100% Ethanol	Nicola Watson	Morphological	Failed
J0866	Phase 2	422437.97	7596054.499	20081202	Arthropoda	Arachnida	Schizomida	Hubbardiidae		sp. 'SCH011'	1	J0866P1T1-1	T92211	100% Ethanol	Terrie Finston	Molecular	HelixSCH011
J0867	Phase 2	422437.97	7595954.499	20081202	Arthropoda	Arachnida	Schizomida	Hubbardiidae		sp. 'SCH011'	1	J0867P2T3-1	T96167	100% Ethanol	Terrie Finston	Molecular	HelixSCH011
J0867	Phase 2	422437.97	7595954.499	20081202	Arthropoda	Arachnida	Schizomida	Hubbardiidae		sp. 'SCH011'	1	J0867P2T1-1	T96162	100% Ethanol	Terrie Finston	Molecular	HelixSCH011
J0928	Phase 2	422637.97	7596054.5	20081202	Arthropoda	Arachnida	Schizomida	Hubbardiidae		sp. 'SCH011'	1	J0928P2T1-5A			Terrie Finston	Molecular	HelixSCH011
J0928	Phase 2	422637.97	7596054.5	20081202	Arthropoda	Arachnida	Schizomida	Hubbardiidae		sp. 'SCH011'	1	J0928P2T1-5	T96166	100% Ethanol	Terrie Finston	Molecular	HelixSCH011
MEJ0076	Phase 2	419946.7082	7595698.905	20081202	Arthropoda	Arachnida	Schizomida	Hubbardiidae		sp.	1	MEJ0076P2T2-4	T96164	100% Ethanol	Nicola Watson	Morphological	Failed
MEJ0076	Phase 2	419946.7082	7595698.905	20081202	Arthropoda	Arachnida	Schizomida	Hubbardiidae		sp. 'SCH011'	1	MEJ0076P2T3-3	T96159	100% Ethanol	Terrie Finston	Molecular	HelixSCH011
MEJ0048	Phase 2	419879.9633	7595939.9	20081202	Arthropoda	Arachnida	Schizomida	Hubbardiidae		sp. 'SCH011'	1	MEJ0048P2T2-3	T96165	100% Ethanol	Terrie Finston	Molecular	HelixSCH011
MEJ0085	Phase 2	419941.6808	7595604.879	20081202	Arthropoda	Arachnida	Schizomida	Hubbardiidae		sp. 'SCH011'	1	MEJ0085P2T3-3A			Terrie Finston	Molecular	HelixSCH011
MEJ0085	Phase 2	419941.6808	7595604.879	20081202	Arthropoda	Arachnida	Schizomida	Hubbardiidae		sp. 'SCH011'	1	MEJ0085P2T3-3	T96163	100% Ethanol	Terrie Finston	Molecular	HelixSCH011
MEJ5548alt	Phase 1	420888.294	7596304.607	20080710	Arthropoda	Arachnida	Schizomida	Hubbardiidae		sp. 'SCH011'	1	MEJ5548altP1T3-2	T92210	100% Ethanol	Terrie Finston	Molecular	HelixSCH011
MEJ5548alt	Phase 1	420888.294	7596304.607	20080710	Arthropoda	Arachnida	Schizomida	Hubbardiidae		sp. 'SCH011'	1	MEJ5548altP1T3-2A			Terrie Finston	Molecular	HelixSCH011
MEJ5548alt	Phase 1	420888.294	7596304.607	20080710	Arthropoda	Arachnida	Schizomida	Hubbardiidae		sp. 'SCH011'	1	MEJ5548altP1T2-2	T92208	100% Ethanol	Terrie Finston	Molecular	HelixSCH011
RC08MEJ0004	Phase 4	420036.6506	7596954.526	20091022	Arthropoda	Arachnida	Schizomida	Hubbardiidae		sp. 'SCH011'	1	RC08MEJ0004P4T2-4	T99567	100% Ethanol	Terrie Finston	Molecular	HelixSCH011
RC08MEJ0015	Phase 4	420033.4152	7596851.769	20091022	Arthropoda	Arachnida	Schizomida	Hubbardiidae		sp. 'SCH011'	1	RC08MEJ0015P4T2-3	T99568	100% Ethanol	Terrie Finston	Molecular	HelixSCH011
RC08MEJ0015	Phase 4	420033.4152	7596851.769	20091022	Arthropoda	Arachnida	Schizomida	Hubbardiidae		sp. 'SCH011'	1	RC08MEJ0015P4T1-5	T99570	100% Ethanol	Terrie Finston	Molecular	HelixSCH011
RC08MEJ0023	Phase 4	419930.7698	7596804.544	20091022	Arthropoda	Arachnida	Schizomida	Hubbardiidae		sp. 'SCH011'	1	RC08MEJ0023P4T2-3	T99569	100% Ethanol	Terrie Finston	Molecular	HelixSCH011
MEJ0007	Phase 1	419891.6269	7596957.681	20080710	Arthropoda	Arachnida	Schizomida	Hubbardiidae		sp. 'SCH011'	1	MEJ0007P1T2-1	T92209	100% Ethanol	Terrie Finston	Molecular	HelixSCH011
MEJ0007	Phase 1	419891.6269	7596957.681	20080710	Arthropoda	Arachnida	Schizomida	Hubbardiidae		sp.	1	MEJ0007P1T2-1A			Nicola Watson	Morphological	Failed
MEJ0007	Phase 1	419891.6269	7596957.681	20080710	Arthropoda	Arachnida	Schizomida	Hubbardiidae		sp. 'SCH011'	1	MEJ0007P1T1-1	T92207	100% Ethanol	Terrie Finston	Molecular	HelixSCH011

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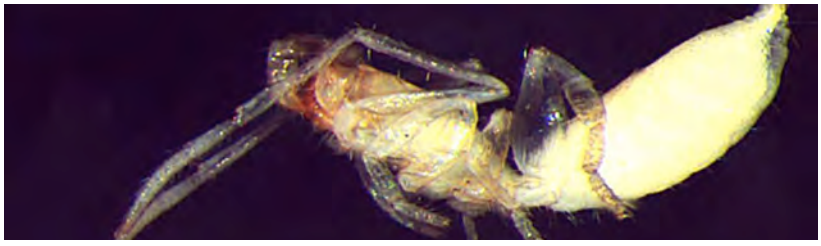
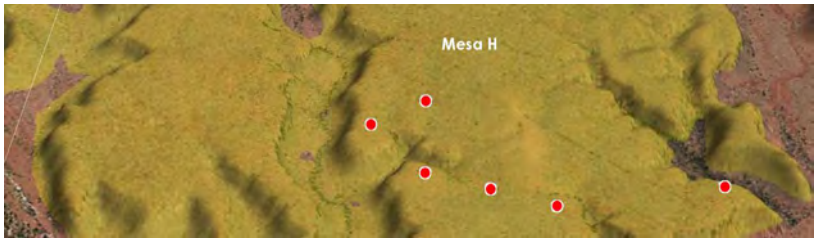
Mesa H Project Subterranean Fauna Habitat and Impact Risk Assessment





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1.0 Introduction

1.1 Project Background

Rio Tinto is evaluating the potential development of a number of iron ore deposits within the Robe River valley in the Pilbara region of Western Australia. This includes the development of the Mesa H deposit (15 km southwest of Pannawonica) (Figure 1.1).

Previous studies have documented the occurrence of subterranean fauna communities within the Robe River valley, including both troglofauna (air-breathing species living below ground but above the water table) and stygofauna (species living in groundwater systems). Troglofauna, in particular, demonstrate extreme short-range endemism as a result of geological barriers, with many Robe River valley species being isolated to individual mesa formations (Biota 2006a, Harvey et al. 2008). Some stygofauna species can also represent short-range endemic (SRE) taxa and all are restricted to groundwater habitats. Given these considerations, subterranean fauna are of relevance to the environmental impact assessment (EIA) of proposed developments affecting their habitat (EPA 2016a).

The development of the Mesa H deposit has the potential to impact subterranean fauna, and Rio Tinto commissioned Biota Environmental Sciences (Biota) to complete subterranean fauna surveys to collect baseline data to inform the assessment of these impacts (Biota 2019). This report draws on the findings of those surveys, and combines this with project definition provided by Rio Tinto, to assess the potential impacts on troglofauna and stygofauna of the Mesa H project.

1.2 Terminology

For the purposes of this report, the following terms are used as defined below:

- development envelope – the Mesa H project boundary, which will accommodate the full extent of the physical components of the project (Figure 1.1);
- desktop review area – an area encompassing the development envelope, and a 15 km square around it, used by Biota (2019) to take account of data from previous surveys undertaken near Mesa H (Figure 1.1);
- drawdown extent – the spatial extent of the maximum groundwater dewatering influence for the base case for the Mesa H project, which extends beyond the development envelope to the east and southeast (Figure 1.1); and
- survey area – the area surveyed for subterranean fauna by Biota (2019), including the development envelope and drawdown extent, and reference sites outside of this areas within the Robe River valley (Figure 1.1).

1.3 Purpose and Scope of this Report

The purpose of this report is to inform the impact assessment of proposed mining activities within the Mesa H development envelope. It is intended as a supporting study to the Environmental Review Document Rio Tinto is preparing for the formal assessment of the proposed Mesa H project under Section 38 of the *Environmental Protection Act 1986*.

This report consolidates the results of all subterranean fauna data from the survey area with available habitat information to develop a model of demonstrated and inferred fauna distributions and habitat connectivity. The key characteristics of the Mesa H project, and their potential impact mechanisms, are then considered against this, to provide a risk-based assessment of the impacts on subterranean ecosystems within the development envelope, consistent with current Environmental Protection Authority (EPA) guidance (Section 2.1).

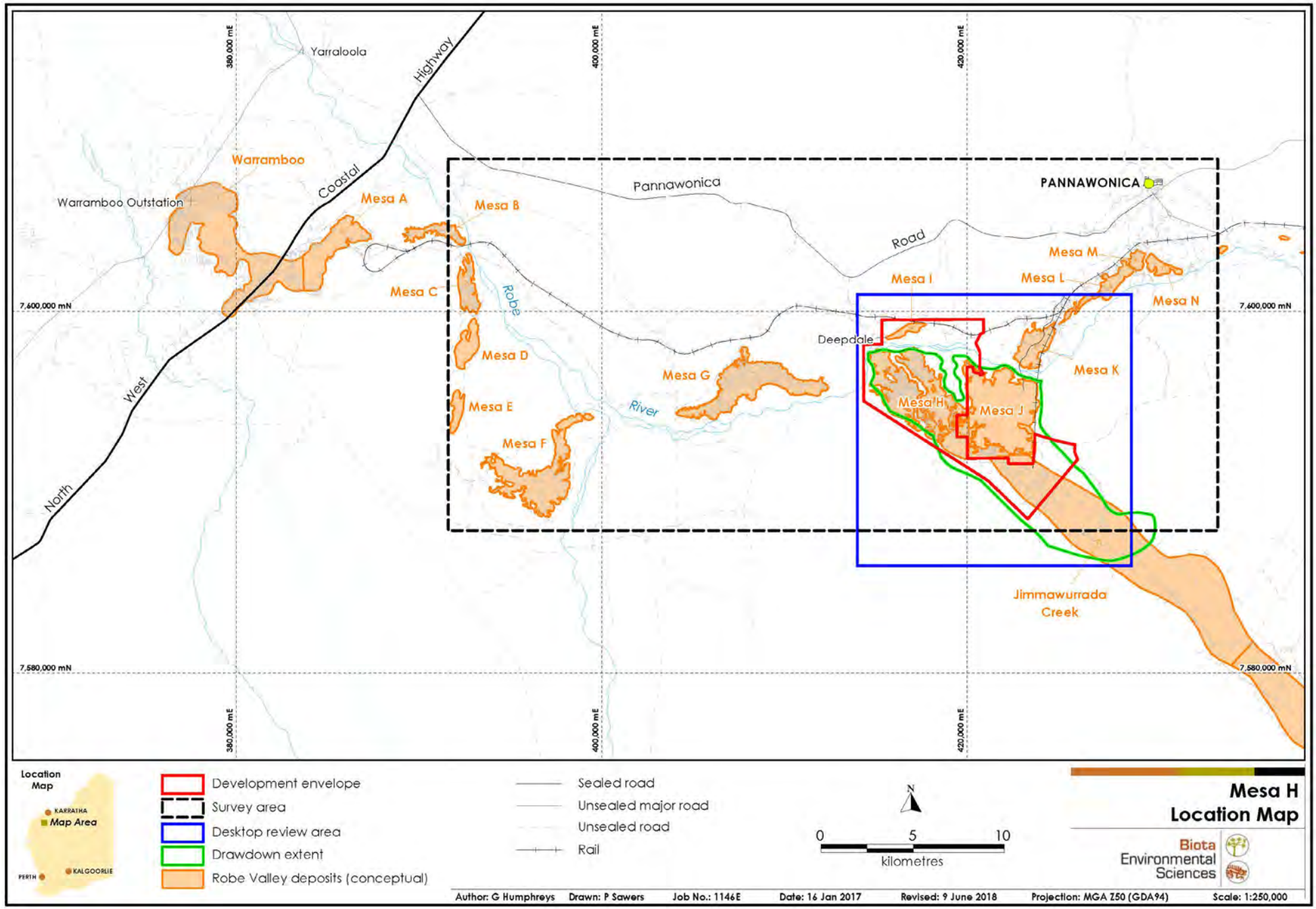

Figure 1.1: Location map of the Mesa H project area.

2.0 Methodology

2.1 Policy Framework

The impact assessment was completed in accordance with:

- EPA Statement of Environmental Principles, Factors and Objectives (EPA 2018);
- Environmental Factor Guideline – Subterranean Fauna (EPA 2016a);
- Technical Guidance - Subterranean fauna survey (EPA 2016b); and
- Technical Guidance - Sampling methods for subterranean fauna (EPA 2016c).

2.2 Approach

This impact assessment has adopted an overall approach of initially identifying all subterranean fauna receptors relevant to the EPA assessment of the Mesa H project (on the basis of the Biota (2019) surveys) and defining the habitats within which they occur. Key receptors were then identified and the predicted impacts of the project, including extent, consequences and resilience of the key receptors, were then assessed, including the level of confidence in predictions.

This approach is aligned with EPA (2018) guidance on determining the significance of impacts: in the case of species or habitats that are more widespread than the impact area, are not of conservation significance, or otherwise unlikely to be impacted, the project would be considered unlikely to have a significant impact in the context of EPA's objective for subterranean fauna.

While all subterranean fauna were considered, the species, communities or habitats that are of restricted distribution, or otherwise of conservation significance, were treated as the key receptors for more detailed evaluation of potential impacts, which is consistent with the guidance provided by EPA (EPA 2016a, 2018).

The logical sequence followed by this document then is to:

1. review, characterise and quantify the key aspects of the Mesa H project to define potential impact sources and pathways (Section 2.3);
2. document all subterranean fauna species and communities present in the development envelope (for troglofauna and stygofauna) and the drawdown area (for stygofauna only), and determine if they represent key receptors (Section 2.4); and
3. delineate the habitats occupied by the key receptors and assess the risk of significant impacts arising from the proposal (Section 2.5 and 2.6).

2.3 Impact Sources and Pathways

2.3.1 Impact Sources

Impact sources inherent to the Mesa H project were identified by collating and reviewing relevant project aspects and attributes. These were compiled from the proposal definition provided by Rio Tinto, comprising the key characteristics, development envelope, indicative arrangement, pit and dump designs, and modelling information.

2.3.2 Impact Pathways

Impact pathways are the mechanisms by which the impact sources result in an impact on subterranean receptors, and these can be broadly categorised as either direct or indirect (EPA 2016a). The most important, direct impact pathways are well recognised and have regularly arisen during past EPA assessments involving impacts on subterranean fauna.

These direct pathways, such as troglofauna habitat removal for mine pits, can typically be spatially quantified and are thereby the clearest to assess. Direct impacts were addressed here through the use of MapInfo Professional Geographical Information System (GIS) v12 (MapInfo). The components of the indicative arrangement and groundwater modelling outputs provided by Rio Tinto were intersected in GIS with subterranean fauna habitats, records of key receptors and other ecological data to quantify impact extents and identify the predicted influence of the proposal.

2.4 Identification of Subterranean Fauna Key Receptors

Key subterranean fauna species and habitat receptors in this impact assessment were those from the list of all relevant subterranean receptors that:

1. meet the criteria outlined in Section 2.4.1 and 2.4.2 below; and/or
2. the basis for their conservation listing and identified threatening processes are relevant to the proposed development; and/or
3. their known distribution, habitat requirements and ecology suggest they may be significantly affected by the impact pathways arising from the project.

This provided a means of focussing the list of all subterranean species known from the development envelope and drawdown extent down to those species most relevant to the impact assessment. Other species recorded during subterranean fauna surveys determined by Biota (2019) as widespread were excluded from the final impact assessment, and records where species level determinations could not be made were excluded from consideration altogether.

Similarly, some subterranean habitats occurring in the development envelope would not be considered key receptors. The criteria applied for determining habitats to be key receptors, and therefore considered in this impact assessment, are detailed in Section 2.4.3.

2.4.1 Species and Communities of Conservation Significance

All species or ecological communities occurring or likely to occur in the development envelope and drawdown extent that are currently listed as:

1. Threatened species under the Commonwealth *Environment Protection and Biodiversity Conservation* (*EPBC) Act 1999*;
2. Schedule species under the State *Wildlife Conservation Act 1950*;
3. Priority species by the Department of Biodiversity, Conservation and Attractions (DBCA); or
4. Priority Ecological Communities (PECs) recognised by DBCA.

All qualified as key receptors for this impact assessment.

2.4.2 Other Species of Significance

Consistent with Biota (2019), for the purposes of this report, other subterranean fauna known from the development envelope that are relevant to impact assessment but not formally listed as conservation significant were categorised as:

- Confirmed short-range endemic (SRE) species: Species where sufficient taxonomic expertise is available, and with adequate representation in the Western Australian Museum collections or genetic databases, that are known to be limited in distribution.
- Potential SRE species: Species where there is insufficient taxonomic knowledge, or there are too limited a number of collections, to determine SRE status. Habitat, morphology, molecular or taxonomic data is deficient for these species, but they belong to groups that may display short-range endemism.

Where species recorded by Biota (2019) are either confirmed or potential SREs, they were treated as key receptors.

2.4.3 Subterranean Habitat Receptors

Subterranean fauna habitats treated as key receptors were identified as either Medium or High prospectivity for stygofauna or troglofauna, following the methodology detailed in Section 2.5.

2.5 Habitat Assessment

2.5.1 Stygofauna Habitat Information Review

The suitability of geological formations as core habitat for subterranean fauna is predominantly determined by the availability of cavities and spaces within the rock type, and potential for water and nutrient infiltration and movement. In the case of stygofauna, this may be refined to where such rock formations occur below the water table and, in the Pilbara, where the depth from the ground surface to the water table does not exceed approximately 40-50 m (Halse et al. (2014); Eberhard et al. (2009); Biota (unpublished data)).

Several geological units are now well recognised as being core habitat for stygofauna as they characteristically form fractures, interstices, cavities and vugs, which allows for fauna dispersal and nutrient infiltration. These units include limestone karstic systems, calcrete, alluvium, gravels, fractured rock aquifers, limonite and dolomite (Marmonier et al. 1993, Humphreys 1999, Halse et al. 2014). In the broader Robe Valley setting, important habitat that has also been well documented with diverse stygofauna communities occurring in the locality includes valley fill units where alluvium, gravels, calcrete and channel iron deposits (CID) occur below the water table (Biota 2010, 2015, 2016a). Where these units occur below water table in the Mesa H development envelope, they were also identified here as potential key habitat receptors for stygofauna (Section 2.5.3).

Hydrogeological and stratigraphic information was used to identify and delineate stygofauna habitat, by considering inputs both:

1. spatially (2D) – including accounts of the aquifers and host rock types documented in Rio Tinto hydrogeology reports, Rio Tinto surface geology mapping and regional Geological Survey of WA (GSWA) surface geology; and
2. vertically (3D) – using Rio Tinto drill logs and stratigraphic cross-sections, a digital elevation model constructed from contour data (to identify units associated with valleys and drainage systems), depth to water table, and hydrogeological descriptions of the vertical arrangement, hydrogeological conductivity and connectivity of aquifers.

2.5.2 Troglofauna Habitat Information Review

Like stygofauna, core habitat for troglofauna is also a function of available spaces within the rock formation, along with the ability to maintain a consistently high humidity and the potential for nutrient input from surface systems (Humphreys 1991, Dole-Oliver et al. 2009, Biota and DC Blandford & Associates 2013)

Geological units previously recognised as primary troglofauna habitat include karstic limestone systems, calcrete and CID above water table (Humphreys 1991, Marmonier et al. 1993, Biota 2006a). Physical characteristics common to these formations again include fractures, caverns, vugs, or interstices of sufficient size to physically accommodate troglobitic fauna. Many of these formations include lithologies with important hydrological functions, such as impeding layers and clay lenses which store infiltrated water from recharge events, maintaining humidity in the system (Biota and DC Blandford & Associates 2013).

The importance of above water table CID formations as troglofauna habitat in the Robe Valley, particularly when occurring as mesa landforms, has now been well established (Biota 2006a, 2007, 2009a, Harvey et al. 2008, Biota and DC Blandford & Associates 2013). All CID units above water table were therefore treated as potential key habitat receptors for more detailed assessment here, with other rock types present that had suitable physical characteristics also considered (Section 2.5.4).

Troglofauna habitat was determined in a similar fashion to stygofauna, by consideration of inputs both:

1. spatially (2D) – Rio Tinto surface geology mapping and the spatial extent of Rio Tinto CID ore body strands (which provide more detailed descriptions of CID structure, grade and texture); and

2. vertically (3D) – CID thickness modelling completed by Rio Tinto (see Appendix 1), Rio Tinto drill logs and stratigraphic cross-sections, a digital elevation model (to identify units associated with elevated mesa landforms), downhole geophysical data including cavities and depth to water table (which effectively sets the lower limit of troglofauna habitat) (Appendix 1).

2.5.3 Stygofauna Habitat Characterisation

The habitat units identified from the inputs consolidated in Section 2.5.1 were assigned a likelihood to support stygofauna of Low, Moderate or High, based on the following attributes:

A) Presence of interstitial spaces or vugs.

B) Structural continuity, hydraulic connectivity and transmissivity of the local occurrence of the geological unit below the water table.

C) Demonstrated occurrence of stygofauna in equivalent rock types during previous surveys.

D) Fine sediments such as clays and silts do not dominate the geological unit.

E) Surface conditions permit infiltration of surface water and nutrients.

F) The geological unit is saturated and occurs below the water table.

Likelihood categories were then determined for each geological unit as:

High – Majority (five or more) of attributes confirmed for the unit, including the presence of continuous, transmissive aquifer (A, B, D). Surface geology sufficiently porous to allow nutrient infiltration from surface inputs (E), and unit partially or completely saturated below the water table (F). Stygofauna routinely recorded from the same rock type (C)

Medium – Unit at least partially saturated below the water table (F). Presence of interstitial spaces and cavities (A), with limited fine sediments within the unit (D). Stygofauna occasionally recorded from this geology during previous surveys (C).

Low – Suitable geological unit may occur only above the water table within the study area. Rock type may have limited interstitial spaces (A) however the unit may also be dominated by fine sediments, which reduce usability of spaces (D). Stygofauna not known from previous studies sampling of the same geology (C).

The adequacy of the habitat characterisation was then assessed by plotting all available stygofauna records from the survey area within the High and Medium likelihood habitat extents in MapInfo GIS software. This enabled a more accurate delineation of areas of prospective habitat on the combined basis of physical habitat attributes and the presence of confirmed fauna records.

Spatial correlation between the records and the habitat units assessed as High and Medium likelihood for stygofauna was then used to infer other prospective stygofauna habitat in the same units outside of sampling locations.

2.5.4 Troglofauna Habitat Characterisation

Similar to stygofauna, the habitat units identified as likely troglofauna habitat from the information consolidated in Section 2.5.2 were assigned a likelihood to support troglofauna of Low, Moderate or High, based on the following attributes:

A) Presence of cavities, vugs and interstitial spaces.

B) Known hydration, weathering or significant cavity zones.

C) Presence of clay lenses or impeding layers to maintain stable humidity.

D) Demonstrated occurrence of troglofauna in equivalent rock types during past surveys.

E) Occurs above water table within the survey area.

Likelihood categories were then assigned to the geological units as:

High – Majority (four or more) of habitat attributes confirmed for the unit, including, known to occur above water table (E), presence of interstitial spaces (A) and significance cavity zones (B), and troglofauna routinely recorded from the same rock type (D).

Medium – Suitable geology likely or known to occur above the water table in the survey area (E). Geology known to have interstices or vugs (A) and troglofauna have occasionally been detected in similar rock types previously (D). Geology may be subject to seasonal inundation (e.g. alluvium and colluvium). Where known, units of high prospectivity were categorised as medium if less than 5 m in thickness.

Low – Suitable geology only occurs below water table in the survey area. Rock type may have B), C) and E) characteristics but locally lacking suitable habitat space. Few or no troglofauna records from previous sampling of the same rock type (D).

Similar to stygofauna, the adequacy of the troglofauna habitat characterisation was then assessed by plotting all available troglofauna records from the survey area within the High and Medium habitat extents in MapInfo. Spatial correlation between the records and the High and Medium likelihood habitats both validated their status as troglofauna habitat, and was used to infer other prospective habitat in the same units outside of sampling locations.

2.6 Impact Assessment

2.6.1 Impact Assessment Model

This document considers impacts in a hierarchical framework, with outcomes for the key receptors treated as a consequence of the generalised impact stages shown in Figure 2.1.

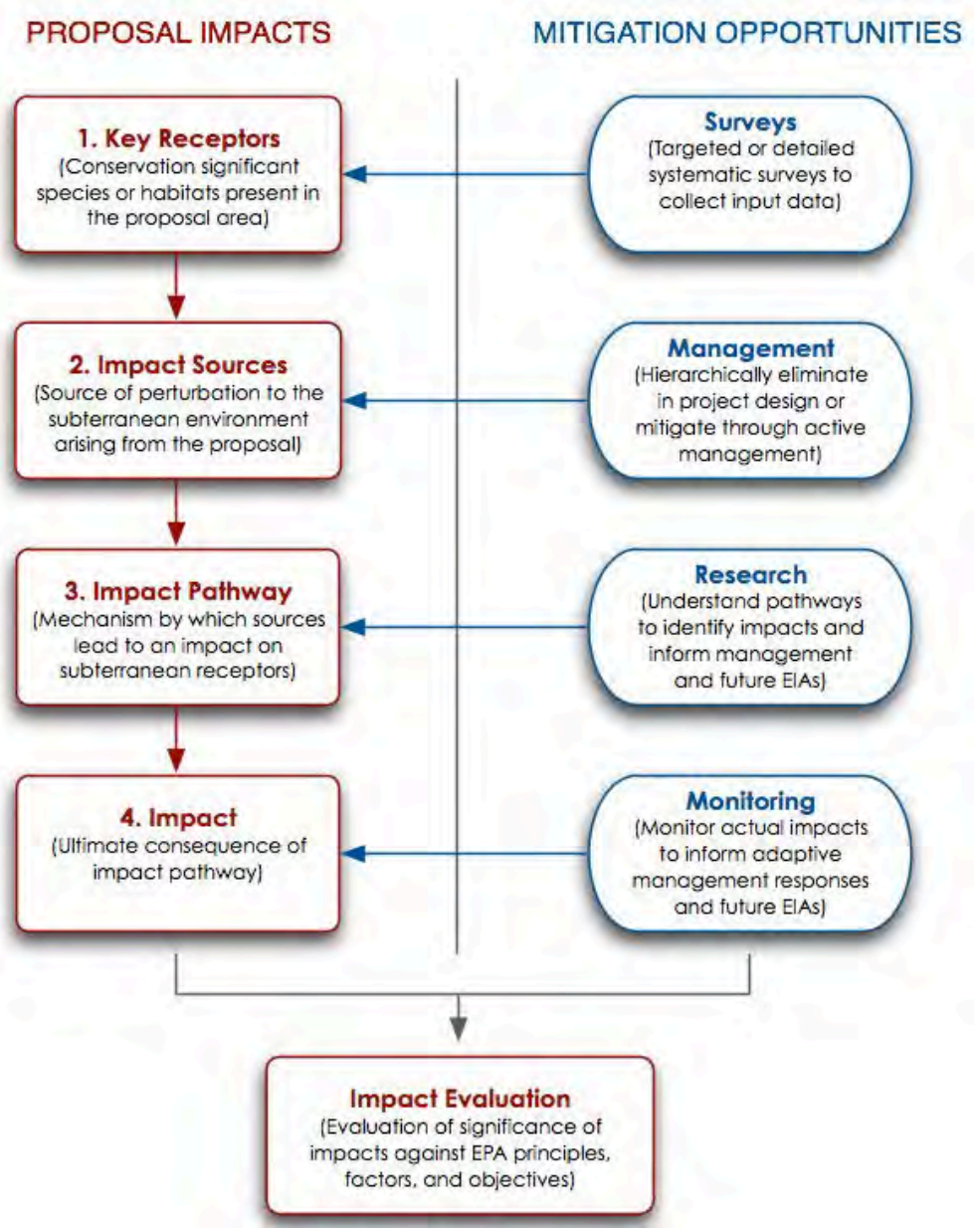

Figure 2.1: Environmental impacts assessment model used in this report.

Opportunities exist at each of the impact stages to address the impact sequence and mitigate the ultimate impact, via project design, management, research or appropriate monitoring and management response (Figure 2.1).

The identification of primary impact sources provides the first opportunity to reduce or eliminate potential impacts at the early project feasibility stage through design modifications (Figure 2.1). The Rio Tinto project design for the Mesa H proposal, and the adjustments already made by the proponent to eliminate impacts, have therefore been considered as part of this impact assessment.

Literature reviews for indirect impact pathways have been conducted previously and were leveraged to inform these assessments where relevant. Anecdotal observations and inference-based information on impact pathways from existing mining operations have also been considered in this impact assessment where informative for particular pathways and key receptors.

Opportunities usually exist for research or monitoring to better document the nature of actual impacts arising from identified pathways and to inform management at the final impact source tier (Figure 2.1). As these are effectively a lagging mitigation approach, they have not been considered in this impact assessment, given the current stage of the proposal's formal assessment.

2.6.2 Impacts

Impacts are the ultimate consequences of project impact pathways, and at a generic level they are reasonably well recognised. These consequences include impacts on key receptors such as:

- individual mortality;
- habitat loss;
- habitat fragmentation and population subdivision;
- reduced population viability; and
- local extinction.

The prediction of impacts should ideally be evidence-based, but the documentation of impacts is often subjective or anecdotal and there is a general paucity of empirical data from field programs that adequately quantify the impacts on subterranean ecosystems.

In recognition of this, impacts on key receptors were conservatively assessed on the basis of the identified impact pathways and giving consideration to two key criteria comprising:

1. spatial extent of the predicted impact (where this could be quantified), as a surrogate for population impacts; and
2. duration of the impact, considered as short-term (less than one year), long-term (years to decades), or permanent.

The extent, duration and magnitude of the impacts on the key receptors were placed into local and regional context to assist in assessing significance, considering:

- the documented and inferred distribution of the species or assemblage it forms part of;
- the spatial and vertical (2D and 3D) extent of suitable subterranean fauna habitats; and
- what is known or currently hypothesised in respect of subterranean fauna ecology, particularly whether species and communities are predisposed to impacts from a given pathway.

These considerations allowed the likely consequences and magnitude of the impact to be assessed, which was categorised as:

- Negligible: displacement or loss of individual animals;
- Minor: reduction of less than 10% of the known or inferred distribution and habitat extent;
- Moderate: reduction of 10-50%[1] of the known or inferred distribution and habitat extent; or
- Major: loss of more than 50%[1] of the known or inferred distributional extent and/or change in conservation status of the species.

[1] Derived from the International Union for the Conservation of Nature (IUCN) Red List criterion whereby a species' conservation state would shift from the Least Concern category to Vulnerable (IUCN 2012).

The level of certainty with which this assessment could categorise the risk of impacts on the key receptors was then assessed as:

- High: the outcome is quantifiable and can be predicted with confidence from a reasoned evidence base or the impact has previously occurred during similar mining developments;
- Medium: a reasonable body of data exist to predict the outcome and it could reasonably be expected to arise from the current proposal;
- Low: the outcome has not previously occurred during similar mining developments, but expert opinion or other data suggest it might arise, or there is insufficient information to quantify the impact.

2.6.3 Impact Evaluation

The significance of the identified impacts on the key receptors was then evaluated by reference to the EPA's objective for subterranean fauna, which comprises: "*To protect subterranean fauna so that biological diversity and ecological integrity are maintained.*" (EPA 2016a). Ecological integrity, in this context, is "*the composition, structure, function and processes of ecosystems, and the natural range of variation of these elements*" (EPA 2016a).

In practice, this is a somewhat challenging definition to objectively measure significance against for subterranean ecosystems in particular. Instead then, this impact assessment has adopted a more reductionist approach by addressing the specific items that EPA (2018) indicates the EPA will give regard to in determining whether an impact is significant.

Paraphrasing from EPA (2018) to those relevant to subterranean fauna and the current proposal, these comprise:

1. values, sensitivity and quality of the environment which is likely to be impacted – informed by the identification of key receptors (Section 2.4);
2. extent (intensity, duration, magnitude and geographic footprint) of the likely impacts, including cumulative impacts where appropriate – addressed here through the identification of impact sources and pathways arising from the proposal (Section 2.3);
3. consequence of the likely impacts (or change), including the resilience of the environment to cope with the impacts or change – addressed here as set out in Section 2.6.2; and
4. level of confidence in the prediction of impacts and the success of proposed mitigation – qualitatively assessed but within a defined framework, as set out in Section 2.6.2.

On this basis then, this impact assessment treats a significant impact (after EPA (2016a)) as a Moderate or Major impact on a key receptor that is predicted to arise with High or Medium certainty (following the criteria in Section 2.6.2).

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3.0 Project Definition

3.1 Development Envelope

The Mesa H project includes the development of above and below water table open cut iron ore mine pits and associated infrastructure, including water management infrastructure. The current indicative project design for the proposal is shown in Figure 3.1.

Based on Rio Tinto (2017a), and subsequent information on project revisions provided by Rio Tinto, the characteristics of the proposal comprise:

1. Mine pits - development of open above water table (AWT) and below water table (BWT) iron ore pits, including advance abstraction of groundwater to lower the water table to access the ore body.
2. Dewatering infrastructure – infrastructure including but not limited to bores, pipelines, and discharge outlet(s) to effect the dewatering of the ore body (Section 3.2).
3. Surplus water management – including but not limited to use in processing, on-site use and controlled discharge to the Robe River and tributaries.
4. Mineral waste management – including but not limited to backfilling, ex-pit waste dumps, low grade ore dumps, topsoil and sub-soil stockpiles.
5. Processing facilities – the project will be supported by the existing processing facilities at Mesa J but may require other processing facilities including but not limited to waste fines storage facilities.
6. Support facilities – including but not limited to workshops, power supply infrastructure, hydrocarbon storage, laydown areas, offices and wastewater treatment plants.
7. Surface water management – including but not limited to surface water diversion drains, levees and culverts.
8. Linear infrastructure – including but not limited to heavy vehicle and light vehicle access roads, upgrades to existing vehicle access roads; pipelines and power (including sub-stations) and communications distribution networks.
9. Water supply – utilising groundwater abstracted for dewatering, surface water that reports to pits, the existing Mesa J bore field (Southern Cutback bore field) and potential additional bores.

For the purposes of this impact assessment, and in the interests of conciseness, the proposal characteristics can be functionally grouped under five headings that present essentially similar potential impacts to subterranean ecosystems (Section 4.1). In reference to project characteristics 1 to 9 listed above, these categories comprise:

- Mine pits: 1. Mine pits;
- Water management: 2. Dewatering infrastructure and dewatering (Section 3.2), 3. Surplus water management and 9. Water supply;
- Waste dumps and stockpiles: 4. Mineral waste management;
- Haul roads and access roads: 8. Linear infrastructure; and
- Processing and support infrastructure: 5. Processing facilities, 6. Support facilities and 7. Surface water management.

Project characteristics are grouped under the five categories above for the balance of this impact assessment.

Rio Tinto has also identified a proposed Mining Exclusion Zone (MEZ), within which no mine pits will be created (Figure 3.1). The primary purpose of the MEZ is to provide for the retention of adequate troglofauna habitat to ensure that EPA's objectives for the Subterranean Fauna factor can be met.

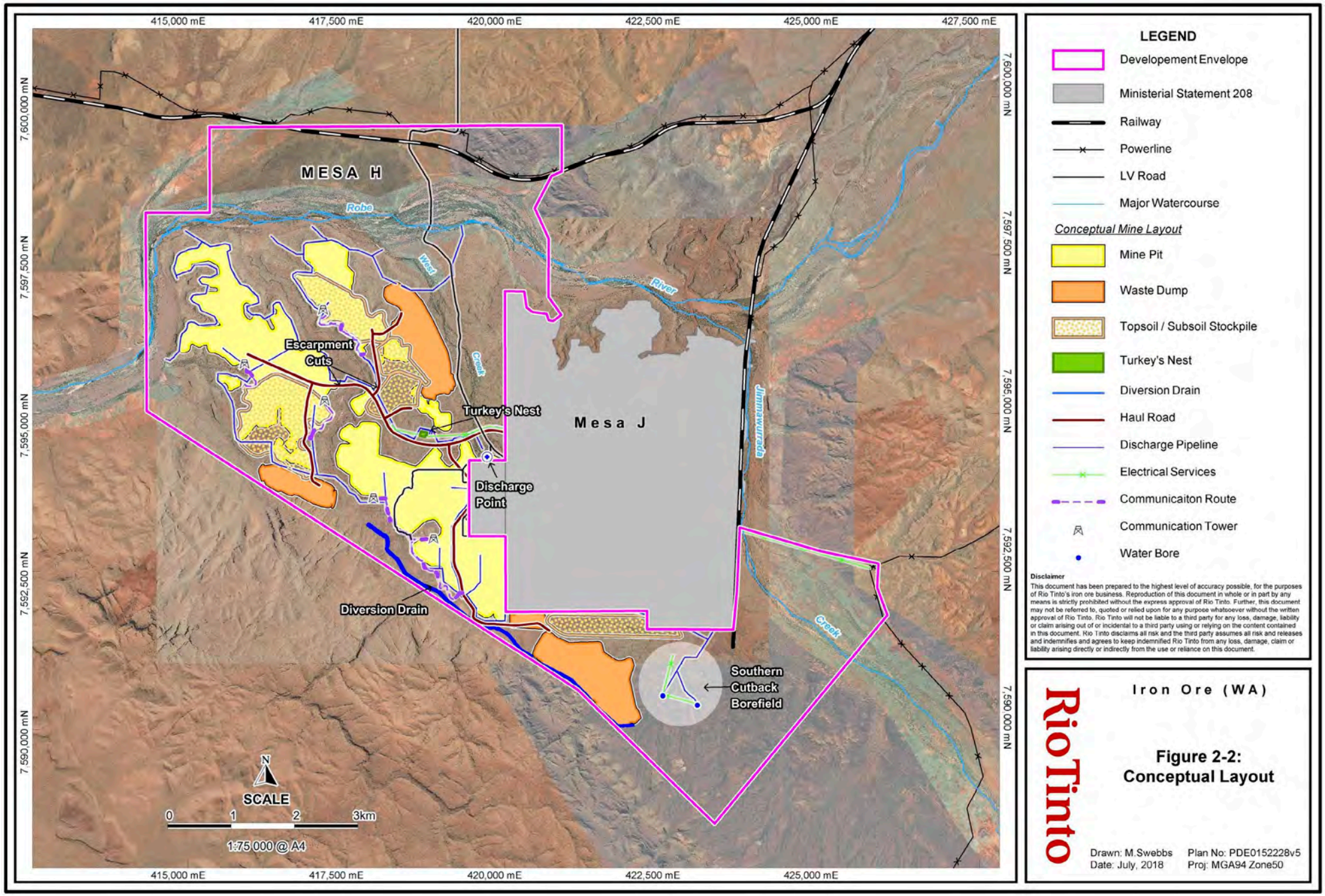


Figure 3.1: Development envelope and project footprint for the Mesa H proposal (source: Rio Tinto).

3.2 Dewatering Extent

Approximately 20% of the Mesa H ore body currently occurs BWT and dewatering will be required to access the ore. In addition, a water supply (proposed from the Southern Cutback Borefield) will be required to meet wet ore processing water demands. The combination of groundwater abstraction for BWT mining and cumulative drawdown from the borefield for operational supply will result in drawdown of the aquifer systems within the Development Envelope, with the drawdown extending outside of the Development Envelope to the east and southeast (see Figure 3.2).

In the northern portion of the development envelope, the Robe River is predicted to be impacted by less than 1 m of drawdown by the end of mining, which, given the magnitude and frequency of stream flow events, is unlikely to cause any permanent adverse impact to the alluvial aquifers of the system.

Updated hydrogeological modelling based on the inclusion of a thickener plant (Rio Tinto 2019a) estimates that drawdown will lower the water table across a 12 km section of Jimmawurrada Creek, with a maximum predicted drawdown of 9 m over a 6.5 km section (based on pre-mining water table levels) by 2030, mostly as a result of BWT mining at Mesa J. This is the base case impact prediction that is primarily assessed in this assessment. However, if natural recharge is reduced by 50% due to an extended period of drought, as per the H3 numerical model 'Uncertainty Run 2' (Rio Tinto 2019a), then the water table levels could be lowered by almost 3 m in addition to the natural seasonal fluctuations (2-3 m); this would translate to localised changes in water table depths of up to 14 m from pre-mining conditions, or ~18 m bgl by 2030. This latter drought scenario is addressed in the Environmental Review Document (ERD) for the Mesa H proposal, with the primary impact assessment scenario considered here the base case modelling for the maximum predicted drawdown under typical conditions at 2030.

Once mining is complete and dewatering ceases, groundwater levels in the Mesa J and Mesa H mining areas will recover until a balance is reached between groundwater inflows and groundwater outflows (Rio Tinto 2019a). In the event that pit voids are in-filled with waste / waste fines storage, groundwater levels will eventually recover to pre-development levels. The complete aquifer recovery is predicted to take up to 60 years, however, the majority of the drawdown along the Robe River and Jimmawurrada Creek is expected to recover after the first significant stream flow following a cyclonic event (Rio Tinto 2019a).

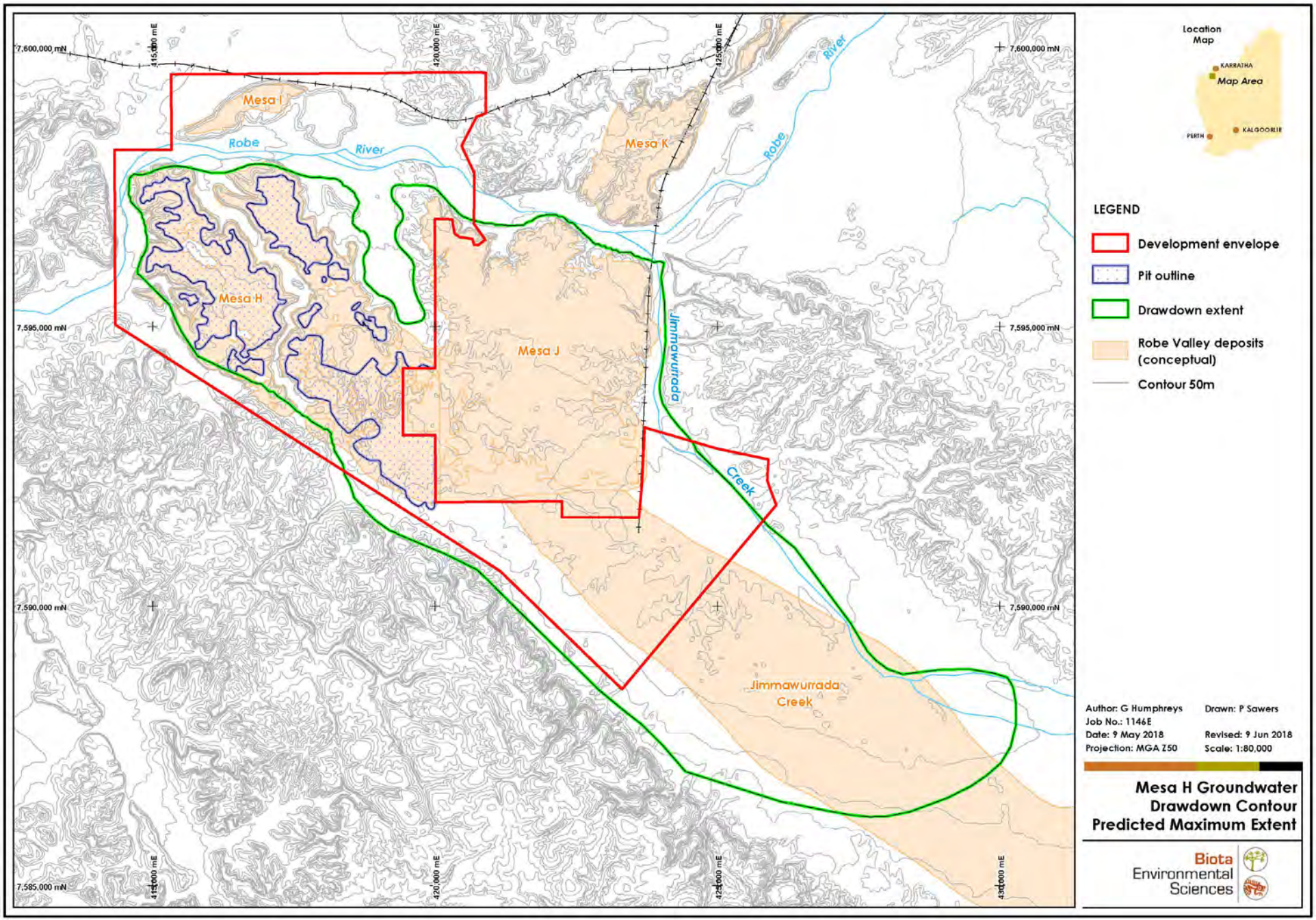


Figure 3.2: Maximum extent of predicted groundwater drawdown from the Mesa H proposal (base case year 2030, including the use of thickener in process water).

4.0 Potential Impacts

4.1 Impact Sources

A summary of the relevant characteristics of the Mesa H project, and the respective impact sources that they represent for subterranean ecosystems, is provided in Table 4.1.

Table 4.1: Summary of relevant characteristics of the Mesa H project and related impact sources.

Relevant Project Characteristics / Impact Sources					
Mine Pits	Water Management	Waste Dumps and Stockpiles	Haul Roads and Access Roads	Processing and Support Infrastructure	Impact Pathway
✓	-	-	-	-	Subterranean habitat excavation
✓	✓	-	-	-	Stygofauna habitat dewatering
✓	-	✓	✓	✓	Removal of vegetation
✓	✓	✓	✓	✓	Altered surface hydrology
✓	-	✓	✓	✓	Vibration
-	-	-	-	✓	Waste fines leakage
-	-	-	-	✓	Hydrocarbon spills

The pathways by which these impact sources may potentially impact on subterranean ecosystems are outlined in Section 4.2.

4.2 Impact Pathways

The sources of impact in Section 4.1 have the potential to affect key receptors via a range of impact pathways. These may either be direct (Section 4.2.1) or indirect (Section 4.2.2) and some impact sources may result in both types of impact pathways.

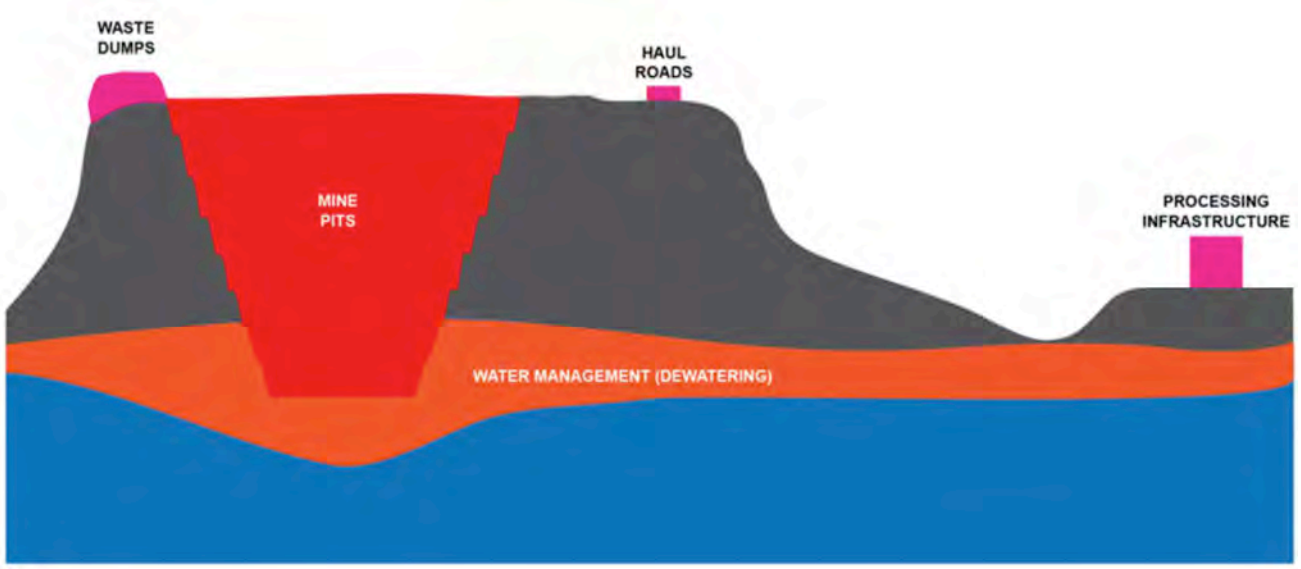
Figure 4.1 summarises the relationship between the impact sources, pathways and types of ultimate impacts on fauna that may arise from the Mesa H project.

4.2.1 Direct

The impact sources identified in Section 4.1 that may affect key receptors via direct impact pathways are:

- Subterranean habitat excavation – leading to habitat loss for both troglofauna and stygofauna, and direct loss of animals occupying the removed habitat, along with potential reduction in habitat quality in adjoining areas.
- Stygofauna habitat dewatering – leading to loss of saturated habitat for stygofauna, and presumed direct loss of animals utilising the dewatered habitat, and possible disturbance responses in individual animals to avoid dewatered areas.

These direct impacts are typically the most significant and primary impacts of the proposal on subterranean fauna receptors, and represent the key impact pathways considered in the balance of this assessment.



Impact Sources	Impact Pathways		Impacts
Mine pits	Excavation	Troglofauna and stygofauna habitat loss	Reduced diversity Reduced ecological integrity
Water management	Dewatering	Stygofauna habitat loss	Reduced diversity Reduced ecological integrity
Waste dumps and stockpiles	Removal of vegetation Sealing ground surfaces	Reduced nutrient input Reduced recharge Reduced humidity	Reduced habitat quality Reduced abundance
Processing and support infrastructure	Removal of vegetation Sealing ground surfaces Vibration Waste fines leakage Hydrocarbon spills	Reduced nutrient input Reduced humidity Reduced recharge Sediment infiltration Hydrocarbon infiltration	Reduced habitat quality Reduced abundance
Haul roads and access roads	Removal of vegetation Sealing ground surfaces Vibration	Reduced nutrient input Reduced humidity Sediment infiltration	Reduced habitat quality Reduced abundance

Figure 4.1: Relationship between impact sources, pathways and impacts on subterranean ecosystems (direct impacts in red and orange; indirect impacts in pink).

4.2.2 Indirect

The impact sources identified in Section 4.1 that may indirectly affect key receptors are:

- Removal of vegetation – as the primary production that provides energy to subterranean ecosystems is assumed to be derived from surface autotrophy, removal of vegetation may lead to a reduction of energy and nutrient inputs, indirectly resulting in a reduction in subterranean habitat quality and the abundance and/or distribution of subterranean fauna;
- Altered surface hydrology – resulting in decreased recharge into water storage within troglofauna habitat (and the potential resultant long term change to humidity), increased run-off and reduced recharge to aquifers;
- Vibration – with the potential to generate increased sediment loads in the aquifer when sediment is mobilised into subterranean habitats during recharge events, and reduce habitat space in troglofauna habitat strata above the water table;
- Waste fines seepage – the proposal includes provision for a waste fines storage facility as part of product wet processing (Section 3.0), which may have some low-level leakage over time,

resulting in localised sedimentation of troglofauna habitat strata and underlying aquifers, but this will be consolidated with existing waste fines management facilities at the current Mesa J operations; and

- Hydrocarbon spills – resulting in localised reduction in groundwater quality and troglofauna habitat quality via small-scale pollutants spills and infiltration into subterranean habitat.

These indirect impact pathways, and the significance of their ultimate impacts, are less well demonstrated and the extent to which they actually result in impacts on subterranean fauna populations is poorly understood.

In the interests of a precautionary assessment, they have, however, been retained here as potential impacts and assessed separately in Section 7.0, but are considered lower-level, secondary impacts compared with the direct impacts identified in Section 4.2.1 above.

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5.0 Key Receptors Species and Communities

5.1 Stygofauna

5.1.1 Impact Area Species

A total of 855 stygofauna specimens were recorded over the five-phase stygofauna survey completed for the proposal, comprising at least 43 species-level taxa (Biota 2019). The recorded fauna was dominated by the Crustacea, which was represented by seven faunal groups and accounted for 98% of the specimens. Excluding indeterminate records, and allowing for species already recorded during the Mesa H survey, an additional 13 species were identified as occurring during the desktop review, bringing the total known fauna to 56 species (Biota 2019). A subtotal of 46 of these species occur within the immediate locality of Mesa H (Rio Tinto 2019b).

While the BWT mine pits are a direct impact (Section 4.2.1), the primary spatial context for the assessment of impacts on stygofauna is the wider groundwater drawdown extent that will arise from the cumulative dewatering required for the proposal (which takes into consideration groundwater drawdown from adjacent projects) (Section 3.2). The drawdown extent also encompasses the area that will be directly impacted by the pits themselves. It is therefore logical to identify the full set of stygofauna species and communities that occur within this extent as the starting point for impact assessment.

Table 5.1 lists the 32 stygofauna taxa documented by Biota (2019) that occur within the dewatering extent.

Table 5.1: All stygofauna species currently known from within the dewatering extent (Impact sites), and any records from outside of the dewatering extent (Reference sites) (species only known from the dewatering extent from desktop assessment records shown in grey; source: Biota (2019)).

Species	Impact Sites	Reference Sites
Oligochaeta		
Enchytraeus sp. 'AP PSS1'	BC186	Robe River valley
Gastropoda		
Hydrobiidae sp. 2**	JW023	-
Ostracoda		
Areacandona sp. 'BOS1039'**	BC186	31
Areacandona triangulum	BC186	MB16MEC0008, MB16MEC0009,West Pilbara
Areacandona brookanthana	JW023	Bungaroo, Ashburton plain
Areacandona lepte	JW011A	West Pilbara
Humphreyscandona fovea	JW021	Bungaroo, West Pilbara
Humphreyscandona waldockae	PSS160	West Fortescue valley
Humphreyscandona sp. 2	JW011A	West Pilbara
Pilbaracandona rosa	JW011A	West Pilbara
Pilbaracandona sp. 'BOS526'**	JW024	Dave Bore, MB17MEH0007
Candoninae sp. 'BOS541'**	JW024	-
Copepoda		
Diacyclops cockingi	JW021, JIMDD080	RR1, MB17MEH007, Common in the wider Pilbara
Diacyclops humphreysi humphreysi	DD13MEH0007, RC13MEH0007, MB17MEH0015, JW024	31, 87, RR1, MB16MEC0008, MB16MEC0009, MB17MEH0007, MB17MEH0009, MB17MEH0010, Common in the wider Pilbara
Halicyclops calm	JW023	Pilbara bioregion
Halicyclops rochai	JW023	Common in Western Australia
Stygoridgewayia trispinosa	BC186, DD13MEH0007, RC13MEH0007, RC13MEH0040, RC14MEH0018, RC14MMEH0053, JW024	25, 31, 32, 34, Dave Bore, Budgie Bore, RR1, MB16MEC0008, MB16MEC0009, MB17MEH0007, MB17MEH0009, MB17MEH0010, Common in the wider Pilbara

Species	Impact Sites	Reference Sites
*Megastygonitocrella unispinosa***	MB17MEH0015	Robe River valley
Parastenocaris sp. 'B28'**	JW023	-
Thermosbaenacea		
Halosbaena tulki	JW021, JW024	23, 31, West Pilbara, Barrow Island
Isopoda		
Kagalana tonde	JW021, JW023, JW024	RR1, 31, West Pilbara, Hardey River
Haptolana sp. 'B01'**	JW024	-
Amphipoda		
*Nedsia hurlberti**	JW021, JW011A	Bungaroo, Barrow Island
*Nedsia sculptilis**	JW021, JW011A	Bungaroo, Barrow Island
Nedsia sp. 'AMM001'	DD13MEH0007, RC12JIM0019, RC13MEH0040, RC13MEH0041, RC13MEH0097, RC14MEH0018, RC14MEH0053, RC16JIM0019, JW024	RR1, 25, 31, 32, 34, Budgie Bore
Nedsia sp. 'AMM026'**	RC13MEH0097	31
Paramelitidae sp. 'AMP003'**	RC13MEH0041	-
Paramelitidae sp. 'AMP035'**	RC13MEH0007	RR1
Paramelitidae sp. 'AMP037'**	BC186	-
Wesniphargus sp. 'AMN004'**	JW024	25
Neoniphargidae sp. 'B02'**	JW021	32
Vertebrata		
*Ophisternon candidum**	JW021, JW023, JW024, MB17MEH0015, BC186	RR1, Control, 25, RRD2, Cape Range

* Species formally listed under legislation as being of conservation significance.
** Species assessed as a potential SRE by Biota (2019) meeting potential SRE criteria.

Sixteen of the 32 species known from the dewatering extent (*Enchytraeus* sp. 'AP PSS1', *Areacandona triangulum, Areacandona brookanthana, Areacandona lepte, Humphreyscandona fovea, Humphreyscandona waldockae, Humphreyscandona* sp. 2, *Pilbaracandona rosa, Diacyclops cockingi, Diacyclops humphreysi humphreysi*, *Halicyclops calm, Halicyclops rochai*, *Stygoridgewayia trispinosa, Halosbaena tulki, Kagalana tonde* and *Nedsia* sp. 'AMM001'), are all relatively abundant and frequently recorded from Reference sites outside of the drawdown extent and/or have known wider distributions in the Pilbara bioregion (Biota 2019). While still informative for context to impact assessment, they are not retained as key receptors for the balance of this assessment as they are not restricted in distribution to the drawdown extent and will remain occurring more widely with the implementation of the Mesa H proposal. This leaves 16 stygofauna species as key receptors (three of conservation significance; Section 5.1.2.1 and 13 potential SREs; Section 5.1.2.2).

5.1.2 Key Receptors

5.1.2.1 Species and Communities of Conservation Significance

Two species of amphipod that occur within the drawdown extent (Table 5.1) are of conservation significance (Biota 2019) and are thereby key receptors for this assessment:

- the amphipod *Nedsia hurlberti* – Schedule 3 (State); and
- the amphipod *Nedsia sculptilis* – Schedule 3 (State).

An additional species of conservation significance, the Blind Cave Eel *Ophisternon candidum* (Vulnerable (Commonwealth); Schedule 3 (State)), occurs within the drawdown extent (Table 5.1) and is therefore also a key receptor for this impact assessment.

One PEC listed by DBCA occurs in the southeast of the drawdown extent (Biota 2019) and is a key receptor for this impact assessment:

- Stygofaunal Community of the Bungaroo Aquifer (Priority 1): "*A unique assemblage of aquatic subterranean fauna including eels, snails and other stygofauna. Threats include groundwater drawdown and mining*" (Department of Parks and Wildlife 2016).

5.1.2.2 Other Species of Significance

Thirteen of the stygofauna species known from the drawdown extent are considered to represent potential SRE fauna, half of which are amphipod taxa (Table 5.1; Biota 2019). As potential SREs, these species are key receptors for this impact assessment and comprise:

- the snail Hydrobiidae sp. 2;
- ostracod *Areacandona* sp. 'BOS1039';
- the ostracod Candoninae sp. 'BOS541';
- the ostracod *Pilbaracandona* sp. 'BOS526';
- the copepod *Megastygonitocrella unispinosa;*
- the copepod *Parastenocaris* sp. 'B28';
- the isopod *Haptolana* sp. 'B01';
- the amphipod *Nedsia* sp. 'AMM026';
- the amphipod Paramelitidae sp. 'AMP003';
- the amphipod Paramelitidae sp. 'AMP035';
- the amphipod Paramelitidae sp. 'AMP037';
- the amphipod *Wesniphargus* sp. 'AMN004'; and
- the amphipod Neoniphargidae sp. 'B02'.

5.2 Troglofauna

5.2.1 Impact Area Species

A total of 150 troglobitic specimens were collected across the six phases of sampling of the Mesa H survey area, with 32 additional specimens from past surveys identified in desktop review (Biota 2019). The survey specimens represented five classes and nine orders, with 32 species-level taxa identified. The orders Coleoptera and Schizomida were the greatest contributors to faunal composition, accounting for 33% and 25% of the specimens, respectively (Biota 2019). Excluding indeterminate records, two additional species (*Barrowdillo* sp. 1 and *Troglarmadillo* sp. 1) were identified as occurring within the development envelope from historical surveys, bringing the total known fauna to 34 species.

Unlike stygofauna, the development envelope fully encompasses all the direct impact sources relevant to troglofauna (Section 4.1) and it therefore sets the spatial context to identify species known from within the proposal impact area. Again unlike stygofauna, there were no Reference sampling sites in the Biota (2019) survey and all sites sampled for troglofauna were inside the development envelope. All 34 species recorded at Mesa H therefore occur within the development envelope.

Table 5.2: All potential SRE troglofauna species currently known from within the development envelope (Impact sites), and any records from outside of the development envelope (Reference sites) (species only known from the development envelope from desktop assessment records shown in grey; source: Biota (2011; 2019)).

Species	Impact Sites	Reference Sites
Pseudoscorpiones		
Hyidae sp.'PH017/PH027'	RC14MEH0252, RC16MEH0264	-
Hyidae sp. 'PH026'	RC16MEH0436	-
Olpiidae sp. 'PO008'	RC15MEH0302	-
Beierolpium sp. 'PO014'	RC16JIM0026	-
Beierolpium sp. 'PO015'	RC16MEH0433	-
Atemnidae sp. 'PA004'	RC15MEH0329	-
Chthoniidae sp. 'PC014/PC015'	GR15MEH0015, RC15MEH0315, RC15MEH0335	-

Species	Impact Sites	Reference Sites
Chthoniidae sp. 'PC055'	MEHRD0834	-
Schizomida		
Paradraculoides sp. 'SCH038'	MEHRC157, RC15MEH0329, RC16MEH0264, RC16MEH0433	-
Paradraculoides sp. 'SCH039'	RC15MEJ0019	-
Hubbardiidae sp. 'SCH011'	J0866, J0867, J0928, MEJ0007, MEJ0048, MEJ0076, MEJ0085, J0866, MEJ5548alt, RC08MEJ0015, RC08MEJ0004, RC08MEJ0023, MEHRC0724	Mesa J (MEZ)
Hubbardiidae sp. 'SCH015/SCH016'	DD13MEH0007, RC12MEH0221, RC14MEH0252, RC15MEH0306, RC16JIM0026, RC16JIM0031, MEHRC0724, MEHRD0870	Redgate
Myriapoda		
Cryptopidae sp. 'SC18'	RC14MEH0388	-
Diplura		
Parajapygidae sp. 'DPA001'	RC14MEH0308	-
Parajapygidae sp. 'DPA009'	MEHRD0758	-
Projapygidae sp. 'DPR008/DPR009/DPR011'	RC15MEH0166, RC15MEH0175, RC15MEH0261, RC16JIM0005	-
Projapygidae sp. 'DPR010'	RC16JIM0005	-
Japygidae sp. 'DJA003'	RC14MEH0388	-
Japygidae sp. 'DJA011'	DD13MEH0007	-
Campodeidae sp. 'DCA005'	GR15MEH0032	-
Isopoda		
Philosciidae sp. 'ISP047'	RC15MEH0382	-
Philosciidae p. 'ISP055'	RC15MEH0427	-
Barrowdillo sp. 1	MEHRDO752, MEHRD0776	-
Troglarmadillo sp. 1	MEHDC0865	-
Troglarmadillo sp. 'ISA046'	RC15MEH0382	-
Armadillidae sp. 'ISA056/ISA057'	MEHRD0577, MEHRD0834	Mesa C
Coleoptera		
Curculionidae sp. 'CCU014'	RC12MEH0221, RC14MEH0252, RC15MEH0302	-
Ptilidae sp. 1/'CP003'	RC16MEH0264, RC12MEH0221	Warramboo
Ptilidae sp. 'Robe Valley'/'CP002'	RC14MEH0238	Robe Valley
Zygentoma		
Nicoletiinae sp. 'TN019'	RC16JIM0006	-
Nicoletiinae sp. 'TN020'	RC14MEH0252	-
Araneae		
Prethopalpus sp. 'ARA052'	RC16JIM0019	-
Gnaphosidae sp. indet. *	RC14MEH0270	-
Blattodea		
?Nocticola sp. 'West Pilbara Complex'	RC12MEH0221, RC16MEH0427	Red Hill

* Gnaphosidae sp. indet. was the only specimen of its family and was retained as a discrete troglobitic taxon (Biota 2019).

Six of the 34 troglofauna species known from the development envelope; Hubbardiidae sp. 'SCH011', Hubbardiidae sp. 'SCH015/SCH016', Armadillidae sp. 'ISA056/ISA057', Ptilidae sp. 1/'CP003', Ptilidae sp. 'Robe Valley'/'CP002' and *?Nocticola* sp. 'West Pilbara Complex', all have documented wider distributions in the region (Table 5.2; Biota 2019).

While the five species of stygofauna known from outside of the dewatering extent were not retained as key receptors (Section 5.1.2), they were very widespread and common in the region, whereas the six troglofauna species with records outside of the development envelope still only have relatively restricted distributions in the Robe Valley, most of which are also subject to potential impacts from other proposals (see Table 5.2). To provide a conservative assessment, they are therefore still

retained as key receptors, meaning all 34 troglofauna species known from the development envelope are treated as key receptors for this assessment (Section 5.2.2.2).

5.2.2 Key Receptors

5.2.2.1 Species and Communities of Conservation Significance

No formally listed troglofauna species are known from the Mesa H development envelope (Biota 2019).

Two PECs listed by DBCA occur within the development envelope (Biota 2019) and are key receptors for this impact assessment:

- Subterranean invertebrate communities of mesas in the Robe Valley region (Priority 1): *"A series of isolated mesas occur in the Robe Valley in the state's Pilbara Region. The mesas are remnants of old valley infill deposits of the paleo Robe River. The troglobitic faunal communities occur in an extremely specialised habitat and appear to require the particular structure and hydrogeology associated with mesas to provide a suitable humid habitat. Short range endemism is common in the fauna. The habitat is the humidified pisolitic strata. Threats include mining"* (Department of Parks and Wildlife 2016); and
- Subterranean invertebrate community of pisolitic hills in the Pilbara (Priority 1): *"A series of isolated low undulating hills occur in the state's Pilbara region. The troglofauna are being identified as having very short range distributions. Threats include mining"* (Department of Parks and Wildlife 2016).

While two separate PECs are recognised by DBCA, for the purposes of this impact assessment they are effectively the same ecological community, being the troglofauna assemblage occurring within Mesa H. The distinction appears to largely be driven by whether the landforms with the extents mapped by DBCA are mesas (the former PEC) or less well formed mesas / hills (the latter), though in practice these landforms are not always clearly delineated in the locality and both contain subterranean assemblages of conservation value.

5.2.2.2 Other Species of Significance

The 34 development envelope species are all regarded as potential SRE fauna (Biota 2019) and are therefore key receptors for this impact assessment.

Twenty of the 34 species were singletons, making comment on their potential wider distributions difficult, but they have been conservatively retained here as potential SRE taxa and key receptors to provide a precautionary assessment.

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6.0 Key Receptor Habitats

6.1 Stygofauna Habitat

Groundwater within the Development Envelope occurs predominantly within three key aquifers:

- Robe River and Jimmawurruda Creek alluvial aquifers: extensive and unconfined superficial aquifer consisting of Quaternary alluvial sediments (shingles, conglomerates and coarse sand), deposited along the contemporary surface drainages with an approximate 20 m thickness and average width of 400 m along the Robe River (Rio Tinto 2017b). The alluvium associated with Jimmawurruda Creek varies in depth from approximately 24 m thickness in the southeast, increasing up to 40 m in thickness in the northwest reaches closest to Mesa H (see Figure 6.1).
- CID aquifer: an unconfined aquifer consisting of CID pisolitic sediments below Mesa H with an average of 20-30 m thickness below the pre-mining water table; and
- Wittenoom aquifer: a largely confined aquifer underlying the CID aquifer, consisting of weathered dolomite and dolomitic shale (Paraburdoo and Bee Gorge Member) and weathered Banded Ironstone Formation (BIF; Marra Mamba Iron Formation) with a thickness of approximately 25 m.

Pre-mining depth to groundwater within the Mesa H CID aquifer is generally between 25 and 45 m below surface within higher elevation areas, but the water table is considerably shallower in the Robe River and Jimmawurruda Creek alluvial aquifers. Depth to pre-mining groundwater in these alluvial aquifers ranges from approximately 4 – 12 m below surface along Jimmawurruda Creek, and approximately 2 – 5 m below surface along the Robe River. These groundwater levels fluctuate by up to 3 m seasonally, depending on climatic variability and rainfall patterns.

The basal Robe Pisolite (Tpb) is a 5 -10 m thick layer deposited at the base of the CID Aquifer, consisting of a variable clay-rich pisolite. While its hydraulic properties have not yet been defined, the largely impermeable physical characteristics of the unit mean it is expected to function as a partial barrier to groundwater flow between the CID Aquifer and the underlying Wittenoom Aquifer (Rio Tinto 2017b).

The Robe River and Jimmawurrada alluvium aquifers and the CID aquifers, are the most likely to provide habitat for stygofauna, based on their physical and hydraulic characteristics. In addition to the extensive data sets that exist from sampling of equivalent aquifers in the locality, the Robe River and Jimmawurrada alluvium aquifers are the primary groundwater system that provides habitat to stygofauna in the wider locality, having yielded many stygofauna records. The Mesa H CID aquifer, while deeper and thereby likely to host less fauna (Section 2.5.1), is also structurally suitable as stygofauna habitat and has some existing data to confirm that stygofauna utilise the aquifer. Given its depth, confined nature, lower transmissivity host rock, and limited connectivity to more superficial systems, the Wittenoom Aquifer is considered unlikely to represent significant habitat for stygofauna.

While detailed aquifer definition exists for the development envelope, this is not available for the wider locality. The aquifers that provide stygofauna habitat at Mesa H broadly correspond to the regional surface geology map units (1:250,000) and more detailed 1:10,000 local Rio Tinto geological mapping available for the locality and provide a means of setting wider context to the stygofauna habitats of the dewatering extent. The units that represent High or Medium likelihood stygofauna habitat within the dewatering extent and the wider locality are summarised in Table 6.1 and mapped in Figure 6.2. All stygofauna records from the locality were plotted on these habitat units (Figure 6.2) and visualised in a three-dimensional isometric view (Figure 6.3).

Table 6.1: Geology units identified as stygofauna habitat in the dewatering extent and wider locality.

Code	Unit	Description	Likelihood to Support Stygofauna (Attributes; Section 2.5.3)
Qr	Alluvium	Unconsolidated fluviatile deposits.	High (A, B, C, D, E, F)
Ql	Lacustrine deposits	Clay, silt; saline in part, flood deposits. Unconsolidated fluviatile and sheet flood deposits in levees and river terraces.	High (A, B, C, E, F)
Qg/Czc	Colluvium	Partly consolidated valley-fill deposits; Unconsolidated to loosely consolidated slope deposits	High (A, C, D, E, F)

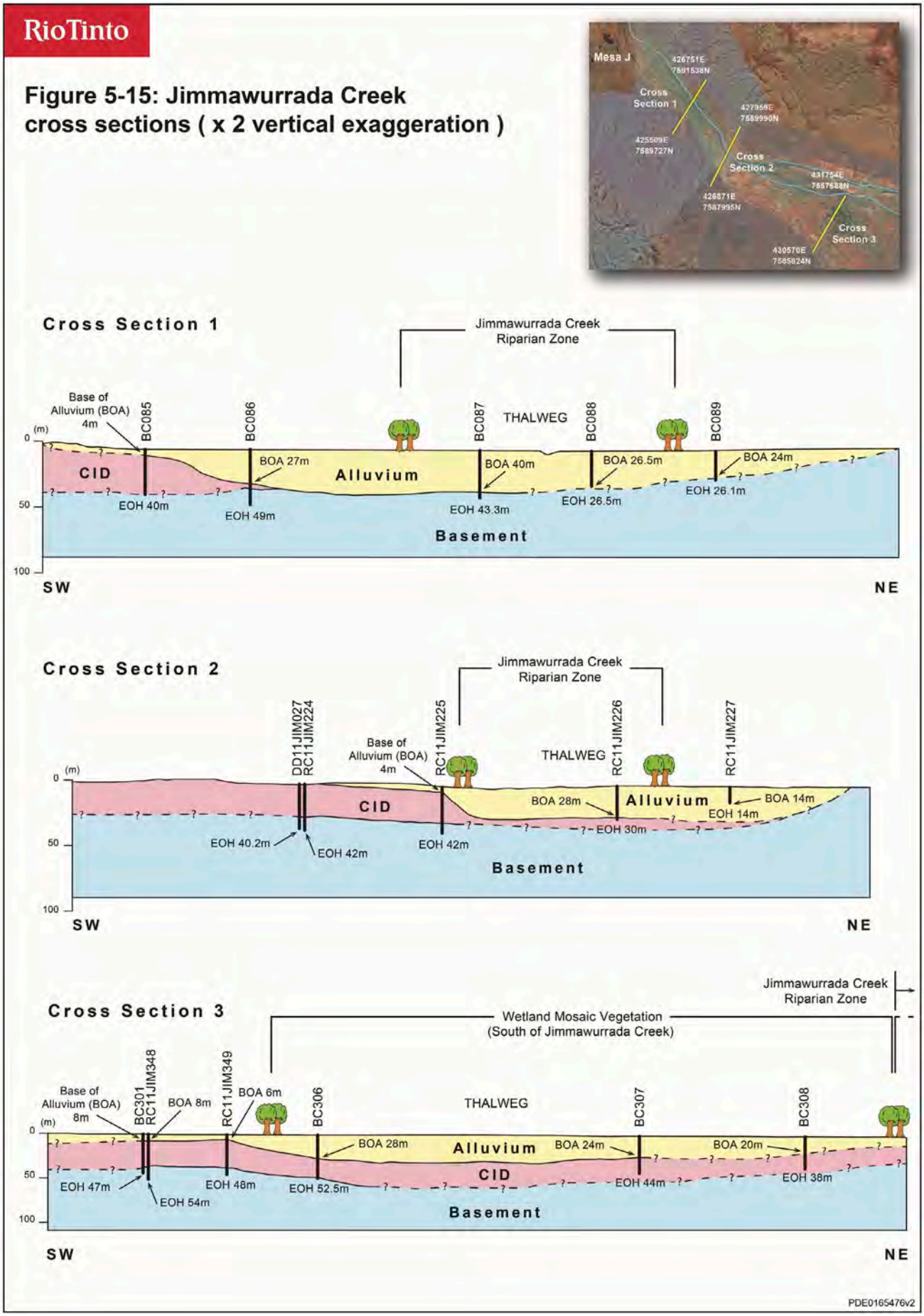

Figure 6.1: Cross-sections of Jimmawurrada Creek, showing depth of alluvium relative to underlying CID and basement units in difference sections of the creek (source: Rio Tinto).

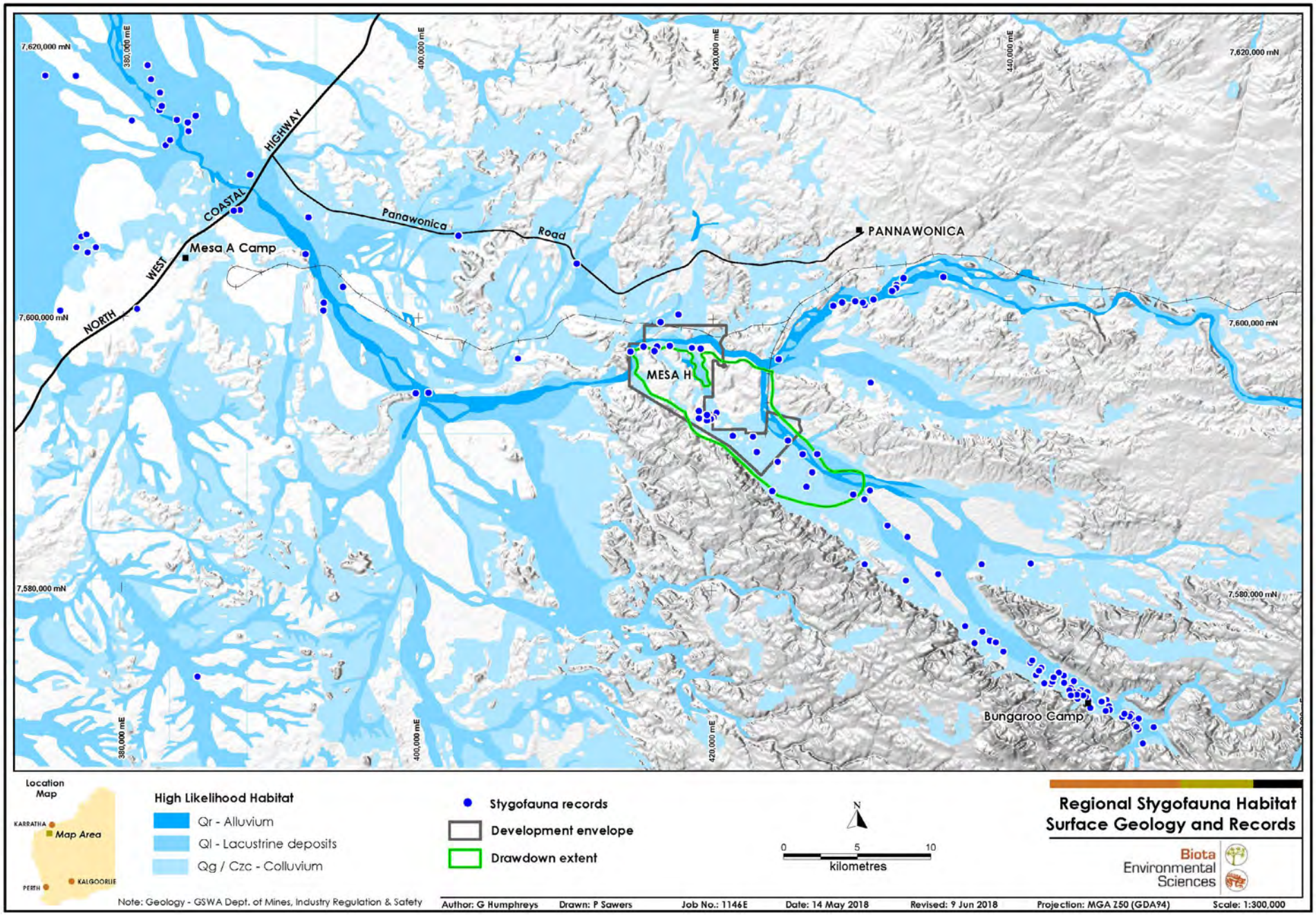

Figure 6.2: Surface geology units representing stygofauna habitat showing spatial relationship with confirmed stygofauna records.

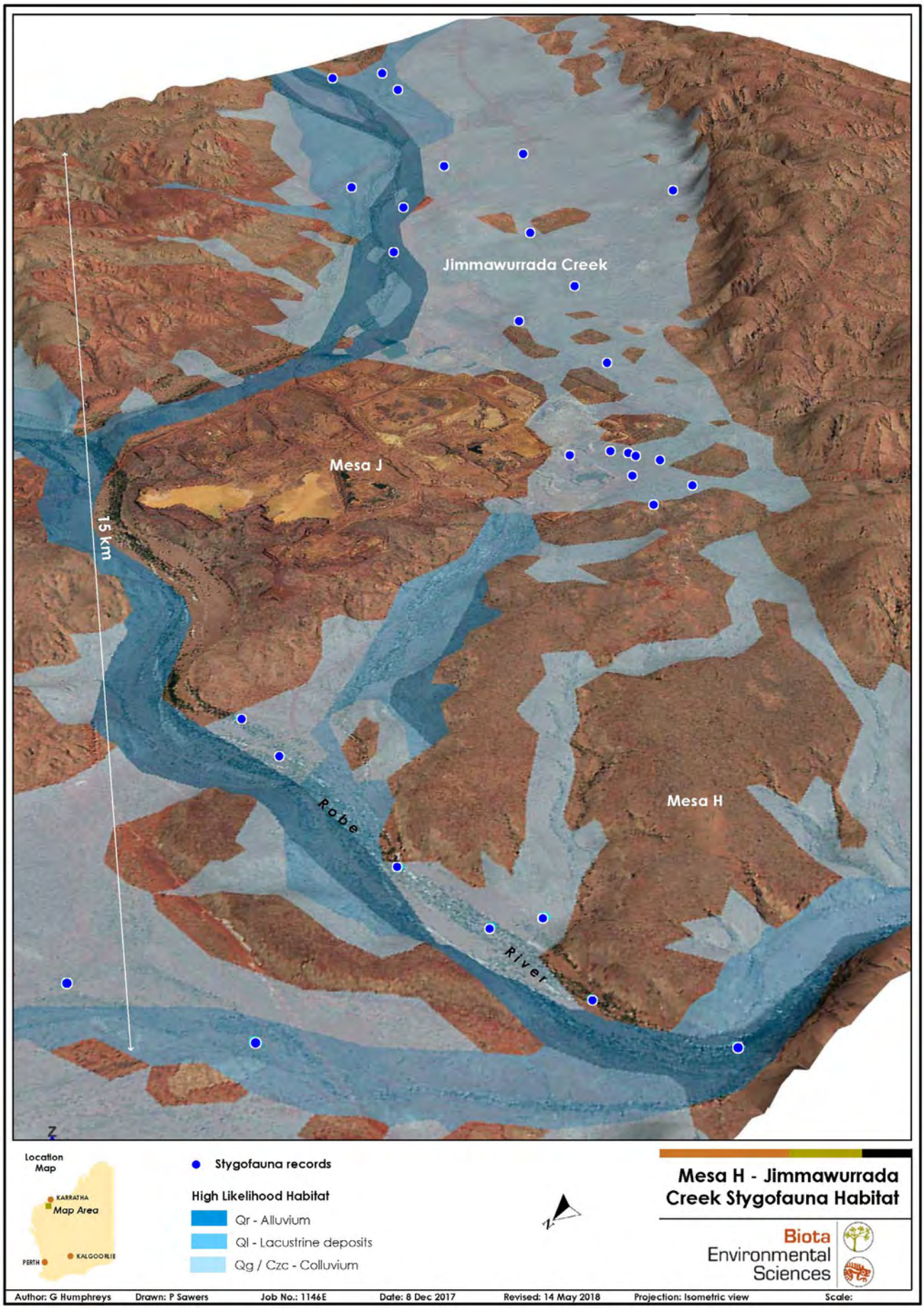

Figure 6.3: Isometric view of stygofauna habitat at Mesa H, overlain with the locations of confirmed stygofauna records.

These show a strong spatial correlation with stygofauna record locations, with 129 of the 133 known stygofauna locations falling within units mapped as High likelihood habitat (97%) (Figure 6.2). The landscape setting of these units also confirms that these habitats occur as low elevation valley fill units (Figure 6.2 and Figure 6.3).

Given their structural suitability, and this high level of validation from confirmed fauna records, the regional mapping units can be reliably used to set wider context to the impacts of the proposal on stygofauna habitat (Section 7.1). Subsequent three-dimensional geological mapping completed by Rio Tinto using 'Leapfrog' modelling software (Appendix 1) has also validated this approach across the Development Envelope and within the predicted impact areas for the proposal.

6.2 Troglofauna Habitat

Mesa H is one of several CID deposits that comprise the Robe Pisolite Formation; a series of paleodrainage channels that meander through the Robe River valley. CIDs are often preserved in an inverted topography as mesas landforms which are remnants of ancient palaeochannels in the landscape (Ramanaidou et al. 2003).

The Mesa H development envelope includes 13 surface geology units (Biota 2019). By area however, the majority of the development envelope is accounted for by just two of these units: colluvium, accounting for 36%, and the CID Robe Pisolite Formation (a further 33%) (Biota 2019). (Figure 6.4; Table 6.2). Both of these geological units have been shown to represent suitable habitat for subterranean fauna in the Robe valley and the wider Pilbara region, with CID / Robe Pisolite in particular recognised as core habitat for troglofauna (Section 2.5.2).

At a finer scale, Rio Tinto classify CID deposits such as Mesa H into intra pisolite strata or 'strands', based on mineral grade, clay content and other structural and textural features (Figure 6.4; Table 6.2). The CID strands that represent troglofauna habitat at Mesa H comprise:

- Tp - Tertiary pisolite;
- Tpb - Basal Tertiary pisolite, which ranges from conglomeratic to clay rich, and relatively vuggy at Mesa H;
- Tpc - Tertiary pisolite with clay strata;
- Tpd - Denatured Tertiary pisolite, similar to Tpm but with less clay;
- Tph - Hard competent pisolite (mostly below water table at Mesa H);
- Tpm - 'Mixed' Tertiary pisolite composed of altered other pisolitic strands including hydrated material (mostly below water table at Mesa H); and
- Htp - Hardcap – weathered / altered pisolite and goethite, containing many vugs and cavities (mostly superficial at Mesa H)

The prospectivity of the geological units within the development envelope to represent troglofauna habitat was characterised as High, Medium or Low likelihood, based on relevant habitat attributes and how these are represented within the development envelope (see Section 2.5.4).

Following these criteria, the Robe pisolite (Tp) represents core habitat for troglofauna within the development envelope, being broadly assessed as High likelihood of troglofauna occurring, with the strands present at depth within the pisolite (Figure 6.4) mostly also either High or Medium likelihood (Table 6.2). Two other units were identified as having Medium likelihood for fauna to occur, comprising colluvium and Wittenoom formation (Table 6.2; Figure 6.4), and this likelihood is increased when the units occur in contact with the adjacent and underlying Robe pisolite as they do within the development envelope. These units were considered to represent potential troglofauna habitat by EPA (2013), and the Robe Pisolite unit was also used as the basis for mapping the local extent of the two troglofauna PECs that occur in the development envelope (Section 5.1.2.1).

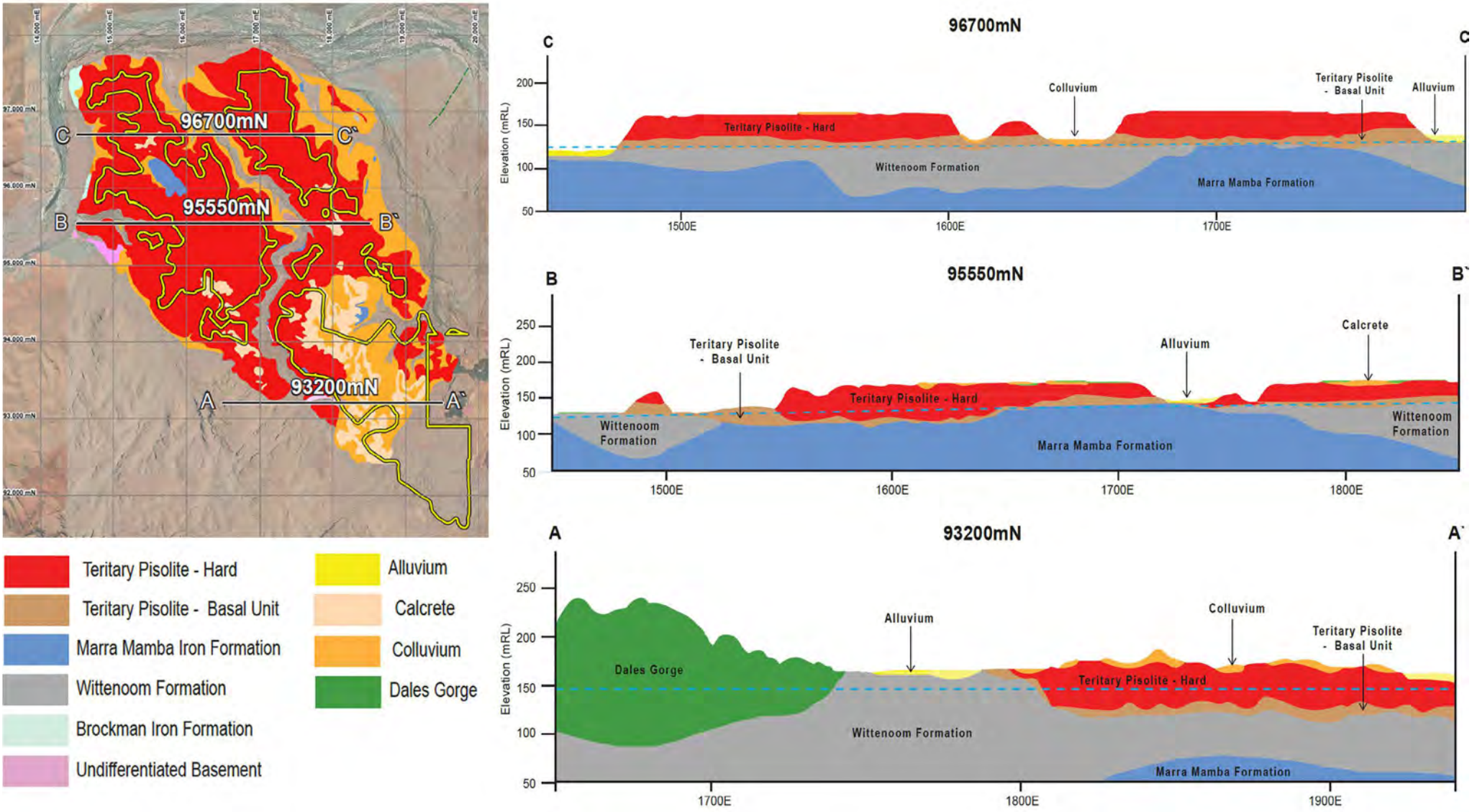

Figure 6.4: Mesa H surface geology (left) and cross-sections (right) illustrating troglofauna habitat strata at depth across three sections of Mesa H (A, B and C) (blue horizontal line on cross-sections represents approximate water table depth).

Table 6.2: Geological units identified as troglofauna habitat within the development envelope.

Code	Unit	Description	Likelihood to Support Troglofauna (Attributes)
Tp	Robe Pisolite	Tertiary pisolitic limonite deposits, which Rio Tinto stratigraphically classifies into strands of:	High (A, B, C, D, E)
	Tpb	Basal, clay and pisolite	Medium (A, B, C)
	Tpc	Clay bands	Low (C)
	Tpd	Denatured and friable ore	Low (C)
	Tph	Competent hard pisolitic ore	High (A, B, C, D, E)
	Tpm	Mix of Tpc, Tpd and Tph	Medium (A, C, E)
	Htp	Hydrated Tertiary pisolite	High (A, B, D, E)
Qg	Colluvium	Unconsolidated to loosely consolidated slope deposits	Medium (A, D, E)
Wd	Wittenoom Formation	Calcitic dolomite	Medium (A, D, E)

Basal pisolite (Tpb) underlies the other Tertiary pisolite strata, and is often below water table in the development envelope (e.g. cross-sections A and B on Figure 6.4). Tpb is, however, still at least Medium likelihood troglofauna habitat in the development envelope in locations where it occurs above water table (e.g. cross-section C on Figure 6.4) (Table 6.2). This is primarily due to its higher frequency of vugs and cavities at Mesa H specifically compared to basal pisolite in other parts of the Robe valley.

Cross-section C of Figure 6.4 also intersects the central creek gorge system that runs north-south through Mesa H, where Tpb outcrops to the surface and also laterally adjoins and overlies dolomite as part of the Wittenoom Formation (shown in grey on Figure 6.4). This latter unit, while not specifically identified in Table 6.2 as it is mostly below water table at Mesa H, also has potential to provide troglofauna habitat in the areas where it is above water table, given it contains cavities and vugs, and that it is in contact with the primary Tertiary pisolite habitat (a Medium likelihood rating; attributes A, D, E; Table 6.2). Additionally, the hydrological and recharge function of this central creek gorge system is likely to deliver water to the subterranean habitats of the Mesa H landform during major recharge events; a key functional process for sustaining humidity and providing organic inputs to subterranean ecosystems (Biota and DC Blandford & Associates 2013).

Rio Tinto provided modelled AWT CID (based on 3D modelling from drillhole data) from across the development envelope and surrounds (Appendix 1) and this was used to generate CID thickness contours to effectively map troglofauna habitat (using the Medium and High likelihood strands from Table 6.2 with a minimum of 5 m thickness AWT). This was then refined spatially on the basis of aerial photography overlain on a digital terrain model to inspect landforms and arrive at a mapped extent of habitat informed by both three-dimensional geology and geomorphology.

All troglofauna records from Mesa H were then plotted on the mapped habitat to provide independent validation of the intrinsic habitat assessment (Figure 6.5). This showed that the landforms associated with the mapped troglofauna habitat have a very strong spatial correlation with known troglofauna distribution, with 98% of the record locations falling within units mapped as habitat (Figure 6.5). Figure 6.6 depicts the habitat in a landscape isometric view, illustrating this strong relationship with mesa and hill landforms. This includes troglofauna records from the central creek gorge system at Mesa H, providing validation of the assessment of basal pisolite (Tpb) overlaying Wittenoom dolomite as troglofauna habitat (Figure 6.6).

The identified troglofauna habitat units can therefore be relied upon as a framework for the balance of this impact assessment.

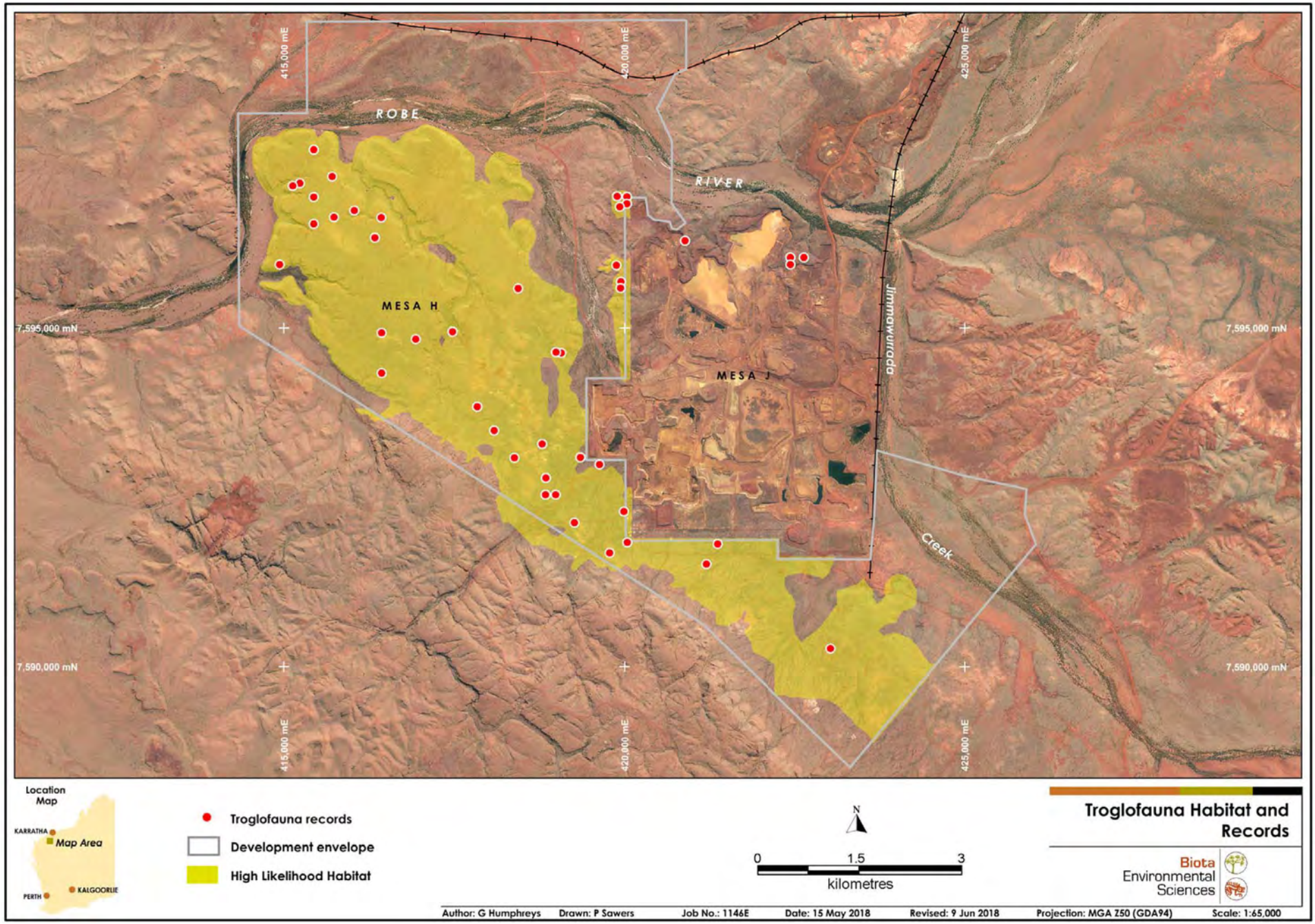

Figure 6.5: High likelihood troglofauna habitat in the development envelope showing spatial relationship with confirmed troglofauna records.

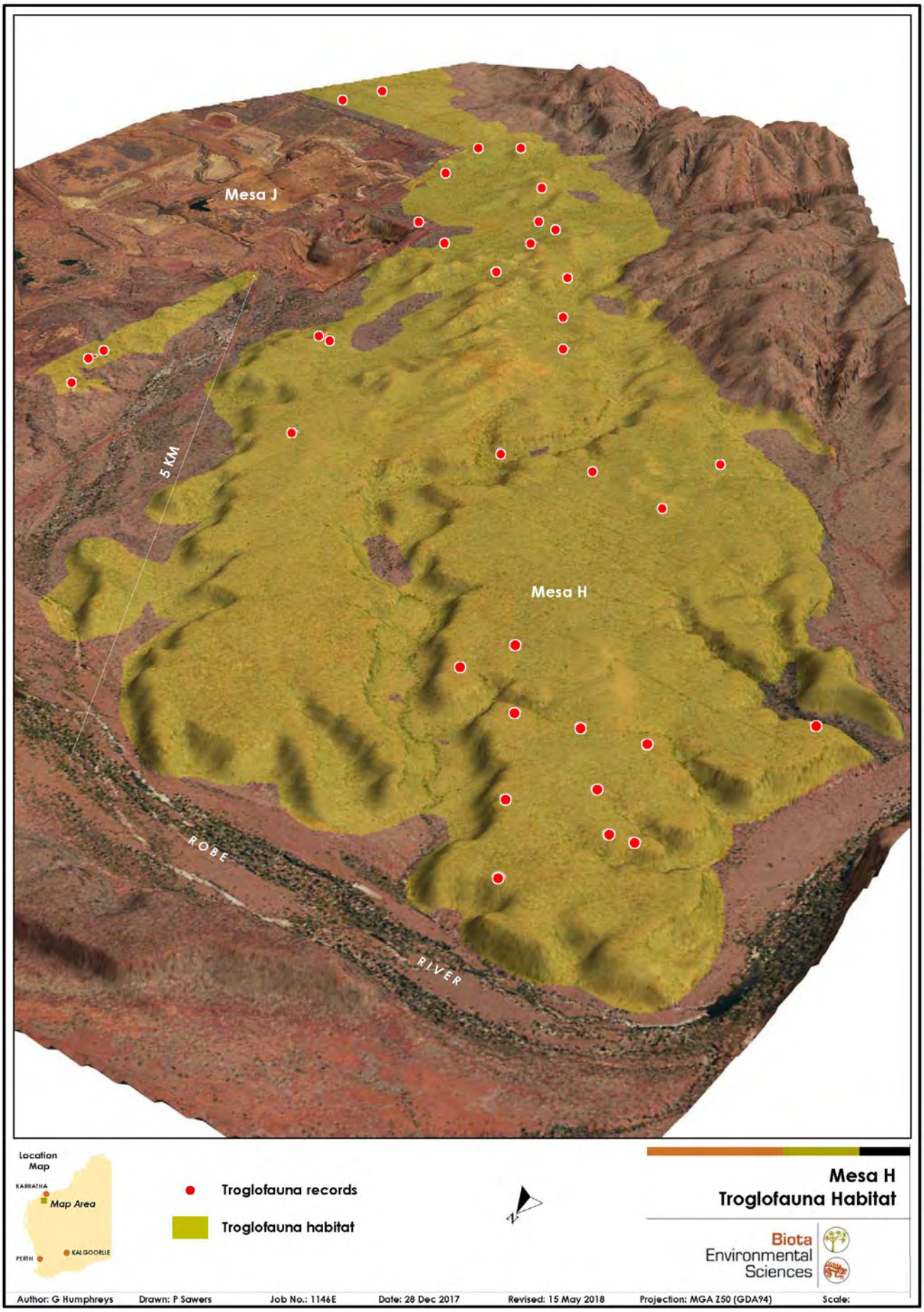

Figure 6.6: Isometric view of troglofauna habitat at Mesa H, overlain with the locations of confirmed troglofauna records.

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7.0 Impact Assessment

7.1 Stygofauna Impacts

Sixteen of the 32 stygofauna species known from the dewatering extent are either of listed conservation significance or are potential SRE taxa, and represent the key stygofauna receptors for this impact assessment (Section 5.1.2).

The 16 relevant species comprise:

- Blind Cave Eel *Ophisternon candidum* – Vulnerable (Commonwealth), Schedule 3 (State);
- the amphipod *Nedsia hurlberti* – Schedule 3 (State);
- the amphipod *Nedsia sculptilis* – Schedule 3 (State);
- the snail Hydrobiidae sp. 2 (potential SRE);
- ostracod *Areacandonda* sp. 'BOS1039' (potential SRE);
- the copepod *Megastygonitocrella unispinosa* (potential SRE);
- the ostracod Candoninae sp. 'BOS541';
- the ostracod *Pilbaracandona* sp. 'BOS526';
- the copepod *Parastenocaris* sp. 'B28';
- the isopod *Haptolana* sp. 'B01';
- the amphipod *Nedsia* sp. 'AMM026' (potential SRE);
- the amphipod Paramelitidae sp. 'AMP003' (potential SRE);
- the amphipod Paramelitidae sp. 'AMP035' (potential SRE);
- the amphipod Paramelitidae sp. 'AMP037' (potential SRE);
- the amphipod *Wesniphargus* sp. 'AMN004'; and
- the amphipod Neoniphargidae sp. 'B02' (potential SRE).

At the ecological community level, there is a single stygofauna key receptor (Section 5.1.2.1):

- Stygofaunal Community of the Bungaroo Aquifer (Priority 1).

7.1.1 Direct Impacts on Stygofauna Key Receptor Species

Direct impacts on stygofauna species comprise both habitat removal where the mine pits extend below water table and the dewatering necessary to enable this to occur (Section 4.2.1). While it is possible stygofauna may be able to actively respond to declining water table levels and move to habitat that remains viable, it is currently assumed that saturated habitat strata that are completely dewatered are no longer viable habitat and the individuals of species utilising those strata are conservatively considered to have been lost due to mortality. Where habitat strata have a substantial saturated thickness, and dewatering would only partially affect this; leaving connected viable habitat, the species would be likely to locally persist.

Sixteen of the 32 receptor species that occur within the dewatering extent have been recorded from Reference sites outside of the drawdown extent and have been commonly recorded elsewhere within the wider Pilbara bioregion (Section 5.1.1). While individuals of these species will be impacted by the mine pits and dewatering, no changes to their conservation status would be predicted given their wider distributions.

Figure 7.1 shows the distribution of the remaining 16 key receptor species relative to the mine pits and the maximum modelled drawdown extent for the proposal, and Table 7.1 summarises the sites they occur at and the level of predicted groundwater drawdown impact.

Ten of 16 key receptors have also been recorded from Reference sites outside of the drawdown extent (Table 7.1). Three of these 10 more widely-recorded species, *Ophisternon candidum*, *Nedsia hurlberti* and *Nedsia sculptilis*, are of formally listed conservation significance, so, while all three are also known from outside the drawdown extent, they are provided specific consideration in Section 7.1.2 in recognition of their elevated conservation status.

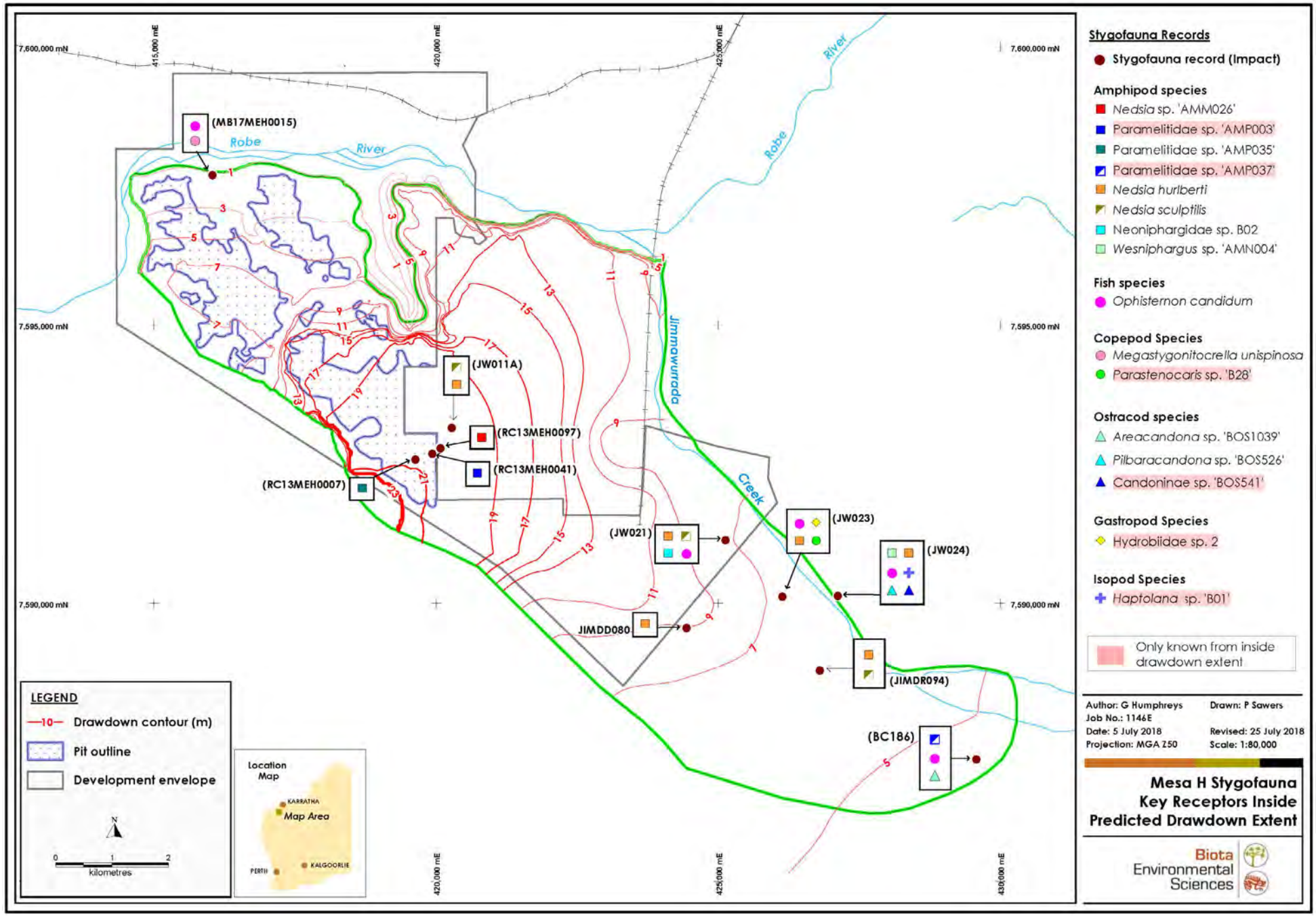

Figure 7.1: Distribution of stygofauna species key receptors within the maximum (2030 base case) proposal drawdown extent.

The other seven key receptors with demonstrated wider distributions would not be placed at significant risk to a change in their conservation status. Three of these species, *Areacandona* sp. 'BOS1039', *Nedsia* sp. 'AMM026' and Neoniphargidae sp. 'B02', were all recorded from outside of the drawdown extent at Reference site 31 further upstream on the Robe River, in the Pannawonica town bore field area ((Biota 2019); Table 7.1). *Megastygonitocrella unispinosa, Pilbaracandona* sp. 'BOS526', *Wesniphargus* sp. 'AMN004' and Paramelitidae sp. 'AMP035', have also been recorded more widely in the Robe River valley, outside of the drawdown extent (Table 7.1).

Table 7.1: Summary of records of impacted stygofauna key receptors relative to the maximum predicted drawdown extent at 2030 under the base case (Reference sites from Biota (2019); Species shaded grey known only from the drawdown extent).

Species	Impact Sites	Predicted Drawdown (m)	Reference Sites; Wider Distribution
*Ophisternon candidum**	MB17MEH0015	1	RR1, 25, RRD2, Control, Cape Range
	JW021	7	
	JW023	6	
	JW024	6	
	BC186	4	
*Nedsia hurlberti**	JW011A	20	Bungaroo Creek headwaters, Barrow Island
	JW021	7	
	JW023	6	
	JW024	6	
	JIMDD080	9	
	JIMDR094	6	
*Nedsia sculptilis**	JW011A	20	Bungaroo Creek headwaters, Barrow Island
	JW021	7	
	JIMDR094	6	
Hydrobiidae sp. 2	JW023	6	-
Areacandona sp. 'BOS1039'	BC186	4	31
Megastygonitocrella unispinosa	MB17MEH0015	1	Robe River valley
Candoninae sp. 'BOS541'	JW024	6	-
Pilbaracandona sp. 'BOS526'	JW024	6	Dave Bore, MB17MEH0007
Parastenocaris sp. 'B28'	JW023	6	-
Haptolana sp. 'B01'	JW024	6	-
Nedsia sp. 'AMM026'	RC13MEH0097	20	31
Paramelitidae sp. 'AMP003'	RC13MEH0041	20	-
Paramelitidae sp. 'AMP035'	RC13MEH0007	21	RR1
Paramelitidae sp. 'AMP037'	BC186	4	-
Wesniphargus sp. 'AMN004'	JW024	6	25
Neoniphargidae sp. 'B02'	JW021	7	31

* Formally listed as being of conservation significance

This leaves six species of stygofauna that are currently known only from the drawdown extent and, from the most precautionary perspective, are potentially restricted in distribution to that area: the aquatic snail Hydrobiidae sp. 2, the ostracods Candoninae sp. 'BOS541', the copepod *Parastenocaris* sp. 'B28', the isopod *Haptolana* sp. 'B01', and two amphipod species: Paramelitidae sp. 'AMP003' and Paramelitidae sp. 'AMP037' (Table 7.1; Figure 7.1).

Four of these six species, Hydrobiidae sp. 2, Candoninae sp. 'BOS541', *Parastenocaris* sp. 'B28' and *Haptolana* sp. 'B01', were recorded from two sites in close vicinity along Jimmawurruda Creek: JW023 and JW024 (Figure 7.1 and Table 7.1). The stygofauna habitat in this area is a sequence of saturated alluvium associated with the creek that is approximately 22-24 m in thickness down to the underlying CID (Figure 7.2). The two sites are on the eastern margin of the predicted drawdown for the proposal (Figure 7.1), with a maximum drawdown of >7 m on the pre-mining water table (Table 7.1 and Figure 7.1). Uncertainty in the model and seasonal water level fluctuation could have under-predicted the maximum drawdown, but it is expected that at least 15 m of alluvium will remain saturated below water table in the area where the four species have been recorded with the implementation of the proposal (see Figure 7.2). In the unlikely event that these species are restricted in distribution to this very small locality, this will still represent a refuge habitat at the time of peak dewatering for the project, which is expected to remain hydraulically connected to saturated alluvium habitat along the length of Jimmawurrada Creek, and will be seasonally connected to a greater extent during major rainfall events (Figure 7.2). These two potentially restricted key receptors are therefore not at significant risk of taxon-level impacts from the dewatering.

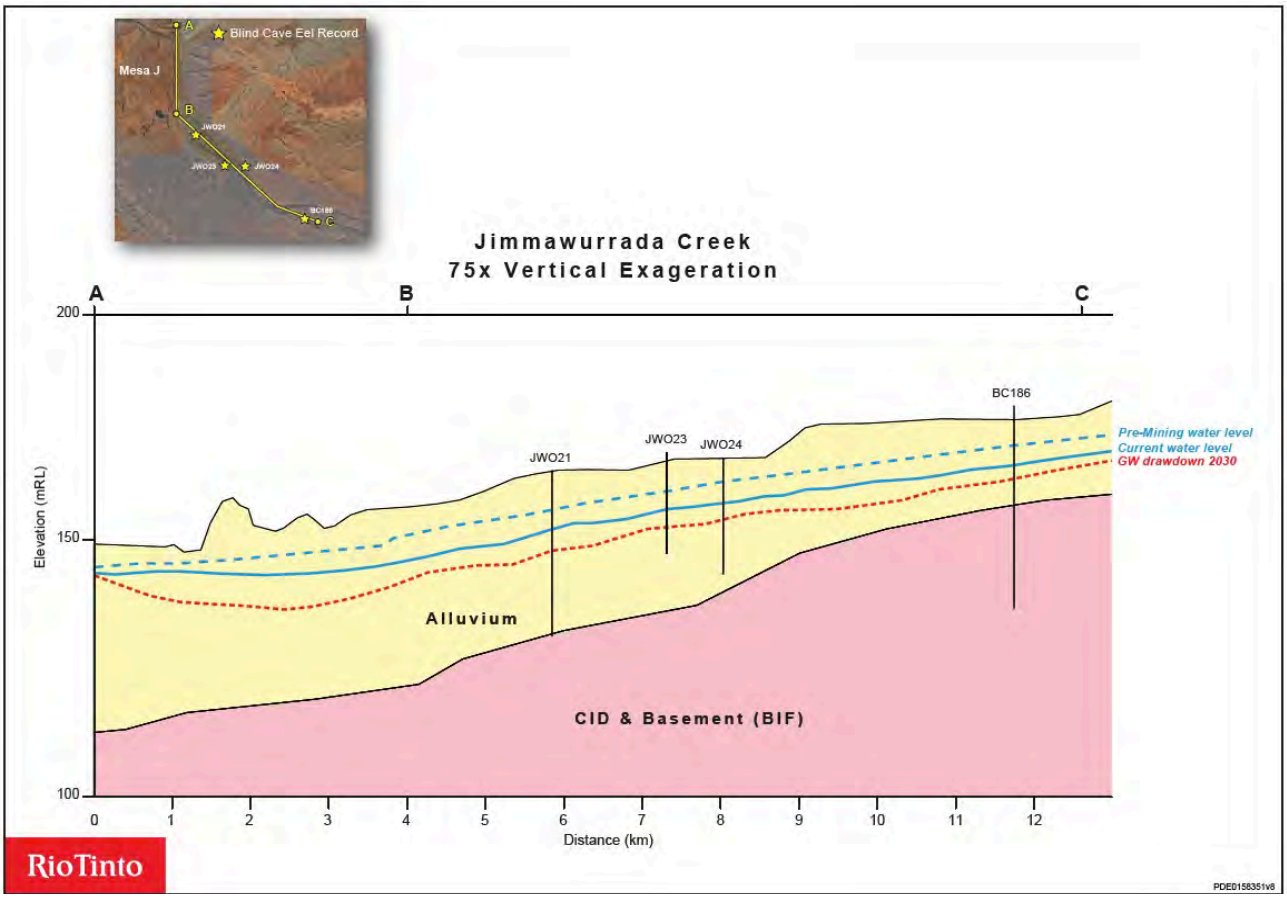

Figure 7.2: Longitudinal cross-section along Jimmawurrada Creek area, showing pre-mining water table, predicted maximum drawdown from the proposal in 2030 (dashed in red) and alluvial and CID stygofauna habitats that will remain saturated (below the red dashed line) (source Rio Tinto).

This leaves the amphipod species Paramelitidae sp. 'AMP003' and Paramelitidae sp. 'AMP037' as the last two species currently known from the drawdown extent. Both are only known from a single Impact site and both will be more substantially affected by the predicted drawdown:

- Paramelitidae sp. 'AMP003' would be the most substantially affected, having been recorded from site RC13MEH0041 within the proposed mine pit area, which will be subject to approximately 20 m drawdown in the water table (Table 7.1; Figure 7.1) and direct habitat removal from mine pit development. Given the location of the site beneath the Mesa H landform, it appears likely that this species occurs at least within the CID aquifer.
- Paramelitidae sp. 'AMP037' was recorded at the southeast limits of the drawdown extent at site BC186, which will be drawn down by >5 m below the pre-mining water table (Table 7.1; Figure 7.1). This site intersects the alluvial aquifer of the Jimmawurrada – Bungaroo Creek system, which represents the habitat the species was recorded from.

The key impact assessment question for these taxa is whether they are truly restricted to their currently recorded sites or actually occur more widely. This can be evaluated on the basis of multiple lines of evidence, utilising both physical and biological information:

1. Animal abundance
   Both species are represented by a single specimen only. With singleton taxa such as these it is difficult to determine if their apparent restriction is real or simply that they are actually more widespread but naturally at low abundance and/or difficult to collect with conventional methods. In cases where species are readily collected in good numbers, but are only ever detected from closely neighbouring sites, it is less likely that the restricted distribution is due to sampling effects and more likely it is genuine. This is not the case with the two amphipod species in question, with only a single individual each, therefore a probability exists that the result is due to ecological sampling effects.

2. Groundwater habitats
   It appears likely that Paramelitidae sp. 'AMP003' occurs within the CID aquifer, which is relatively confined and limited horizontally in the locality (Rio Tinto 2017b). The degree of hydraulic connection between the CID aquifer and the wider alluvial aquifers of the locality is not well defined, but basement groundwater flow may connect it with the Robe River aquifers to the north (Rio Tinto 2017b). The CID in this area is also inter-connected to the southeast with the broader Jimmawurrada – Bungaroo CID aquifer and overlying colluvium (Figure 6.1 and 6.2).

   Paramelitidae sp. 'AMP037' was recorded from site BC186, which intersects the widespread, highly transmissive and connected alluvial aquifer associated with Jimmawurrada Creek (Section 6.1), which overlies a substantive CID aquifer.

3. Assemblage distribution
   Paramelitidae sp. 'AMP003' was collected from site RC13MEH0041. Only one other stygofauna species was recorded from this same sampling site: *Nedsia* sp. 'AMM001' (Biota 2019) which, at a broad level, is morphologically and ecologically similar to Paramelitidae sp. 'AMP003' but occurs widely in the locality, covering a minimum distribution of 501 km^2 based on records from the Biota (2019) survey alone. That result does not indicate a higher risk of Paramelitidae sp. 'AMP003' being locally restricted in distribution, and conversely that it, too, may be more likely to follow a similar distribution pattern to the related, sympatric amphipod species. These observations also lend support to the view above that the CID aquifer beneath Mesa H is connected by groundwater flow to the wider Jimmawurrada – Bungaroo CID aquifer which is directly connected to the Jimmawurrada alluvial aquifer, which in turn is a tributary into (and connected to) the Robe River alluvial aquifer: if this were not the case, it would be very unlikely that *Nedsia* sp. 'AMM001' from site RC13MEH0041 would have remained so genetically similar to other individuals in the wider locality (Biota 2019).

   Multiple other stygofauna species co-occur at site BC186 with Paramelitidae sp. 'AMP037': *Enchytraeus* sp. 'AP PSS1' (which also occurs 39 km away downstream in the Robe River); *Areacandona* sp. 'BOS1039' (also at site 31 at the Pannawonica bore field); *Stygoridgewayia trispinosa* (also at 18 other sites along the length of the Robe Valley up to 59 km away); *Areacandona triangulum* (also recorded at three Reference sites up to 41 km away) and *Ophisternon candidum* (recorded from six other sites along Jimmawurrada and the Robe River) (Biota 2019). With the exception of the singleton Paramelitidae sp. 'AMP037', every other species recorded from site BC186 is more widely distributed within the Robe River valley. As these taxa span a range of body sizes, morphologies and ecologies, their locally widespread distributions do not indicate any evidence of local barriers to fauna dispersal and gene flow for stygofauna, which by inference would also apply to Paramelitidae sp. 'AMP037' at the same site.

4. Distributions of closely-related taxa
   Seventeen other Amphipoda species were recorded by Biota (2019), including four other taxa belonging to the same family as Paramelitidae sp. 'AMP003' and P. sp. 'AMP037'. Revisiting point 1 above regarding low frequency taxa: it is notable that all of the paramelitids were detected from few (or in many cases one) individuals, including two other singleton species (Biota 2019). The only paramelitid amphipod species that was recorded from more than one

site was Paramelitidae sp. 'AMP035', which was recorded within the drawdown extent at site RC13MEH0007 but has been shown to also occur outside of this impact area (Table 7.1). That site is immediately adjacent to site RC13MEH0041, where Paramelitidae sp. 'AMP003' was collected, and the distribution of the more widely recorded, but closely-related, Paramelitidae sp. 'AMP035' then suggests that Paramelitidae sp. 'AMP003' may also occur more widely.

The above lines of physical and biological evidence are all parallel in suggesting connectivity between site RC13MEH0041 (where Paramelitidae sp. 'AMP003' was recorded) and the wider Robe River aquifers and stygal assemblage, and similarly for BC186 (Paramelitidae sp. 'AMP037') and the wider habitats in the locality. Data from other co-occurring species, related amphipod taxa and groundwater habitat information do not signal a high degree of isolation in stygofauna species in the locality of either site where the singleton species were recorded. It appears unlikely that either of the two amphipod species would be truly restricted to the dewatering extent and more likely that their current apparently restricted distributions are due to ecological sampling effects.

7.1.2 Direct Impacts on Conservation Significant Species

Individuals of the Schedule-listed amphipods *Nedsia hurlberti* and *Nedsia sculptilis* will not be directly impacted by the mine pits, but will be impacted by the cumulative dewatering at multiple record sites, with approximately 20 m of groundwater drawdown predicted at JW011A where both species have been historically recorded (Table 7.1).

However, while both species are listed as Schedule 3 at State level, they also occur more widely, both in the west Pilbara and as far afield as Barrow Island (Table 7.1; Figure 7.3; Figure 7.4).

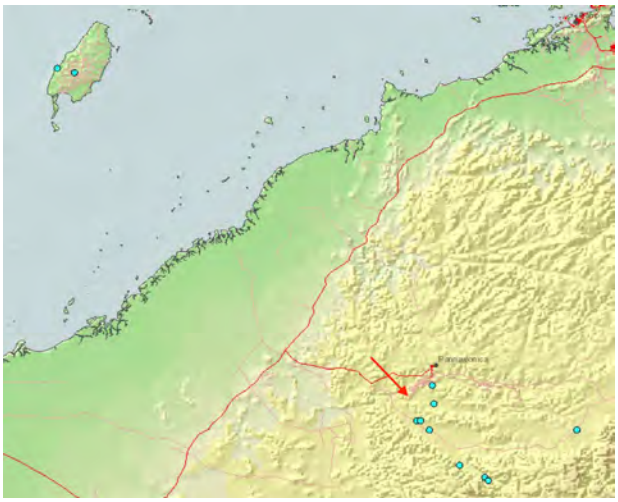

Figure 7.3: Records of *Nedsia hurlberti* on NatureMap (blue circles) (arrow indicates development envelope).

Figure 7.4: Records of *Nedsia sculptilis* on NatureMap (blue circles) (arrow indicates development envelope).

The current survey records of the two species from Mesa H are in addition to those used by DBCA to assign the species' conservation listing, and the local impact on individuals arising from the proposal would therefore not alter their overall current conservation status.

In addition, stratigraphic cross-sections along the length of Jimmawurrada Creek, where site JW021 is situated, combined with hydrogeological modelling, show that a substantial thicknesses of alluvium (a minimum of approximately 17 m) and underlying CID will remain saturated along Jimmawurrada Creek during the period of maximum drawdown for the project (Figure 7.2). While the alluvial aquifer is likely to be the primary habitat for the species, both units provide habitat for stygofauna below water table, meaning this will represent a substantial refugium habitat for both amphipod species at the time of peak dewatering for the project.

The third conservation significant species, the Blind Cave Eel (*Ophisternon candidum*), also occurs along Jimmawurrada Creek and has been recorded from four sites there, in addition to five other sites in the broader locality (Figure 7.5) (Biota 2019). The ecology and distribution of the species is poorly understood (Biota and Helix 2014), but the surveys and related investigations completed for

the Mesa H proposal have substantially improved the overall knowledge base for the species in the west Pilbara (Moore et al. 2018, Biota 2019). Specimen records and eDNA evidence now indicate the species occurs within not only the Bungaroo Creek alluvial aquifer (Biota 2009b), but also in the Jimmawurrada Creek and Robe River alluvial aquifers ((Biota 2019); Figure 7.5).

Spatially then, there are five sites in the Mesa H locality where the species has been recorded that are outside of the proposal's drawdown extent (Figure 7.5). Similar to other stygofauna species, the records of *O. candidum* also show a high spatial correlation to the High likelihood stygofauna habitat units: Taking account of all confirmed record locations, the distribution of this habitat suggests that suitable connected habitat for the species occurs along the length of the Robe River catchment (Figure 7.5). It is notable that one of the Reference site eDNA records for the species came from the Control site sampled by Biota (2019): this site was a surface water pool on the Robe River and consistently yielded eDNA detections for the species from multiple replicate samples (Helix 2018). This may suggest that the species utilises shallow groundwater habitats in the alluvial sequence of the Robe River, including the phreatic zone, and this could contribute to maintenance of gene flow and population connectivity within the species' overall range. This theory is consistent with the Robe River alluvium hypotheses of Moore et al. (2018) and is supported by the subsequent and recent collection of an additional specimen from the phreatic zone of the Robe River during aquatic fauna sampling in a surface pool in the river (WRM 2018, in prep.).

In addition, one of these Reference sites (site 25; Figure 7.5) is part of the Pannawonica town bore field, which is subject to a low level of groundwater drawdown itself, being pumped at sustainable yield for water supply (Rio Tinto 2016). This alluvial aquifer habitat has been abstracted from since 1981 (Rio Tinto 2016), which is indicative of both the significant recharge capacity of the Robe River alluvial aquifer and, by inference, that *Ophisternon candidum* is at least tolerant to this level of groundwater impact in the medium term (with the bore field having being in operation for 37 years at the time the recent eDNA record was obtained; Biota 2019).

Even within the drawdown extent, the alluvial aquifer habitat of Jimmawurrada Creek where *O. candidum* occurs is subject to the same predictions as those noted above for *Nedsia hurlberti* and *N. sculptilis*: that is, when considered vertically, there will be a substantial saturated thickness remaining along the length of the creek at the peak of groundwater drawdown for the project in 2030. Similar to the *O. candidum* records from the Pannawonica town bore field, the sites on sites on Jimmawurrada Creek have also been subject to groundwater drawdown associated with the existing Mesa J operations and the species still utilises the area. Figure 7.2 shows the four sites where *O. candidum* has been recorded along Jimmawurrada Creek, illustrating that a continuous and connected saturated alluvium habitat varying between 5 and 17 m thick will remain within the system at the peak of dewatering. This is in addition to the underlying saturated CID, which may also provide potential habitat to the species (Figure 7.5).

In summary then:

- four of the known sites where *Ophisternon candidum* occurs are currently affected by groundwater drawdown, and will be subject to further groundwater drawdown from between 1 m up to a temporary peak of 6 m on the current water table but a substantial thickness of saturated alluvium and CID will remain as a refuge even within the impact areas (Table 7.1 and Figure 7.2);
- there are a further five known sites where the species occurs within the Robe Valley that are outside of the drawdown extent, including along the Robe River (Figure 7.1);
- inferences drawn from one of those sites at the Pannawonica town bore field suggest the species may be tolerant to lower levels of groundwater perturbations; and
- both the distributions of the known records, and habitat mapping with a strong evidence base from the broader stygal assemblage (Section 6.1), indicate it is likely that the species is distributed more widely along the Robe River catchment alluvial aquifer.

The above suggest that while some individuals of the species may be directly impacted by the groundwater drawdown, the species will remain locally represented within the Mesa H locality, in addition to its possible occurrence further along the connected alluvial aquifer habitats downstream along the Robe River and further afield at Cape Range (Biota 2019).

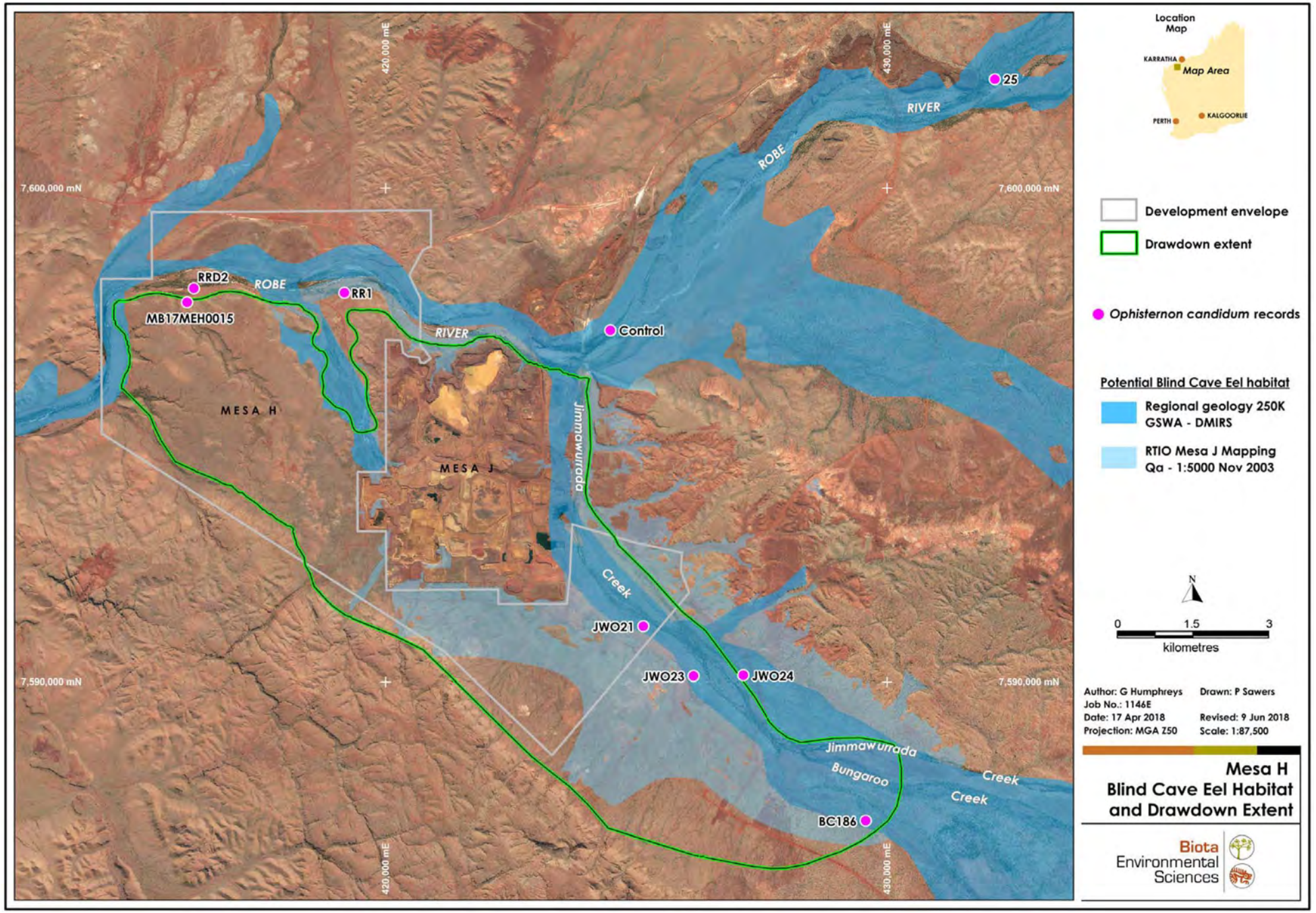

Figure 7.5: Blind Cave Eel Records and potential habitat for the species relative to the extent of direct impacts arising from the Mesa H project.

7.1.3 Direct Impacts on Stygofauna Community and Habitat Key Receptors

This drawdown extent relative to the Stygofaunal Community of the Bungaroo Aquifer PEC is shown in Figure 7.6.

The drawdown extent for the proposal will have a relatively minor effect on the northwestern limit of the PEC as mapped by DBCA. The total mapped extent of the Bungaroo aquifer PEC is 106,703 ha, of which 3,287 ha falls within the drawdown extent (3.1% by area; Figure 7.6). Therefore, while the proposal will have an impact on the PEC, 97% of its extent as currently recognised by DBCA, or over 100,000 ha in real terms, will remain unaffected by the Mesa H proposal.

At the scale of stygofauna habitats in the wider Robe River catchment (as illustrated in Figure 6.2), the proportion of aquifer habitat impacted by the dewatering is an order of magnitude smaller than the PEC impact, and is thereby not considered further in this assessment.

7.1.4 Indirect Impacts

The pathways by which the proposal that may indirectly impact stygofauna comprise:

1. clearing of terrestrial vegetation and hardstand sealing of surfaces, leading to changes to groundwater recharge and nutrient infiltration;
2. increased sedimentation of the aquifers beneath the project footprint due to the creation of waste landforms and waste fines management; and
3. risk of hydrocarbon or other groundwater contamination (see Section 4.2.2).

All of these impact pathways are likely to be secondary tier impacts by comparison to the direct impacts (Section 7.1.1 to 7.1.3) and their effects can typically be minimised through project design and operational environmental management measures that are now well-established and effective. The primary focus for the assessment of the impacts then remains the direct impacts of the proposal on stygofauna from mine pit construction and dewatering.

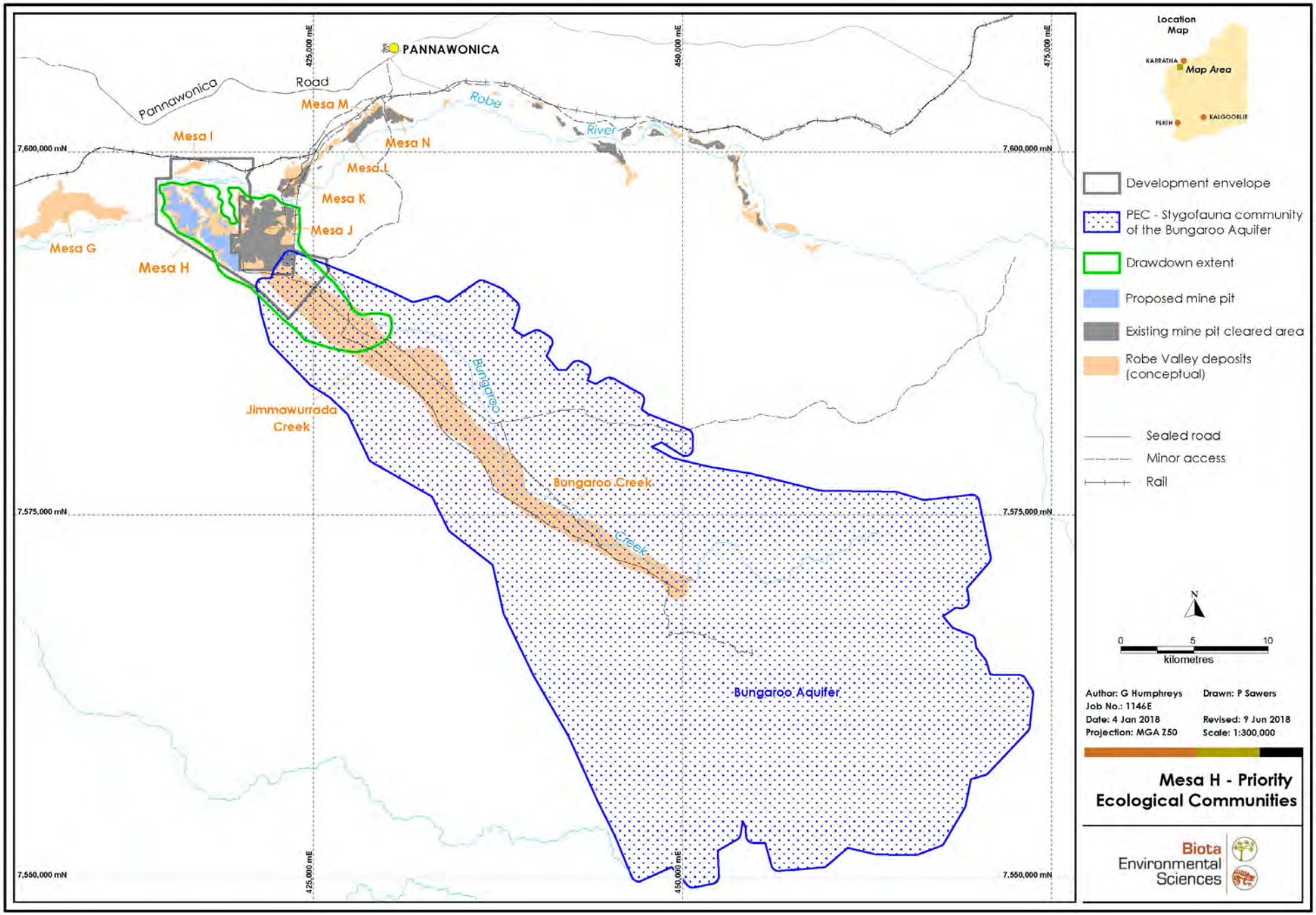

Figure 7.6: Mapped extent of stygofauna community key receptor relative to the extent of direct impacts arising from the Mesa H project.

7.2 Troglofauna Impacts

This assessment identified 33 development area species that are potential SRE taxa and represent the troglofauna key receptors for this impact assessment.

These comprise:

- eight pseudoscorpion species (Hyidae sp.'PH017/PH027', Hyidae sp. 'PH026', Olpiidae sp. 'PO008', *Beierolpium* sp. 'PO014', *Beierolpium* sp. 'PO015', Atemnidae sp. 'PA004', Chthoniidae sp. 'PC014/PC015' and Chthoniidae sp. 'PC055');
- four schizomid species (*Paradraculoides* sp. 'SCH038', *Paradraculoides* sp. 'SCH039', Hubbardiidae sp. 'SCH011' and Hubbardiidae sp. 'SCH015/16');
- one centipede species (Cryptopidae sp. 'SC018');
- seven dipluran species (Parajapygidae sp. 'DPA001', Parajapygidae sp. 'DPA009', Projapygidae sp. 'DPR008/DPR009/DPR011', Projapygidae sp. 'DPR010', Japygidae sp. 'DJA003', Japygidae sp. 'DJA011', and Campodeidae sp. 'DCA005');
- five isopod species (Philosciidae sp. 'ISP047', Philosciidae p. 'ISP055', *Troglarmadillo* sp. 1, *Troglarmadillo* sp. 'ISA046'; and Armidillidae sp. 'ISA056/ISA057');
- three beetle species (Curculionidae sp. 'CCU014', Ptilidae sp. 1/'CP003' and Ptilidae sp. 'Robe Valley'/'CP002');
- two silverfish species (Nicoletiinae sp. 'TN019' and Nicoletiinae sp. 'TN020');
- two spider species (*Prethopalpus* sp. 'ARA052' and Gnaphosidae sp. indet.); and
- one cockroach species *(?Nocticola* sp. 'West Pilbara Complex').

Taken together, the higher order taxonomic composition of the fauna of the development envelope is representative of virtually all components of the best-sampled pisolitic mesa habitats of the Robe valley (Biota 2006a, 2016b, 2017). The development area can therefore be considered adequately sampled (Biota 2019) and the survey data inputs (the first tier of the impact assessment model followed here; Figure 2.1) adequate for the purposes of the current assessment.

At this troglofauna ecological community level, there are also two key receptors for this impact assessment (following the criteria in Section 2.4):

- Subterranean invertebrate communities of mesas in the Robe Valley region (Priority 1); and
- Subterranean invertebrate community of pisolitic hills in the Pilbara (Priority 1) (Section 5.2.2.1).

7.2.1 Direct Impacts on Troglofauna Species Key Receptors

The clearest direct impact on both troglofauna species and communities key receptors is the habitat removal that will occur to accommodate the proposed mine pits (Section 4.2.1). This will result in the loss of troglofauna habitat and the mortality of individual animals occurring within it.

Records of the 33 troglofauna species known from the development envelope are show in Figure 7.7. Six of these 33 have also been recorded from outside of the development envelope and have demonstrated wider distributions:

- two schizomid species: Hubbardiidae sp. 'SCH011' (also known from remnant CID habitat north of Mesa J; Figure 7.7) and Hubbardiidae sp. 'SCH015/SCH016' (previously recorded from 6 km southwest of the development envelope; Biota (2019));
- the isopod species Armadillidae sp. 'ISA056/ISA057' (also known from 27 km to the west at Mesa C (Biota 2019) and is therefore likely to occur more widely at other locations);
- the blattodean ?*Nocticola* sp. 'West Pilbara Complex' (relatively widespread in the locality, including up to 60 km to the south (Biota 2019)); and
- two beetle species: Ptilidae sp. 1/'CP003' and P. sp. 'Robe Valley'/'CP002' (both of which have been recorded more widely within the Robe River valley (Biota 2019).)

The remaining 27 key receptor species have currently only been recorded from within the development envelope (Biota 2019). The key question for this assessment in respect of these species then becomes their distribution relative to the proposed extent of the mine pits.

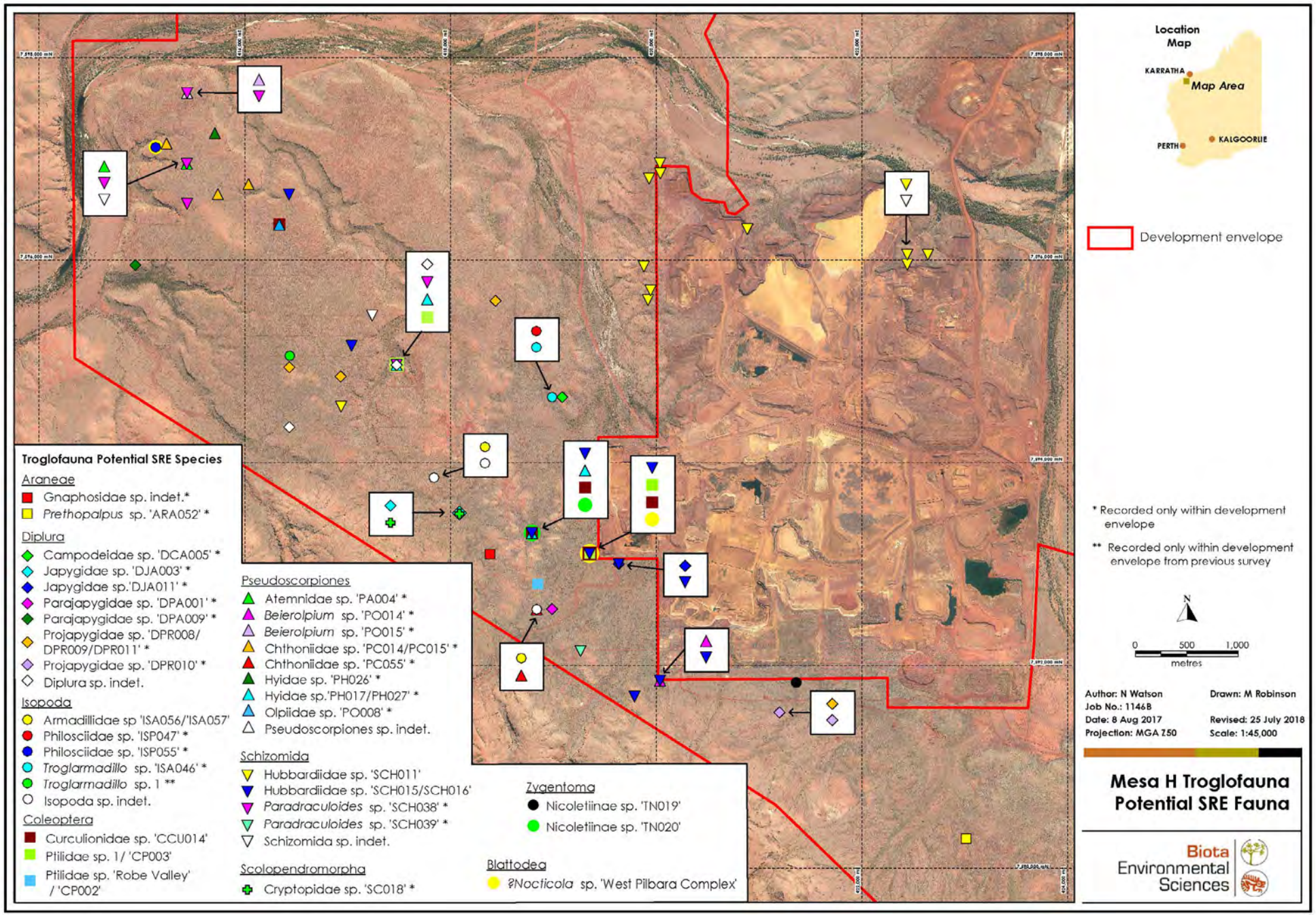

Figure 7.7: Distribution of all troglofauna key receptor species within the development envelope.

The records of the 27 species only known from the development envelope are summarised in Table 7.2, which categorises the sites where they have been recorded into sites within the mine pits and sites outside of this that will not be directly impacted. These data show that 23 of the 27 species have only been recorded from habitat outside of the proposed pit areas, with the proposed pits not directly impacting them at all from current data, and half of those 23 un-impacted species are also confirmed within the MEZ (Table 7.2).

This avoidance of direct impact on most species occurring within the development envelope is due to Rio Tinto's elimination of impacts during the project design (the 'Management' tier mitigation opportunity in the impact assessment model; see Figure 2.1): the design of the mine pit boundaries was specifically tailored to avoid troglofauna species records where feasible, and the MEZ was designed to incorporate locations where species were recorded; adopting a precautionary approach to their distributions. This has resulted in 70% of the development envelope troglofauna species being avoided entirely by the proposed mine pit footprint.

Table 7.2: Troglofauna species currently known only from within the development envelope and their distribution relative to the proposed mine pits (species shaded grey currently only known from the mine pits).

	In-pit Sites	Sites outside of Mine Pits	
Species		Inside MEZ	Other Remnant Habitat
Pseudoscorpiones			
Hyidae sp.'PH017/PH027'	-	RC14MEH0252	- RC16MEH0264
Hyidae sp. 'PH026'	-	RC16MEH0436	-
Olpiidae sp. 'PO008'	-	RC15MEH0302	-
Beierolpium sp. 'PO014'	-	-	RC16JIM0026
Beierolpium sp. 'PO015'	-	RC16MEH0433	-
Atemnidae sp. 'PA004'	-	RC15MEH0329	-
Chthoniidae sp. 'PC014/PC015'	RC15MEH0315	RC15MEH0335	-
Chthoniidae sp. 'PC055'	-	-	MEHRD0834
Schizomida			
Paradraculoides sp. 'SCH038'	MEHRC157	RC15MEH0329, RC16MEH0433	RC16MEH0264
Paradraculoides sp. 'SCH039'	-	-	RC15MEJ0019
Myriapoda			
Cryptopidae sp. 'SC018'	-	RC14MEH0388	-
Diplura			
Parajapygidae sp. 'DPA001'	-	-	RC14MEH0308
Parajapygidae sp. 'DPA009'	-	MEHRD0758	-
Projapygidae sp. 'DPR008/DPR009/DPR011'	RC15MEH0166	-	RC15MEH0261, RC15MEH0175, RC16JIM0005
Projapygidae sp. 'DPR010'	-	-	RC16JIM0005
Japygidae sp. 'DJA003'	-	RC14MEH0388	-
Japygidae sp. 'DJA011'	DD13MEH0007	-	-
Campodeidae sp. 'DCA005'	-	-	GR15MEH0032
Isopoda			
Philosciidae sp. 'ISP047'	-	-	RC15MEH0382
Philosciidae p. 'ISP055'	-	RC15MEH0427	-
Troglarmadillo sp. 1	-	-	MEHDC0865
Troglarmadillo sp. 'ISA046'	-	-	RC15MEH0382
Coleoptera			
Curculionidae sp. 'CCU014'	RC12MEH0221	RC14MEH0252, RC15MEH0302	-
Zygentoma			
Nicoletiinae sp. 'TN019'	-	-	RC16JIM0006
Nicoletiinae sp. 'TN020'	-	RC14MEH0252	-
Araneae			
Prethopalpus sp. 'ARA052'	-	-	RC16JIM0019
Gnaphosidae sp. indet.	-	RC14MEH0270	-

Five of the remaining six species that occur within the mine pits have distributions demonstrated to extend beyond the pit boundaries (Table 7.2; Figure 7.8). Again, this is a function of the proposed mine pit and MEZ design having been specifically modified in response to the troglofauna survey data to avoid or minimise direct impacts.

With the pit design mitigation already undertaken, there is only one species currently known only from within the proposed pit outlines: the dipluran Japygidae sp. 'DJA011' (Table 7.2; Figure 7.8). A key impact assessment question that arises for this proposal, and has arisen for numerous previous proposals where Subterranean Fauna has been a relevant factor, is whether this species is truly restricted to the mine pit impact areas. This can be addressed by consideration of the survey data, distributional records of all troglofauna species known from Mesa H, and the extent and configuration of interconnected troglofauna habitat in the locality.

Both the results of the current Biota (2019) investigations, and past work in the Robe valley (Biota 2006a, 2016b, 2017), indicate that the appropriate spatial scale at which to evaluate this is the CID landforms and associated AWT troglofauna habitat of Mesa H itself. This is due to the endemism common in the fauna, with over 80% of the recorded species only known to occur at Mesa H. This is consistent with the configuration and extent of troglofauna habitat, with the habitats identified for Mesa H bounded by major geomorphological features; comprising the Robe River to the north and Jimmawurrada Creek to the east, and southerly limits on AWT habitat, where the CID habitat abuts the Brockman Iron Formation ranges rising to the southwest (Section 6.2). The context for assessing the risk to the potentially restricted species is therefore to consider whether very small scale and localised restrictions in species distributions could exist within the extent of troglofauna habitat mapped for Mesa H (Figure 6.5 and Figure 6.6 of Section 6.2).

The risk that the species in question is truly restricted to the mine pits can consider:

1. Animal abundance
   The species is represented by a single specimen only. As discussed for the equivalent stygofauna singleton taxa (Section 7.1.1), this makes assessing its true distribution more difficult and introduces the probability that the apparent isolation to the record site is an artefact of ecological sampling effects.
2. Troglofauna habitats
   The combination of surface geology habitat mapping, AWT CID thickness data, and stratigraphic cross-sections (Figure 6.5 and Figure 6.6), all indicate continuity and connectivity of AWT troglofauna habitats across the extent mapped within the development envelope.
3. Assemblage distribution
   Other troglofauna species recorded from the same drillhole as the species in question have demonstrated distributions that extend beyond the direct impact areas. Japygidae sp. 'DJA011' was recorded from DD13MEH0007, where it co-occurs there with Hubbardiidae sp. 'SCH015/SCH016'; a species that has been recorded both inside and outside the pits, including in habitat that will remain unmined 1.2 km to the south (Figure 7.3) and is also known from outside the development envelope (Biota 2019).

   At the overall assemblage level, there are 11 troglofauna species known to occur within the mine pit boundaries and 10 of these have proven wider distributions within Mesa H or further afield, with records from either the MEZ or other troglofauna habitat that will remain unmined (Figure 7.3). This pattern in the fauna indicates connectivity of habitat across the extent of the landform and across the mine pit boundaries, rather than a pattern of very localised isolation. Consistent with this, past surveys at other Robe River valley mesas has shown that troglofauna species typically have distributions equivalent to at least the extent of contiguous, AWT CID landforms, once sufficient sampling has been undertaken to demonstrate this (e.g. Biota 2006b, 2007, 2016c).

The above lines of physical and biological evidence are parallel in suggesting that the dipluran Japygidae sp. 'DJA011' appears unlikely to be truly restricted to the small portions of the Mesa H landform from which it has currently been recorded. Data from other co-occurring species, and the broadly continuous nature of AWT CID habitats within Mesa H, suggest that the apparent restriction of the species is due to ecological sampling effects and that it occurs more widely within the local habitat extent.

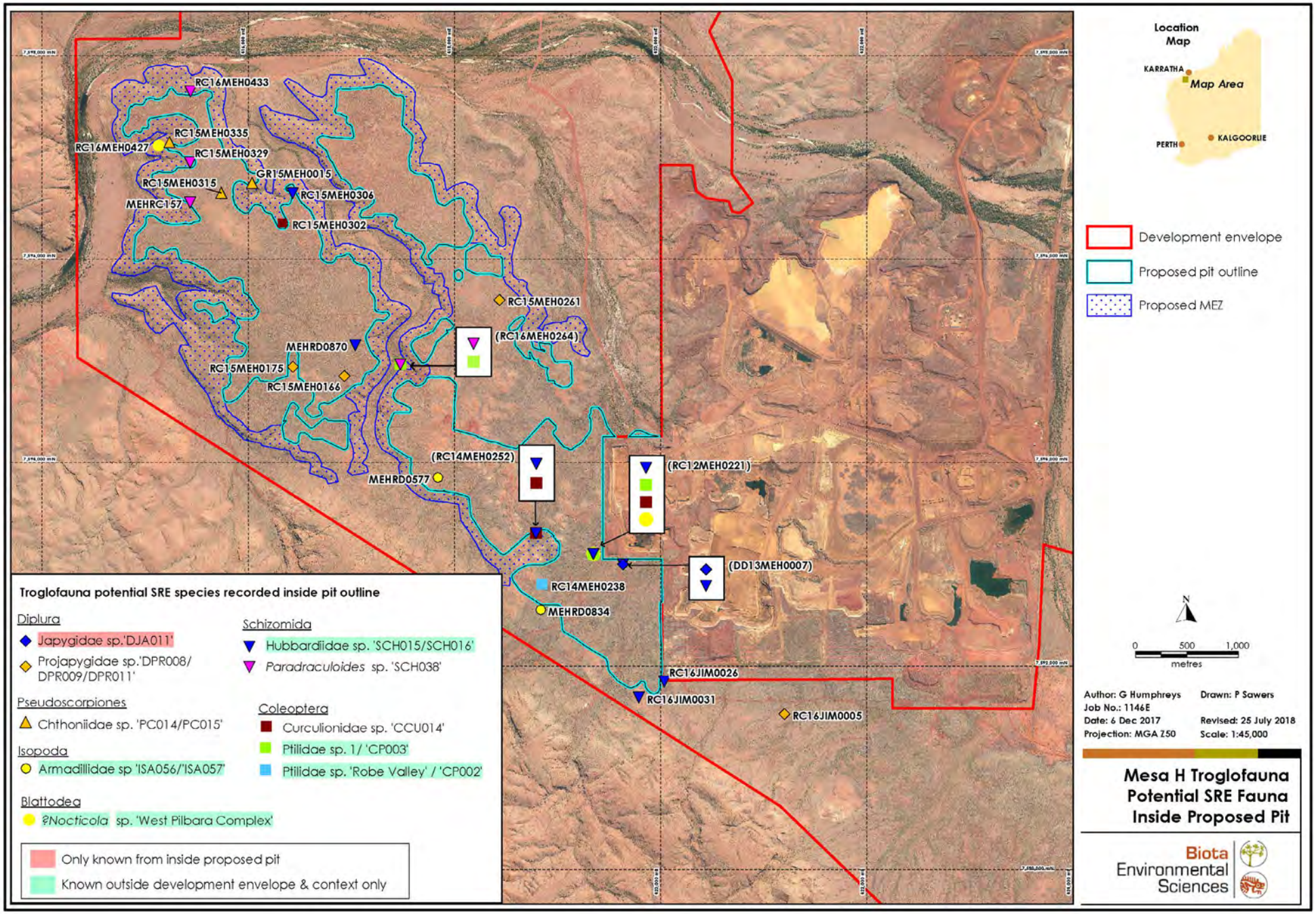

Figure 7.8: Distribution of troglofauna key receptor species relative to the extent of direct impacts arising from the Mesa H project.

7.2.2 Direct Impacts on Troglofauna Community and Habitat Key Receptors

The extents of the two troglofauna PECs relevant to this impact assessment are shown in Figure 7.9, which are the assumed original extent of these PECs, prior to any past disturbance, as mapped by the now DBCA.

As discussed in Section 5.2.2.1, the two PECs appear to have only been distinguished on the basis of perceived landform differences ('mesas' versus 'hills'; Table 7.3), but in reality both actually represent troglobitic communities of elevated CID landform habitats along the Robe River palaeodrainage. This somewhat arbitrary naming has caused spatial overlaps between the buffers of the two PECs; including small areas within the western and eastern parts of the development envelope (Figure 7.9). Given these overlaps, and that DBCA still recognise the PECs as separate entities, the potential impacts of the proposal on each of the PECs have been considered separately.

With the history of resource development in the Robe valley, and consistent with the guidance of EPA (2016a), it is appropriate to place potential impacts on the PECs into a cumulative impact context. Table 7.3 and Figure 7.9 summarise the extent of proportionate habitat loss that has already occurred due to previously approved (in grey on Figure 7.9) and reasonably foreseeable projects (outlined blue on Figure 7.9), and quantify the additional direct loss of PEC extent that will arise as a result of the Mesa H proposal.

Table 7.3: Cumulative direct impacts from the Mesa H mine pits on troglofauna PECs, in context with other habitat removal (ignoring overlaps in mapped PEC extents within the development envelope).

PEC	Original Assumed Extent of PEC	Current Extent after Other Habitat Loss *	Extent after Habitat Loss from this Proposal	Incremental Impact
Subterranean invertebrate communities of mesas in the Robe Valley region	13,753.9 ha (100%)	11,773.4 ha (85.60%)	11,764.2 ha (85.53%)	9.20 ha (0.07%)
Subterranean invertebrate community of pisolitic hills in the Pilbara	9,889.7 ha (100%)	7,952.3 ha (80.41%)	7,164.2 ha (72.44%)	788.1 ha (7.97%)

*Including both impacts that have already occurred or are reasonably foreseeable from other proposed developments.

The incremental impact of the proposal on the 'Subterranean invertebrate communities of mesas in the Robe Valley region' PEC is very minor at 0.07% of its original extent (Table 7.3). This is especially the case when the mapping of this PEC that falls within the development envelope is almost certainly only a buffer area on the true extent of the PEC itself (Figure 7.9).

The incremental loss of habitat from the 'Subterranean invertebrate community of pisolitic hills in the Pilbara' PEC is greater at 7.97% of its original extent (Table 7.3). This is largely a function of this second PEC being restricted to just Mesa H and the Warramboo locality (Figure 7.9), as both were considered by DBCA to represent 'hills' rather than mesas. Even with this, over 72% of the original assumed extent of this PEC, at 7,164.2 ha, would still remain with the implementation of the Mesa H proposal (Table 7.3). Combining both PECs, given that they both represent effectively the same types of troglobitic communities within elevated CID landform habitats along the Robe River palaeodrainage, provides a total incremental impact of 3.4 % of the combined PECs.

Within the spatial extent of Mesa H itself, a key assessment question relates to the viability of troglofauna populations in the habitat that will remain once mining is complete; particularly in respect to the in-pit troglofauna species remaining at Mesa H. This is likely to be a function of the extent, configuration and intactness of the portions of the Mesa H landforms left undisturbed by proposed mining activities; both within the proposed MEZ and in other remnant habitat within and adjoining the development envelope.

Figure 7.10 shows the mapped extent of troglofauna habitat at Mesa H, and the area that would be directly impacted by the mine pits. The total area of troglofauna habitat within the development envelope is 2,497.3 ha, and 751.5 ha of this falls within the mine pit boundaries, leaving approximately 70% of the spatial habitat unmined (1,745.8 ha) (Figure 7.10). The MEZ, which Rio Tinto has committed to not mine and thereby has greater certainty of retention, accounts for approximately a quarter of this habitat area at 443.3 ha. Overall, the unmined habitat would include records of 33 of the 34 troglofauna species known from the development envelope in a relatively well connected and contiguous extent of AWT troglofauna habitat (Figure 7.10).

From a three-dimensional habitat volume perspective, Rio Tinto mine planning and modelling has also calculated the remaining volume of the CID strands representing habitat for troglofauna on completion of the project: this will exceed 50% of the current pre-mining habitat volume, similar to past Robe Valley projects which have been approved to proceed (e.g. EPA 2007).

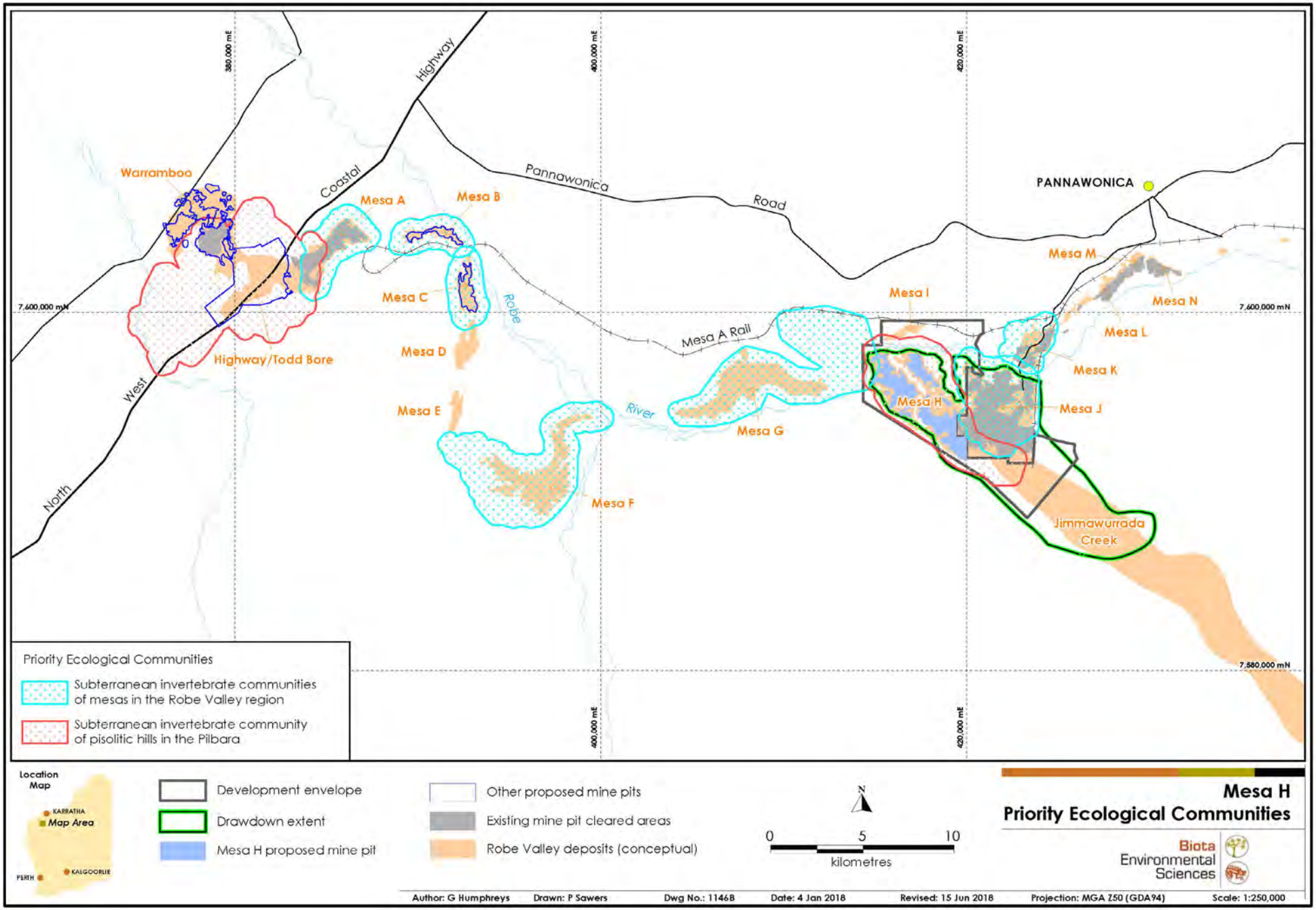

Figure 7.9: Mapped extent of troglofauna communities key receptors relative to the extent of direct impacts arising from the Mesa H project.

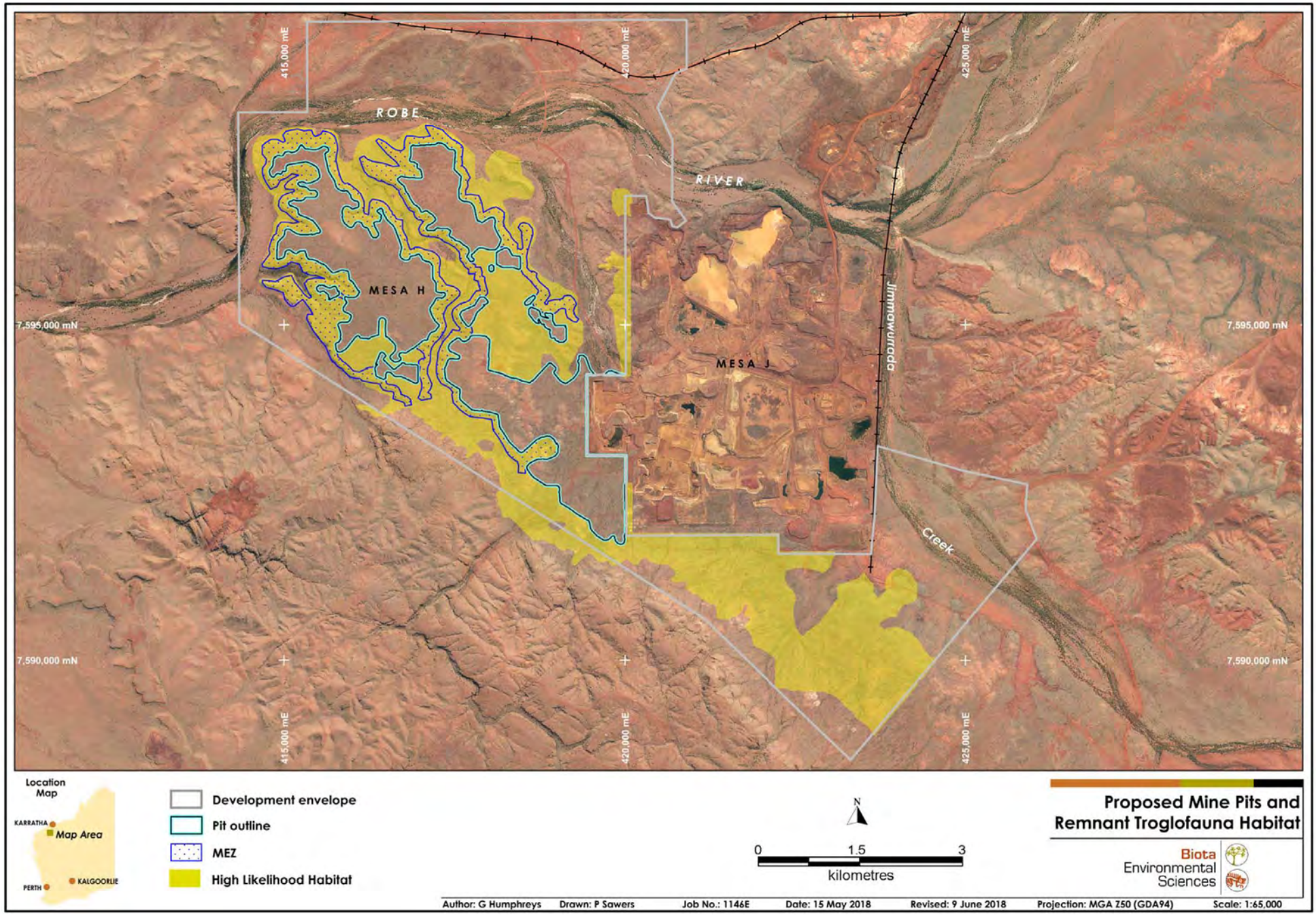

Figure 7.10: Extent of proposed mine pits and troglofauna habitat that will remain intact within the development envelope.

7.2.3 Indirect Impacts

In addition to the primary impact of habitat removal for mining pits, other indirect impacts could also affect troglofauna habitat retained within the development envelope outside of the pit outlines (as identified in Section 4.2.2). The ongoing suitability of habitat to support troglofauna in these ex-pit areas is linked to the maintenance of the existing biophysical conditions and processes that contribute to the stable and humid conditions that characterise troglofauna habitat. Indirect impact pathways have the potential to degrade habitat quality by reducing, or locally altering, these conditions and processes (Section 4.2.2).

The only indirect potential impact that will remain in operation for the long term will be the effect of the waste dumps arising from the proposal (Section 3.0; Figure 3.1). The waste dumps have the potential to reduce hydrological and nutrient inputs to underlying troglofauna habitat, which could in turn reduce habitat quality or animal abundance (Section 4.2.2; Figure 4.1). This impact mechanism has not, however, been empirically demonstrated to occur, and some limited data suggest that troglofauna persist beneath waste dumps in at least the medium term (with schizomid records from beneath waste dumps at nearby Mesa K, decades after their creation; Biota (2007)). Despite this, and in the interests of a precautionary assessment, a GIS spatial analysis was conducted for this assessment, intersecting the proposed waste dump footprints shown on Figure 4.1 with the records of all troglofauna species known from the development envelope. This analysis showed that not only are none of the 33 species known from Mesa H restricted in distribution to the waste dump footprints, but there are in fact no records of any troglofauna from either the Biota (2019) survey or desktop sources. This result, combined with the earlier observations that this impact process has not been clearly proven, suggest that the indirect impact of the waste dumps would not be significant (a Negligible impact with at least a Medium level of certainty, following the framework set out in Section 2.6.2).

Compared to direct impacts, the spatial extent, duration and magnitude of the impact footprints that could arise from the other indirect impact pathways are all relatively limited (Section 3.0). The majority of the indirect impact pathways can also be further mitigated through project design, environmental management controls and monitoring during project implementation. The primary focus for the assessment of the impacts then remains the direct impacts of the proposal on troglofauna.

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8.0 Conclusions

This impact assessment followed a series of defined criteria to identify species and ecological community key receptors of potential impacts from the Mesa H project. The impact sources and pathways arising from the proposal have been imposed on the known distributions of the species and community key receptors to identify potentially significant impacts. Sections 8.2 and 8.1 synthesise these outcomes with the models of subterranean fauna habitat presented earlier in Section 6.0, to arrive at an assessment of the risk of significant impacts on troglofauna and stygofauna respectively.

To recap Section 2.6.2, the framework used for reaching an assessment on the significance of the potential impacts was based on consequences and magnitudes of the impact for the receptors, and level of certainty:

Consequences of Impact	Criteria
Negligible	Displacement or loss of individual animals
Minor	Reduction in less than 10% of the known or inferred distribution and habitat extent
Moderate	Reduction in 10-50%[2] of the known or inferred distribution and habitat extent
Major	Loss of more than 50%[2] of the known or inferred distribution and habitat extent and/or change in conservation status of the species

Level of Certainty	Criteria
High	The outcome is quantifiable and can be predicted with confidence from a reasoned evidence base or the impact has previously occurred during similar mining developments
Medium	A reasonable body of data exists to predict the outcome and the outcome could reasonably be expected to arise from the current proposal
Low	The outcome has not previously occurred during similar mining developments, but expert opinion or other data suggest it might arise, or there is insufficient information to quantify the impact

A significant impact (after EPA (2016a)) is considered for the purposes of this review to be a Moderate or Major impact on a key receptor that is predicted to arise with High or Medium certainty (following the criteria in Section 2.6.2).

The concluding assessment is summarised for species and ecological community receptors for stygofauna and troglofauna in Sections 8.1 and 8.2, respectively.

8.1 Stygofauna

8.1.1 Species Receptors

A total of 32 species of stygofauna occur within the modelled dewatering extent for the proposal, which sets the spatial limit of predicted direct impacts.

Sixteen of these species are widely distributed in the region and not of listed conservation significance and the impact of the dewatering would not be significant at taxon level; assessed as Minor with a High degree of certainty (the extent and duration of the impact has been quantitatively predicted, approached conservatively and a sound data set exists to demonstrate the species' wider occurrence).

[2] Derived from the International Union for the Conservation of Nature (IUCN) Red List criterion whereby a species' conservation state would shift from the Least Concern category to Vulnerable (IUCN 2012).

Thirteen of the remaining 16 species are potential SREs that occur within the dewatering extent, with the other three being species of conservation significance that are addressed separately in Section 8.1.2 below.

Seven of the 13 potential SRE species occurring within the drawdown extent (*Areacandona* sp. 'BOS1039', *Pilbaracandona* sp. 'BOS526', *Megastygonitocrella unispinosa, Nedsia* sp. 'AMM026', Paramelitidae sp. 'AMP035', *Wesniphargus* sp. 'AMN004' and Neoniphargidae sp. 'B02') were recorded outside of the drawdown extent, or have demonstrated wider distributions in the locality, and would not be placed at significant risk to a change in their conservation status. Based on this, and the considerable extent of stygofauna habitat in the locality (Figure 6.2), the impact of the dewatering on these seven taxa would not be considered significant at species level (a Minor impact with a High degree of certainty).

Four of the remaining six potential SREs within the drawdown extent (Candoninae sp. 'BOS541', *Haptolana* sp. 'B01', Hydrobiidae sp. 2 and *Parastenocaris* sp. 'B28') were all recorded from the alluvial habitats of Jimmawurrada Creek at sites JW023 and JW024. With the wider distributions of other potential SRE stygofauna species in the survey area, it is unlikely that these species are truly restricted to the vicinity of these two sites, but even if this was the case, refugial habitat will be retained there at the peak of modelled dewatering. The predicted drawdown at these sites is moderate at a less than 7 m below the pre-mining water table level, leaving a saturated alluvial sequence varying between 5 and 17 m in thickness connected along the length of the creek at the peak of the proposal impact (Section 7.1.1). These refugia would also be additionally hydraulically connected and supplemented during flooding and seasonal recharge events along Jimmawurrada Creek. Based on this, and recognising that the species are likely to be more widely distributed, the impact of the dewatering on these four taxa would not be considered significant at species level (a Minor impact with a High degree of certainty).

The final two potential SRE species, Paramelitidae sp. 'AMP003' and Paramelitidae sp. 'AMP037', are currently known only from the drawdown extent from several areas that would be more significantly dewatered (drawdowns of 20 m and 4 m on the pre-mining water table respectively, and direct removal of habitat for Paramelitidae sp. 'AMP003'; Section 7.1.1). Both biological and physical evidence suggests connectivity of aquifer habitats and stygofauna populations to at least the local catchment scale, and that the apparent very small distributions of these two species is due to ecological sampling effects (Section 7.1.1). Assuming this is the case, these species would also not be significantly impacted (Minor impact with a High degree of certainty).

However, as this is a risk-based approach, the distribution of these singleton species cannot be assessed with confidence with the available data, and a more precautionary approach may be to assess the impact on the assumption that they are locally restricted and a greater proportion of their known distribution would be impacted by the dewatering, meaning the predicted impact would be significant (a Moderate or Major impact with a High degree of certainty).

8.1.2 Species of Conservation Significance

Three stygofauna species occurring within the drawdown extent are of formally listed conservation significance, but two (the Schedule 3 amphipods *Nedsia hurlberti* and *N. sculptilis*) also occur far more widely in the region. The dewatering extent would represent less than 10% of the known distributional extent for both species, and would thereby represent a Minor impact, in addition to the likelihood that refugia habitat will be retained locally within the alluvial aquifer of Jimmawurrada Creek (Section 7.1.2). Given the level of hydrogeological investigation completed to understand the predicted impacts and habitat change, and the distributional data for both species, the assessment of a Minor level of impact would be regarded as having a High degree of certainty, which would not be significant for most stygofauna species. However, given the Schedule listing of the two *Nedsia* taxa, it is possible that the impact may be elevated on that basis to be deemed significant.

The impact assessment context and predictions for the third conservation significant species, the Blind Cave Eel *Ophisternon candidum*, is broadly similar to that for *Nedsia hurlberti* and *N. sculptilis*: *O. candidum* was recorded from the same site as the two amphipod species (JW021) and appears to have a similar distribution, with additional records following the alluvial aquifer of the Jimawurrada-Bungaroo Creek system and into the Robe River aquifer (Section 7.1.2). It appears possible that all three species may occur further downstream on the Robe River. Sequencing data from multiple genes have also shown that the *O. candidum* specimen from drawdown extent site BC186 had a very low level of divergence from specimens at Cape Range; at the level typically seen within the same species (Foster and Humphreys 2011, Moore et al. 2018).

Quantitative predictions from hydrogeological modelling indicate that a substantial thickness of alluvial habitat between 5 and 17 m thick will remain saturated along Jimmawurrada Creek (Section 7.1.2). The species also occurs locally along the habitats of the Robe River – which will not be affected by the drawdown greater than natural water table fluctuations – and this distribution may extend downstream in the same system (with a population of apparently the same species also occurring at Cape Range). The consequences of the dewatering on that basis could therefore be assessed as a Minor impact (less than 10% of the known distribution) with Medium certainty. However, there are several factors that indicate the certainty with which impacts on *O. candidum* can be predicted differs from that for *Nedsia hurlberti* and *N. sculptilis*. These include, that:

- the species has a higher conservation status than the two amphipod species (listed at Commonwealth as well as State level); and
- the much larger body size of the species compared to the amphipods, which could affect the ability of individuals to move horizontally or vertically through cavities and interstices within saturated habitat.

These considerations suggest that additional caution is warranted regarding the confidence with which impacts can be predicted for *O. candidum*. A more precautionary position might be to assume that the same species only occurs within the local habitat extent within the Robe River valley (as shown in Figure 7.5) and that the quality and availability of this habitat would be reduced. Hydrogeological modelling suggests this scenario is unlikely, but this conservatism provides some balance to the uncertainties in predictions listed above. Within this framework then, the impact on *O. candidum* would be significant, amounting to a Moderate impact with High certainty.

8.1.3 Ecological Community Receptors

The impacts on both the Stygofaunal Community of the Bungaroo Aquifer PEC would not be considered significant within the framework used here (Minor (<10%); with a maximum impact on the PEC of 3.1% by area, with much of the drawdown being relatively minor compared to the scale of the aquifer).

8.2 Troglofauna

8.2.1 Species Receptors

A total of 33 troglofauna species are known from the development envelope. Six of these have been recorded from outside of the development envelope and have demonstrated wider distributions in at least the Robe River valley (Hubbardiidae sp. ‘SCH011’, Hubbardiidae sp. ‘SCH015/SCH016’, Armadillidae sp. ‘ISA056/ISA057’, ?*Nocticola* sp. 'West Pilbara Complex', Ptilidae sp. 1/'CP003' and Ptilidae sp. 'Robe Valley'/’CP002’; Section 5.2.2.2). At 751.5 ha in extent, the direct impact of the mine pits on these six taxa would not be significant at the species level (<10% of known distribution with a High degree of certainty).

The remaining 27 key receptor species have currently only been recorded from within the development envelope and their distributions cannot be assumed to extend beyond the habitat mapped at Mesa H. The consequence of the direct impact of the mine pits on these species can

be assessed on the basis of their record locations within Mesa H and the proportional habitat loss predicted for the proposal. Based on current data there are no records of 22 of the 27 species recorded at Mesa H from within the mine pit areas. Taken at face value, this would indicate a Negligible impact but it is also likely that the species actually occur more widely within the landform; including within the mine pit boundaries. Thus at present, those 22 species would not be significantly impacted by the proposal, but a more precautionary assessment may treat them as equivalent to the remaining seven species known to occur within the mine pits. Six of these latter species confirmed within the pits also have records within the MEZ or other habitat that will remain intact post-mining. While the direct impact of habitat removal for the mine pits on these species would still be considered significant (Moderate at 10-50% of their known distributions with a High degree of certainty), 1,745.8 ha of mapped troglofauna habitat, and more than 50% of the pre-mining volume, remaining unmined on completion of the project, which would include known records of 32 of the 33 troglofauna species known from Mesa H.

Only one of the 33 development envelope species has thus far been recorded solely from within proposed pits: the dipluran Japygidae sp. 'DJA011' (Section 5.2.2.2). It is possible that this species only occurs within these direct impact areas, which would represent a Major impact on this species (loss of more than 50% of the known or inferred distributional extent) and thereby a significant impact following EPA (2016a).

However, available biological and physical connectivity evidence indicates that it is far more likely that the species is distributed to at least the scale of the troglofauna habitat mapped for Mesa H and the impacts on it at taxon level is likely to be equivalent to the other key receptor species known only from the development envelope (remaining as a significant impact, but at the Moderate consequence level rather than Major).

8.2.2 Ecological Community Receptors

The cumulative and incremental impact of the proposal on the 'Subterranean invertebrate communities of mesas in the Robe Valley region' PEC is very minor at 0.07% of its original extent and would not be significant under the framework used in this assessment.

The cumulative and incremental loss of habitat from the 'Subterranean invertebrate community of pisolitic hills in the Pilbara' PEC is greater at 7.96% of its original extent, but this would still not be assessed as a significant impact following the framework here (>10% of known distribution with a High degree of certainty).

8.3 Summary of Significant Impacts

8.3.1 Stygofauna

While all stygofauna species and ecological community receptors occurring within the drawdown extent will be impacted to some degree, impacts on five of the 16 stygofauna species present have been identified here as being potentially significant. As discussed in Section 8.1.1 and 8.1.2, impacts on four of these five species would only be considered significant if a precautionary position is adopted to the assessment, which is the context within which these final conclusions are presented. The species in question comprise:

1. Paramelitidae sp. 'AMP003' and Paramelitidae sp. 'AMP037' (Moderate or Major impact with High certainty);
2. the Schedule 3 amphipods *Nedsia hurlberti* and *N. sculptilis* (a Minor impact with High certainty, but still considered significant given the species Schedule listing); and
3. Schedule 3 Blind Cave Eel *Ophisternon candidum* (Moderate impact with High certainty).

8.3.2 Troglofauna

There are 27 species of troglofauna currently known only from the development envelope and 22 of these do not have any records from within the mine pit areas, which, taken on the basis of existing data, would indicate they would not be significantly impacted (Section 8.2.1).

However, again in the interests of providing a precautionary assessment, all 27 could be considered likely to occur more widely within Mesa H, as the 22 species possibly also occur within habitat inside the mine pit boundaries. The troglofauna species and ecological community receptors that would be significantly impacted within this precautionary context then comprise:

1. 26 potential SRE troglofauna species known only from within the development envelope but with confirmed records outside of the mine pits (Moderate impact with High certainty); and
2. a single potential SRE troglofauna species known only from within the mine pits: the dipluran Japygidae sp. 'DJA011' (Major impact with High certainty).

8.3.3 Conclusions

While Section 8.3.1 and Section 8.3.2 above present precautionary assessments (consistent with EPA (2018)), a more realistic assessment is provided here in closing. These conclusions adopt a balanced appraisal based on the combined survey and desktop data sets, and the body of biological and physical evidence collated in this assessment for both ecological groups.

That more realistic context would suggest that for:

- Stygofauna: Impacts 1, 2 and 5 above should be revisited, with impacts on four of the stygal species; Paramelitidae sp. 'AMP003', Paramelitidae sp. 'AMP037', *Nedsia hurlberti* and *N. sculptilis* (points 1 and 2 of Section 8.3.1) no longer assessed as significant (Minor impacts with High certainty); and
- Troglofauna: the impact on the troglofauna species known only from within the mine pits; Japygidae sp. 'DJA011' (point 5 of Section 8.3.2) should still be considered significant, but should be consolidated with the other 26 troglofauna taxa considered under point 4 of Section 8.3.2 as a Moderate impact with High certainty.

In closing then, the significant impacts on subterranean fauna from the Mesa H proposal comprise:

- the impact of groundwater drawdown arising from the dewatering on the Schedule 3 Blind Cave Eel *Ophisternon candidum* (a Moderate impact with High certainty); and
- the impact of habitat removal for mine pits on 27 potential SRE troglofauna species known only from within the development envelope but with confirmed records outside of the mine pits (Moderate impact with High certainty).

While these impacts would be considered significant (after EPA (2016a)), neither of the impacts would be assessed as Major under the framework used here (Loss of more than 50% of the known or inferred distribution and habitat extent and/or change in conservation status of the species), and both *Ophisternon candidum* and the 27 species of troglofauna will remain represented in subterranean fauna habitat outside of the proposal's impact footprint after the closure of the Mesa H operations.

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9.0 Glossary

Congener	Belonging to the same genus.
Development envelope	The predicted maximum ground disturbance area for the proposed development.
EIA	Environmental Impact Assessment.
EPA	Environmental Protection Authority of Western Australia.
GIS	Geographical Information System.
Ground disturbance	Any construction or operational ground disturbing activity that results in the removal of native vegetation, landforms and/or the disturbance of topsoil.
Indicative arrangement	The current conceptual design for proposed pit locations and boundaries, overburden storage areas and infrastructure.
Interstices	An opening or space, especially a small or narrow one between mineral grains in a rock or within sediments or soil.
Receptor	A subterranean fauna species, ecological community or habitat occurring or likely to occur within the development envelope that may be impacted by the proposal.
Locality	The area encompassed within a 40 km buffer on the development envelope.
Short-Range Endemic (SRE)	A species that has a naturally small distribution and is often characterised by having poor dispersal capabilities, confinement to disjunct habitats and low fecundity.
Stygobite / Stygofauna	Obligate groundwater fauna.
Taxon	A group of organisms identified as comprising a taxonomic unit (e.g. a species) (“taxa” = plural).
Taxonomy	Theory and practice of biological classification.
Troglobite / Troglofauna	Species living obligatory in caves; also blind, depigmented and often having an elongate body morphology.
Troglomorphic	Pertaining to morphological, behavioural and physiological characters that are convergent in subterranean populations (Christiansen 1962).
Troglophilic / Troglophile	Species able to live and reproduce underground as well as in the surface environment (Wilkens et al. 2000).
Vug	A small cavity in a rock or vein, often with a mineral lining of different composition from that of the surrounding rock.

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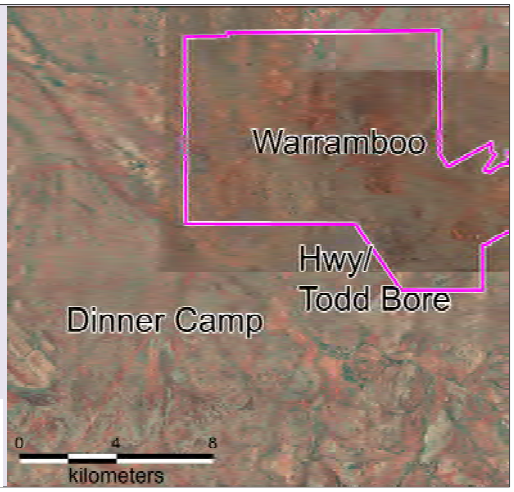
Appendix 1

Conceptual Flowchart of Troglofauna Habitat CID Modelling

Conceptual Methodology for Subterranean Fauna Habitat Modelling

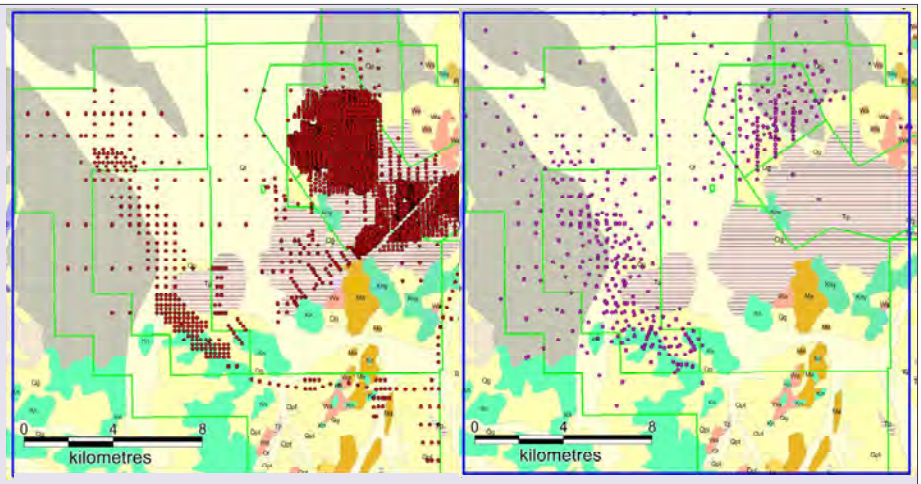
Warramboo/Highway/Tod Bore, Q1 2018

1. Define the location



2. Collate available data sources

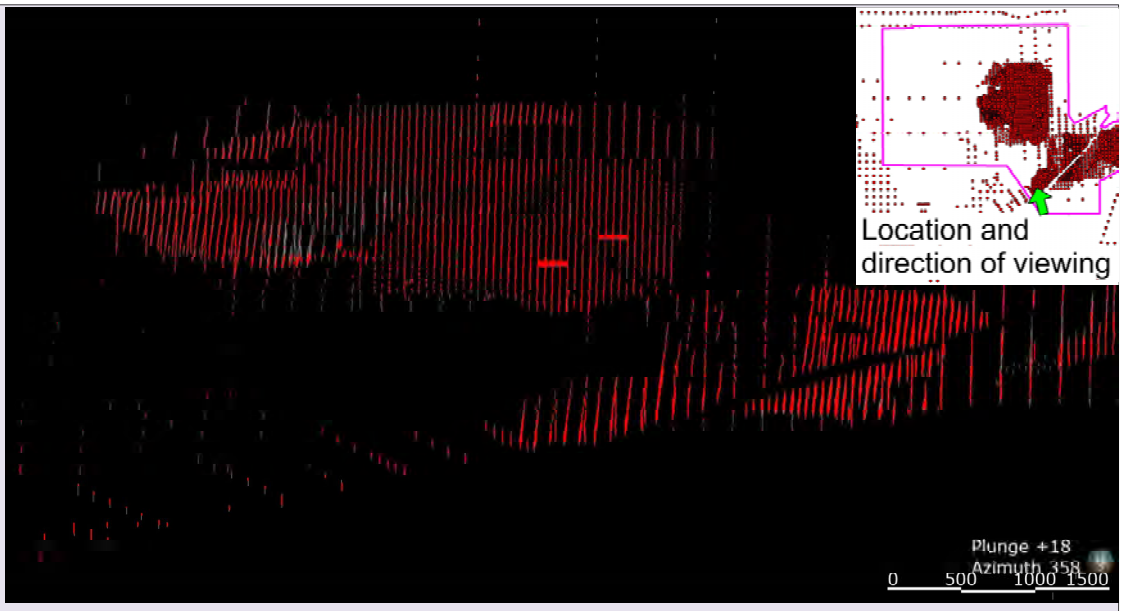
- geological mapping
- geophysical mapping
- downhole drilling information
- geotechnical information
- core data (if available), including photos



Red dots = geological drill logs available Historical publicly available data (DMIRS)

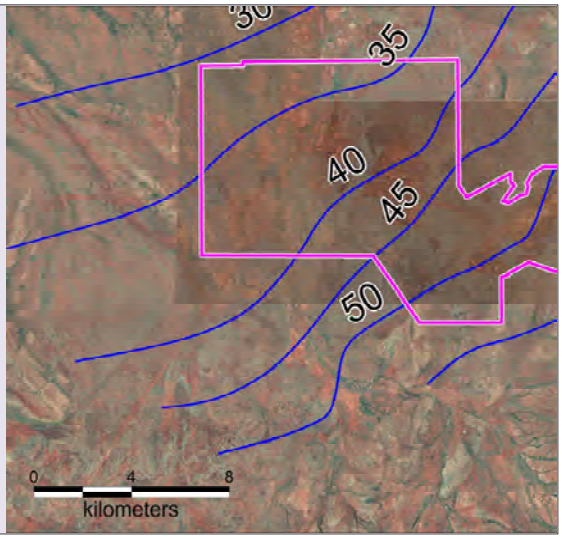
3. Calculate habitat thickness at each data point (drillhole)

In this case habitat was channel iron deposits (CID)



Cross section shows a 3D tilted image of CID thickness in each hole (red bars)

4. Establish water table levels using groundwater contour data

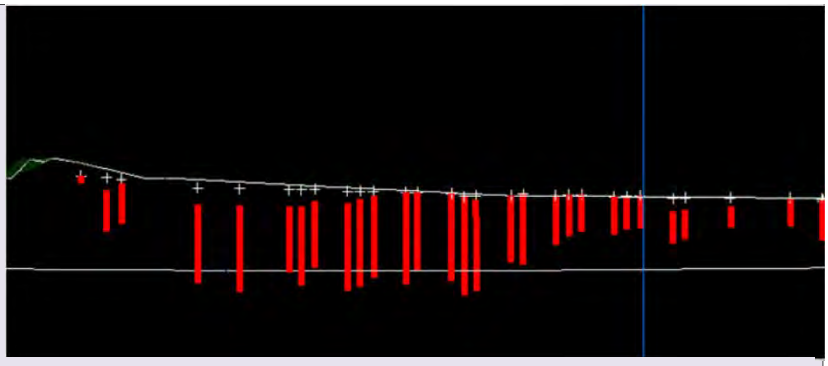


Mesa A Hub proposed Part IV boundary

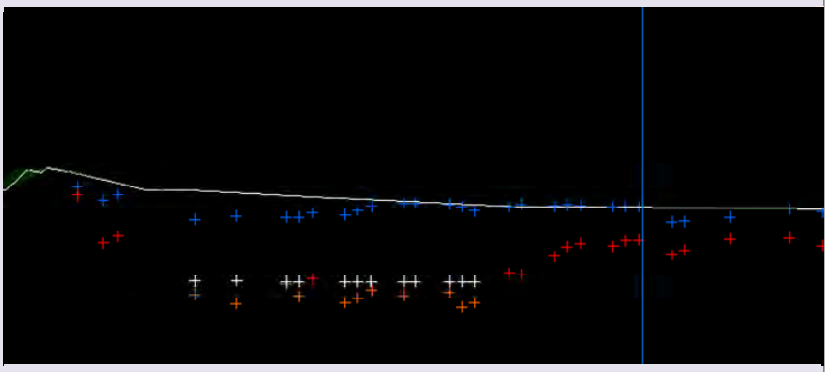
pre-mining water contours

5. Calculate thickness of above water table CID

Troglofauna don't reside below the water table



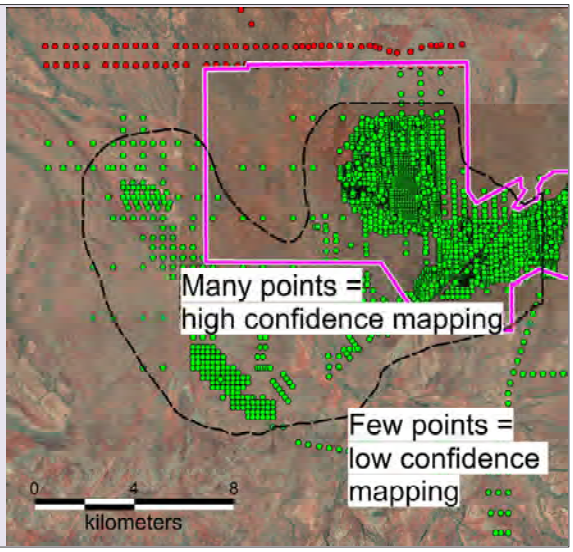
Cross section showing CID depth (red bars) in relation to the water table (lower white line)



Resulting above water table CID depth once below water table is removed. Top of CID interval (blue), bottom of CID interval (red) and water table (white).

6. Determine high and low confidence areas

Based on drill hole density



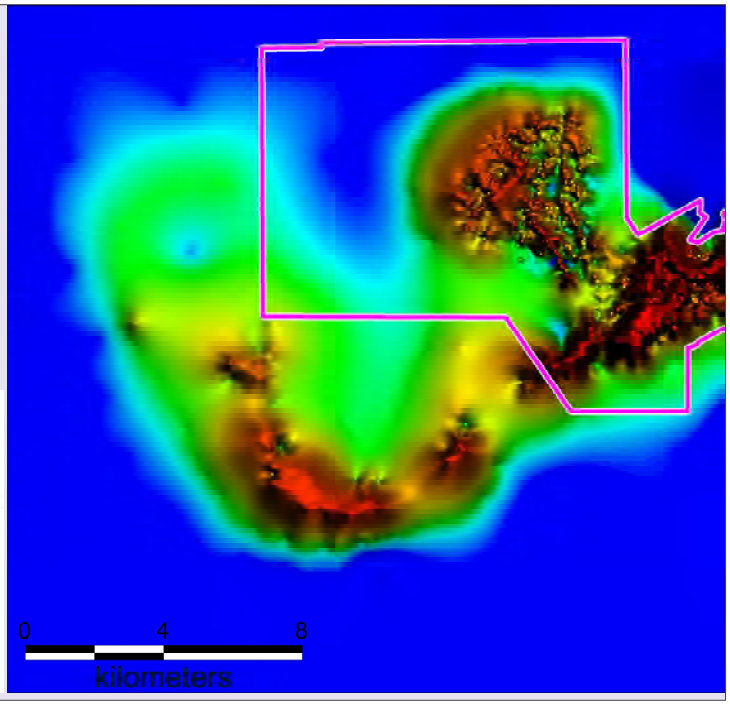
high confidence interval

Mesa A Hub proposed Part IV boundary

Drill holes

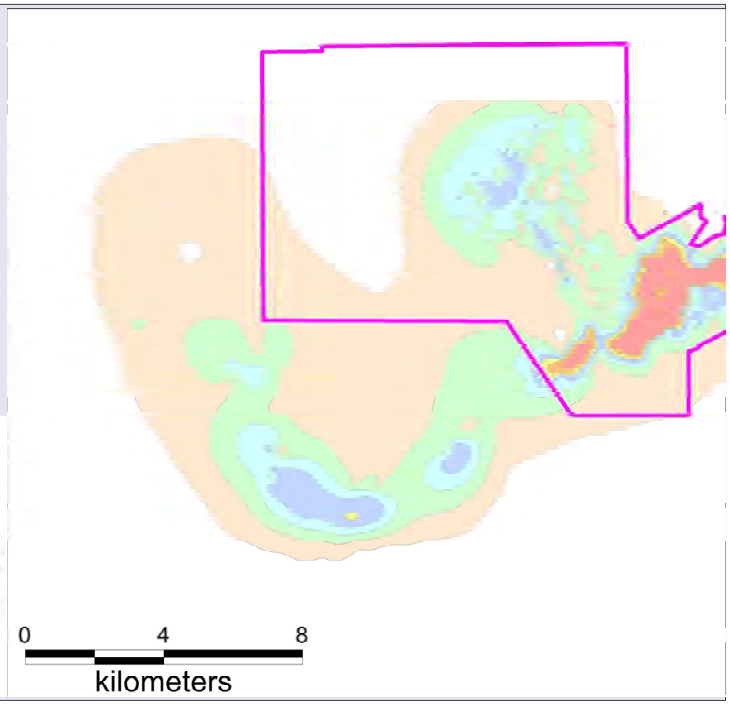
7. Create 3D surface/ raster map of above water table CID thickness

Use spatial interpolation of point data combined with confidence information



8. Produce CID contour map

Use pre-defined categories to split the 3D surface/ raster image into sections

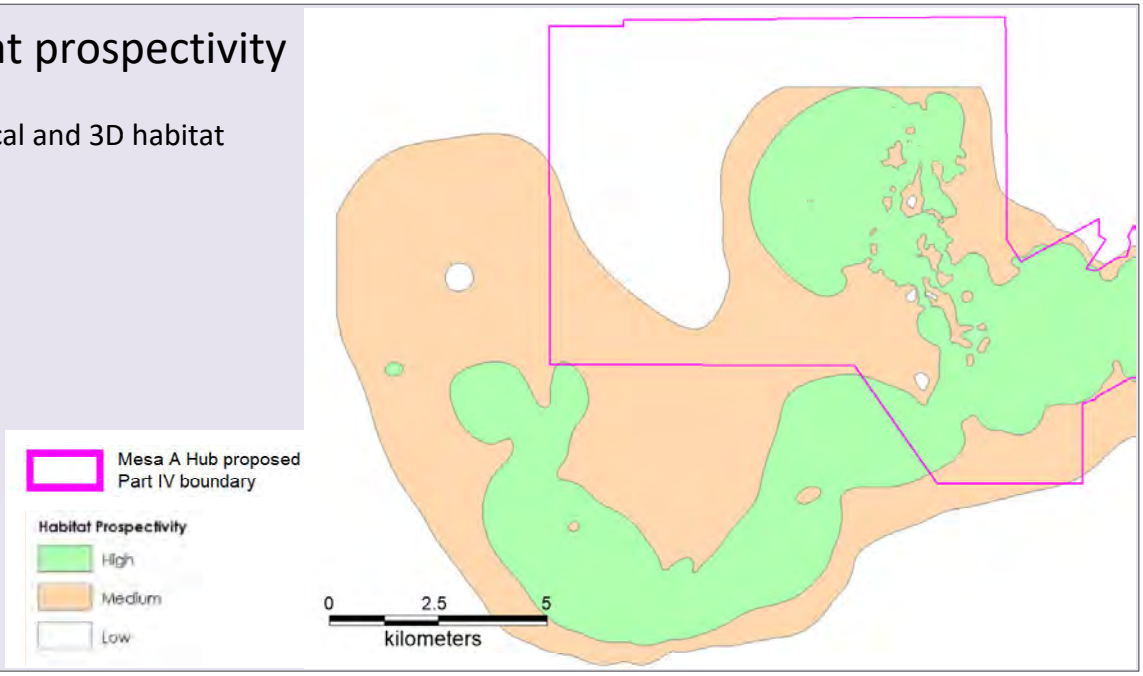


10. Determine habitat prospectivity categories

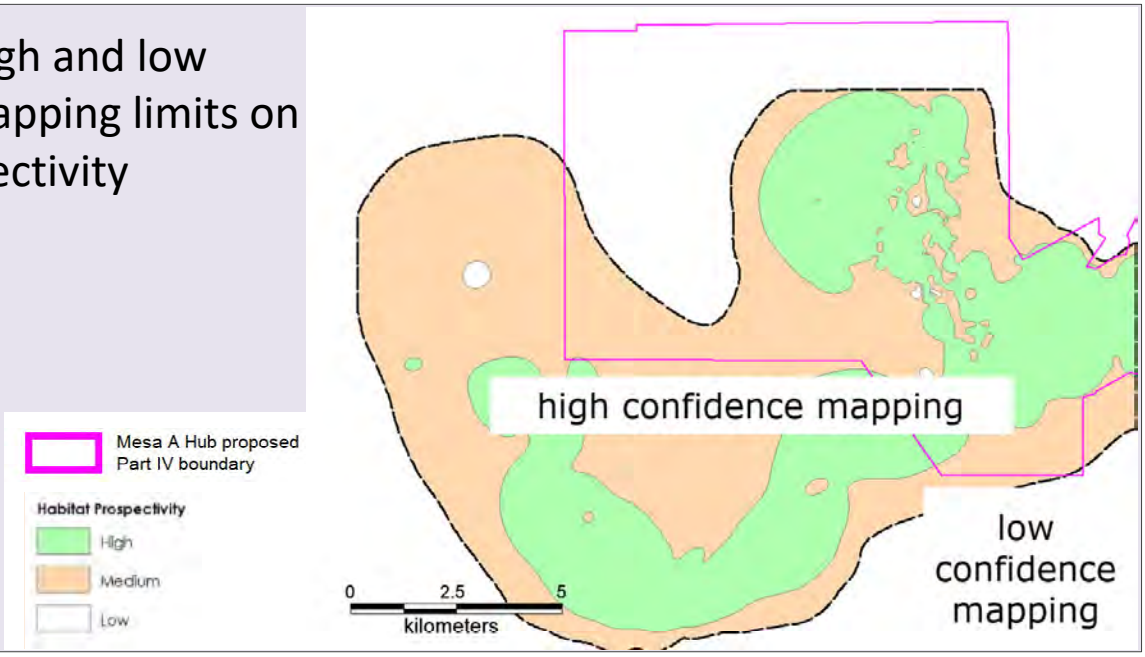
Habitat prospectivity	Geological Unit
High	Robe Pisolite (TP; >5m thickness)
Medium	Robe Pisolite (TP; 1-5m thickness)
Low	Robe Pisolite (TP; <1m thickness)

11.Map habitat prospectivity

Amalgamate geological and 3D habitat thickness maps



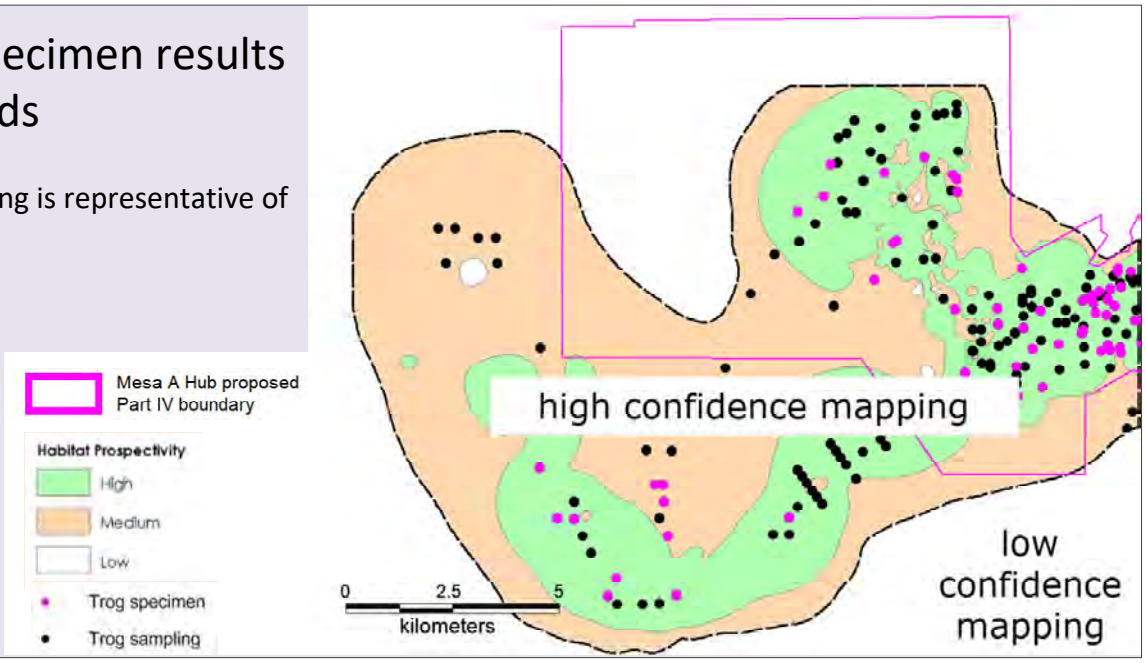
12. Overlay high and low confidence mapping limits on habitat prospectivity mapping



13. Overlay specimen results and null records

Validate that modelling is representative of actual results

*Note that troglofauna records outside the high confidence interval are located in a different geological habitat which requires a separate modelling analysis.



eDNA Metabarcoding Preliminary Report: Blind Cave Eel survey in the Pilbara WA

Prepared for

Rio Tinto
Level 24, 152-158 St Georges Terrace
Perth, WA, 6000

Prepared by

Trace and Environmental DNA (TrEnD) Laboratory

Curtin University

21st March 2018

Report Authors: Dr Nicole White and Prof. Michael Bunce (TrEnD laboratory)

Signature:

(Dr Nicole White) **Date: 21st March 2018**

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Executive Summary:

Overall Project objective:

The aim of this pilot project was to use an environmental DNA (eDNA) metabarcoding approach to determine presence/absence of Blind Cave Eel (*Ophisternon candidum*) from within and outside the Mesa H project area in the Pilbara region of Western Australia. The data was to be incorporated into an environmental impact statement (EIS) by Rio Tinto. This interim report documents the results to date and will be superseded by the final report on the project which involves replication of data and design of new assays for eel detection.

Outputs:

- Two collection trips in 2017 were conducted (i) June 2017: 91 water samples from 18 bores were collected and filtered by Michelle Guzik (University of Adelaide. (ii) December 2017: 85 water samples were collected and filtered by Jason Alexander (Biota) from 16 bores and one open surface water sample from the Robe River (5x 1 liter replicates). The TrEnD lab at Curtin University successfully isolated DNA from 122 of these samples.
  .
- As a preliminary first-pass to determine the presence of Blind Cave Eel (*O. candidum*) from 122 water membranes the TrEnD labs Fish 16S assay was used. Although this DNA assay (Fish 16S) isn't specific for Blind Cave Eel our previous research has demonstrated successful amplification of eel DNA.

- The June 2017 water membranes detected the possibility of Blind Cave Eel (*O. candidum*) from bore JW021. The December 2017 water membranes detected the possibility of Blind Cave Eel (*Ophisternon candidum*) from bore 25 and bore RR1. This result is preliminary in nature – detections are currently un-replicated. Additional sites could yield eel signatures as assays are repeated and modified.

- Blind Cave Eel (*O.candidum*) tissue was sourced from the Western Australia Museum (WAM) for comparative purposes. We have sequenced the 16S barcode from this sample.

- Comparisons of the potential Blind Cave Eel (*O. candidum*) DNA sequences from bore JW021 with the National Centre for Biotechnology Information (NCBI) database showed an 85.9% match to *O. bengalense*, an eel-like fish found in northern Australia and 85.9% match to *Synbranchid* sp., a freshwater eel-like fish.

- Comparisons of the potential Blind Cave Eel (*O. candidum*) DNA sequences from bore 25 and RR1 with the NCBI database showed an 87.7%% match to *O. bengalense* and 87.1% match to *Synbranchid* sp.

- Comparisons of the potential Blind Cave Eel (*O. candidum*) DNA sequences from bore JW021, 25 and RR1 with the reference sample obtained from the WAM showed 100% match to the DNA sequences obtained from bore JW021 and 97% match to the DNA sequences from bore 25 and RR1. The genetic sequences in bores 25 and RR1 are 100% similar to each other but distinctly different from the WAM reference or the JW021 sequence. The significance of this genetic difference is unknown.

Recommendations:

- An eDNA approach using a Fish 16S assay has successfully detected Blind Cave Eel from three bores within and outside the Mesa H project area. The sensitivity and reproducibility of these findings still need to be confirmed by the ongoing research program. The successful detection of Blind eel from a non-invasive sample speaks to the promise of eDNA approaches for the detection of taxa in subterranean environments.

1. Introduction

eDNA refers to all genetic material that is recovered from environmental substrates (such as water or sediment). DNA directly from an organism (e.g. microorganisms) as well as trace amounts of DNA that are shed by all organisms is collectively termed eDNA. This preserved, but often degraded, genetic material provides a means to audit species composition and communities at a given location. When combined with recently developed DNA sequencing technologies (termed 'next generation' or 'high-throughput' sequencing), eDNA can provide a wealth of information for studies of introduced marine pests (IMP), biodiversity surveys, food web dynamics, and diet analysis.

Potential applications for monitoring using eDNA include:

- Biosecurity: to detect the presence/absence of introduced species
- Environmental Impact Assessment: baseline/ongoing monitoring and assessment; audit
- Conservation: to detect the presence/absence of threatened species

Rio Tinto has partnered with the Trace and Environmental DNA (TrEnD) Laboratory at Curtin University to develop eDNA tools for Blind Cave Eel (*Ophisternon candidum*) as a means to use DNA-based bio surveys in groundwater monitoring and management.

eDNA sampling has benefits over other traditional survey methods including:

- highly cost-effective monitoring compared to traditional survey methods
- rapid sample collection that is non destructive to habitats, flora and fauna
- non-reliance on individuals with taxonomic expertise, provision of consistent results between monitoring programs, independent of surveyors

The objectives of this project, albeit preliminary, were to use an environmental DNA (eDNA) metabarcoding approach to determine the presence/absence of Blind Cave Eel (*Ophisternon candidum*) a threatened species within the groundwater systems of the Pilbara in Western Australia, specifically the Mesa H area (Rio Tinto). The data was to be incorporated into an environmental impact statement.

2. Methods and Samples

Water samples were collected by Michelle Guzik (University of Adelaide; June 2017) and Jason Alexander (Biota; December 2017) and filtered using a Sentino pump (Pall corporation) as outlined in TrEnD standard operating procedures (available upon request). Turbidity in the water resulted in varying volumes of water that could be filtered between the bores and replicates (see table 1 below and attached electronic data file).

Table 1

Bore water collected by Michelle Guzik (June 2017)								
AWFS ID	**Bore Hole**	**Collection me**	**Date filtered**	**Sample 1 (A)**	**Sample 2 (B)**	**Sample 3 ©**	**Sample 4 (D)**	**Sample 5 (E)**
AWFS-I17-106 (A, B, C, D, E)	JIMWE003	Bailer	13/06/2017	250mL	750mL	1L	1L	650mL
AWFS-I17-107 (A, B, C, D, E)	JW021	Bailer	13/06/2017	700mL	700mL	600mL	600mL	800mL
AWFS-I17-108 (A, B, C, D, E)	BC186	Bailer	13/06/2017	1L	1L	1L	1L	1L
AWFS-I17-109 (A, B, C, D, E)	JW024	Bailer	13/06/2017	1L	1L	1L	700mL	1L
AWFS-I17-110 (A, B, C, D, E)	BC276	Bailer	14/06/2017	1L	500mL	500mL	500mL	250mL
AWFS-I17-111 (A, B, C, D, E)	BC667	Bailer	14/06/2017	250mL	250mL	250mL	1L	1L
AWFS-I17-112 (A, B, C, D, E)	BCP001	Bailer	14/06/2017	250mL (colle	250mL (colle	250mL	1L	1L
AWFS-I17-113 (A, B, C, D, E)	BC458	Bailer	15/06/2017	1L	1L	1L	1L	1L
AWFS-I17-114	Robe River	Container	14/06/2017	700mL	NA	NA	NA	NA
AWFS-I17-115 (A, B, C, D, E)	BUNWO1108	Bailer	15/05/2017	700mL	1L	1L	1L	500mL
AWFS-I17-116 (A, B, C, D)	BUNWB13	Bailer	15/05/2017	1L	750mL	750mL	750mL	NA
AWFS-I17-117 (A, B, C, D, E)	BUNWB09	Bailer	15/06/2017	1L	800mL	800mL	800mL	1L
AWFS-I17-118 (A, B, C, D, E)	BC401	Bailer	16/06/2017	1L	600mL	500mL (colle	1L	1L
AWFS-I17-119 (A, B, C, D, E)	BUNWB08	Bailer	16/06/2017	1L	1L	1L	1L	1L
AWFS-I17-120 (A, B, C, D, E)	BC225	Bailer	15/06/2017	1L	1L	1L	1L	1L
AWFS-I17-121 (A, B, C, D, E)	JIMWE004	Bailer	16/06/2017	1L	1L	1L	800mL	800mL
AWFS-I17-122 (A, B, C, D, E)	BC292	Bailer	16/06/2017	250mL	1L	1L	1L	1L
AWFS-I17-123 (A, B, C, D, E)	BUNWO0773	Bailer	16/06/2017	500mL	500mL	500mL	1L	1L
AWFS-I17-124 (A, B, C, D, E)	PZ11BUN008	Bailer	16/06/2017	600mL	250mL	250mL	250mL	250mL

Bore water collected by Jason Alexander (Biota; December 2017)							
AWFS ID	**Site**	**Easting**	**Northing**	**Date**	**Hole depth**	**Drilled**	**Notes**
AWFS-I18-001 (A,B,C,D,E)	25	432152	7602229	2017-12-13			
AWFS-I18-002 (A,B,C,D,E)	31	432929	7603179	2017-12-13			
AWFS-I18-003 (A,B,C,D,E)	200/Dave Bore	392512.032	7607435.55	2017-12-12			PSS089
AWFS-I18-004 (A,B,C,D,E)	BC186	429578	7587212	2017-12-13			Confirmed eel record 200
AWFS-I18-005 (A,B,C,D,E)	BC401	443563	7574126	2017-12-13			
AWFS-I18-006 (A,B,C,D,E)	Budgie Bore	382494.738	7615587.3	2017-12-12			
AWFS-I18-007 (A,B,C,D,E)	JW023	426138	7590140	2017-12-13			Confirmed Eel record 201
AWFS-I18-008 (A,B,C,D,E)	JW024	427126	7590154	2017-12-13			Confirmed Eel record 201
AWFS-I18-009 (A,B,C,D,E)	MB16MEC0009	393590.062	7601144.51	2017-12-12	43	Drilled 2016	
AWFS-I18-010 (A,B,C,D,E)	MB17MEH0008	417119.5	7600417	2017-12-14	18	29-Aug-17	
AWFS-I18-011 (A,B,C,D,E)	MB17MEH0010	416440	7599848	2017-12-12	30	31-Aug-17	
AWFS-I18-012 (A,B,C,D,E)	MB17MEH0015	416041	7597690	2017-12-14	37	3-Nov-17	
AWFS-I18-013 (A,B,C,D,E)	RR1	419176	7597904	2017-12-14	17.2		depth to water 1.87
AWFS-I18-014 (A,B,C,D,E)	MB16MEC0008	393565	7600580	2017-12-12	36	Drilled 2016	
AWFS-I18-015 (A,B,C,D,E)	MB17MEH0007	417663.8	7600421	2017-12-14	30	29-Aug-17	
AWFS-I18-016 (A,B,C,D,E)	MB17MEH0009	416435.8	7599848	2017-12-12	43	30-Aug-17	
AWFS-I18-017 (A,B,C,D,E)	Control	424478	7597147	2017-12-11			

eDNA was extracted using Qiagen Blood & Tissue DNeasy kits in the TrEnD laboratory at Curtin University in dedicated facilities (inclusive of laboratory clean rooms) suited for eDNA workflows. eDNA derived from the Fish 16S assay was amplified using PCR, followed by sequencing on an Illumina MiSeq in the TrEnD Laboratory. Negative laboratory controls were included (and sequenced if identified as positive) to control for environmental laboratory contamination.

The 16S DNA sequences recovered were compared to the National Centre for Biotechnology Information (NCBI) database for taxonomic identification and to reference Blind Cave Eel (*Ophisternon candidum*) obtained from the WAM (P.34817-001).

3. Results and Discussion

The following table outlines the taxonomic assignments from each bore water sample for which suspected Blind Cave Eel (*Ophisternon candidum*) was amplified and sequenced. Taxonomic assignments are to genera and species with the per cent match genetic similarity to the DNA sequences contained on the reference database (NCBI). At the time of this report, the taxonomic assignments for the DNA sequences obtained from the bore water samples (i.e. DNA 'barcodes') are listed in the table below and the electronic file accompanying this report. The environmental laboratory controls for this work were identified as negative and not included in the Table.

Table 2

Taxonomic Assignments			
AWFS ID	**Bore**	**% match (NCBI)**	**Species**
AWFS-I17-107B	JW021	85.9	Synbranchid sp. VietNam-TC-2002 haplotype 1
		85.9	Ophisternon bengalense voucher MRS haplotype OB1
AWFS-I18-001A	25	87.1	Synbranchid sp. VietNam-TC-2002 haplotype 1
		87.1	Ophisternon bengalense voucher MRS haplotype OB1
AWFS-I18-013A	RR1	87.1	Synbranchid sp. VietNam-TC-2002 haplotype 1
		87.1	Ophisternon bengalense voucher MRS haplotype OB1
AWFS-I18-013C	RR1	87.1	Synbranchid sp. VietNam-TC-2002 haplotype 1
		87.1	Ophisternon bengalense voucher MRS haplotype OB1
AWFS-F18-005 BlindEel_WAM P.34817-001		85.9	Synbranchid sp. VietNam-TC-2002 haplotype 1
		85.9	Ophisternon bengalense voucher MRS haplotype OB1

Fish DNA was detected in a number of sampling locations. This preliminary report is only reporting on, and presenting data from, those bores that yielded eel DNA.

Comparisons of the potential Blind Cave Eel (*O. candidum*) DNA sequences from bore JW021 with the NCBI database showed an 85.9% match to *O. bengalense*, an eel-like fish found in northern Australia and 85.9% match to *Synbranchid* sp., a freshwater eel-like fish (see Table 2). The DNA barcode recovered from JW021 was a 100% match to the reference DNA sequence from the WAM Blind Cave Eel (*O. candidum*) sample. Eel DNA was recovered in one of two replicates from bore JW021

Comparisons of the potential Blind Cave Eel (*O. candidum*) DNA sequences from bore 25 and RR1 with the NCBI database showed an 87.7%% match to *O. bengalense* and 87.1% match to Synbranchid sp. (see table 2). The DNA barcode recovered from bore RR1 and bore 25 was a 97% match to the reference DNA sequence from the WAM Blind Cave Eel (*O. candidum*) sample. Eel DNA was recovered in two of the five replicates from bore RR1 and one of five replicates from bore 25.

The genetic sequences in bores 25 and RR1 are 100% similar to each other but distinctly different from the WAM reference or the JW021 sequence. The significance of this genetic difference is

unknown it may represent variation within the species or a distinct lineage. There is a distinctive DNA 'insertion' in the sequences obtained from JW021 and the WAM reference that is the major distinguishing feature (see Figure 1)

Figure 1: 16S DNA sequences from bore JW021, RR1, 25 and *O. candidum* (WAM P.34817-001)

4. Findings, Recommendations and Concluding remarks

The Fish 16S metabarcoding assay utilised on the bore water samples collected in June and December 2017 detected the potential Blind Cave Eel (*O. candidum*) in three of 34 bores. To our knowledge this represents the first time an eDNA based approach has been used in the ground water system(s) in the Pilbara for the detection of a restricted species. The gaps in the reference databases often prevent definitive assignments to genus and/or species at the time of this report. Although comparisons of the suspected Blind Cave Eel (*O. candidum*) DNA sequences with the DNA sequences obtained from a tissue sample of Blind Cave Eel (*O. candidum*) from the WAM indicate the strong likelihood of Blind Cave Eel (*O. candidum*). Current laboratory work is underway to sequence the complete mitochondrial genome from the WAM reference sample and develop a metabarcoding assay specific for Blind Cave Eel (*O. candidum*). Once completed, the Blind Cave Eel (*Ophisternon candidum*) metabarcoding assay will be used to re-screen the 122 water samples to validate the findings from the Fish 16S assay and potentially find additional bores that may contain Blind Cave Eel (*O. candidum*).

The DNA yields recovered from the bores was low and, as expected, not every replicate from positive wells yielded a positive detection. The sensitivity of the assays and the level of replication appropriate is yet to be determined for bores in the Pilbara. The development of additional assays and optimisation of existing assays (and sampling protocols) is ongoing and will likely enhance the likelihood of detections.

5. Appendices and additional information

- An electronic file titled; Appendix_BlindCaveEel_March2018.xlsx is attached to this report.

- Additional information on sampling and methods are available from TrEnD upon request however the exact nature of the assays and workflow are proprietary.

- Below is a list of acronyms, abbreviations and definitions that may apply to aspects of this report.

% value in data	Represents the percentage similarity of a DNA sequence recovered from a sample compared to reference sequences in a database (e.g. compared to DNA databases such as GenBank or references generated in-house)
(x) value in data	Represents the frequency the % value was recorded in the dataset
16S rRNA	The 16S rRNA refers to a conserved gene region of mitochondrial DNA, which codes for a subunit of the ribosome. 16S rRNA is found in all eukaryotes making it a good candidate for DNA barcoding and is used extensively to detect vertebrate taxa such as fish and mammals.
18S rRNA	The 18S rRNA refers to a conserved gene region of nuclear DNA, which codes for a subunit of the ribosome. 18S rRNA is found in all eukaryotes making it a good candidate for DNA barcoding
18S IMS reference database	Reference 18S rRNA sequences of invasive marine species that are available in DNA databases
Assay	In the context of metabarcoding an assay is a molecular test (using PCR) that is implemented to target a group of taxa within a mixed biological substrate. It is akin to using a magnet to selective enrich for needles (the target) in the context of a haystack (the total DNA from a sample).
COI	The gene region that is being used as the standard barcode for almost all animal groups is a 648 base-pair region of the mitochondrial cytochrome c oxidase 1 gene ("CO1"). COI is proving highly effective in identifying birds, butterflies, fish, flies and many other animal groups. COI is not an effective barcode region in plants because it evolves too slowly, but two gene regions in the chloroplast, matK and rbcL, have been approved as the barcode regions for plants
CO1 IMS reference database	Reference COI sequences of invasive marine species that are available in DNA databases
DNA	Deoxyribonucleic Acid (DNA) is the hereditary material that contains the genetic information of an organism
DNA metabarcoding	Is a genetic technique that simultaneously amplifies and sequences barcode regions

	(e.g. COI, 18S, 16S) of many different species in parallel
eDNA	Environmental DNA (eDNA) refers to genetic material that is recovered from an environmental substrate (e.g. water, sediment, air)
eukaryotes	An organism where cells contain a nucleus surrounded by a membrane and has the DNA bound together by proteins (histones) into chromosomes. The cells of eukaryotes also contain an endoplasmic reticulum and numerous specialised organelles not present in prokaryotes, especially mitochondria, golgi bodies, and lysosomes
Fisheries	Department of Primary Industries and Regional Development, Fisheries Division, Aquatic Biosecurity Section
GenBank	Publically available repository of genetic information. Contains the barcode information of genes that have previously been sequenced
Genome	A genome is all the genetic material of an organism. It consists of DNA (or RNA in RNA viruses). The genome includes both the genes (the coding regions) and the noncoding DNA. In eukaryotes it refers to the genomes of the nucleus, mitochondria and chloroplasts. In prokaryotes, there is a single genome (as they do not contain mitochondria or chloroplasts)
Illumina MiSeq	Next generation sequencing platform developed by the company Illumina
IMP	Introduced marine pests
IMS	Introduced marine species
Metabarcoding assay	A PCR reaction using a specific set of primers that simultaneously amplifies the same gene target from multiple species
Mitochondria	The mitochondrion (plural mitochondria) is a double membrane-bound organelle found in all eukaryotic organisms, although some cells in some organisms may lack them (e.g. Red blood cells). It contains its own genome
Mitogenomes	Refers to the mitochondrial genome
NGS	Next generation sequencing or second generation sequencing refers to massively parallel sequencing technology, as opposed to first generation sequencing or sanger sequencing where only a single template is sequenced at one time
Nucleotide	A compound consisting of a nucleoside linked to a phosphate group. Nucleotides form the basic structural unit of nucleic acids such as DNA
PCR	Polymerase chain reaction (PCR) is the technique that is used to amplify (akin to photocopying DNA) specific regions of the genome from specific groups of taxa
Primer	A short DNA strand (≈20bp in size) used in PCR to target particular groups of organisms and genes. Two of them are required for PCR (a forward and a reverse)
Primer binding site	A primer-binding site is the target region of a genome where the primer attaches to start replication. The primer binding site is on one of the two complementary strands of a double-stranded nucleotide polymer, in the strand which is to be copied, or is within a single-stranded nucleotide polymer sequence
prokaryote	Any of the typically unicellular microorganisms that lack a distinct nucleus and

	membrane-bound organelles and that are classified as a kingdom (Prokaryotae syn. Monera) or into two domains (Bacteria and Archaea)
RNA	Ribonucleic acid (RNA) is a polymeric molecule implicated in various biological roles in coding, decoding, regulation, and expression of genes
rRNA	ribosomal ribonucleic acid is the RNA component of the ribosome, and is essential for protein synthesis in all living organisms
Sequence	DNA sequencing is the process of determining the precise order of nucleotides within a DNA molecule. It includes any method or technology that is used to determine the order of the four bases—adenine, guanine, cytosine, and thymine—in a strand of DNA
Shotgun sequencing	Refers to randomly sequencing short pieces of DNA (≈150bp in size) after shearing or cutting DNA (e.g. fragmenting a genome)
TrEnD	Trace and Environmental DNA laboratory, Curtin University

Follow-up Report: eDNA metabarcoding for Blind Cave Eel survey in the Pilbara WA

Prepared for

Rio Tinto
Level 24, 152-158 St Georges Terrace
Perth, WA, 6000

Prepared by

Trace and Environmental DNA (TrEnD) Laboratory

Curtin University

13th August 2018

Report Authors: Dr Nicole White (TrEnD laboratory)

Signature:

Dr Nicole White **Date:** **13 August 2018**

Disclaimer:
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Executive Summary:

Overall Project objective:

The aim of this pilot project was to use an environmental DNA (eDNA) metabarcoding approach to determine presence/absence of Blind Cave Eel (*Ophisternon candidum*) from within and outside the Mesa H project area in the Pilbara region of Western Australia. The data was to be incorporated into an environmental impact statement (EIS) by Rio Tinto.

Outputs:

- This report is a follow-up of the results from the EelFishCOI 'molecular magnet' designed for Blind Cave Eel (*Ophisternon candidum*) detection. This report presents the eDNA results following on from the report issued to RioTinto on the 13th July 2018 by the TrEnD lab.

- The presence of Blind Cave Eel (*Ophisternon candidum*) DNA was confirmed from two sample sites of the Robe River and bores JW021, JW024, BC186, 25, RR1 and MB17MEH0015. Blind Cave Eel DNA was not previously detected from MB17MEH0015 with the EelFish16S assay reported on 13th July 2018. Re-screening all 122 eDNA water membranes collected in June and December 2017 with Fish16S and EelFishCOI 'molecular magnets' confirms the presence of *O. candidum* from this additional bore.

Recommendations:

- This is the first time eDNA metabarcoding methods have been implemented in the Pilbara groundwater systems. The Fish16S, EelFish16S and EelFishCOI metabarcoding assays designed by the TrEnD lab indicates that an eDNA approach is able to detected Blind Cave Eel (*Ophisternon candidum*) from the survey area as a non-invasive method. Blind Cave Eel (*Ophisternon candidum*) DNA was isolated and DNA sequenced from 6 bores sampled, in addition to two open surface water samples collected from the Robe River, which indicates eDNA metabarcoding is capable of detecting threatened species. Finally it is worth noting that these eDNA assays are performing at the limits of detection and further gains in sensitivity may be achievable with optimised sampling.
-

1. Introduction

eDNA refers to all genetic material that is recovered from environmental substrates (such as water or sediment). DNA directly from an organism (e.g. microorganisms) as well as trace amounts of DNA that are shed by all organisms is collectively termed eDNA. This preserved, but often degraded, genetic material provides a means to audit species composition and communities at a given location. When combined with recently developed DNA sequencing technologies (termed 'next generation' or 'high-throughput' sequencing), eDNA can provide a wealth of information for studies of introduced marine pests (IMP), biodiversity surveys, food web dynamics, and diet analysis.

Potential applications for monitoring using eDNA include:

- Biosecurity: to detect the presence/absence of introduced species
- Environmental Impact Assessment: baseline/ongoing monitoring and assessment; audit
- Conservation: to detect the presence/absence of threatened species

Rio Tinto has partnered with the Trace and Environmental DNA (TrEnD) Laboratory at Curtin University to develop eDNA tools for Blind Cave Eel (*Ophisternon candidum*) as a means to use DNA-based bio surveys in groundwater monitoring and management.

eDNA sampling has benefits over other traditional survey methods including:

- highly cost-effective monitoring compared to traditional survey methods
- rapid sample collection that is non destructive to habitats, flora and fauna
- non-reliance on individuals with taxonomic expertise, provision of consistent results between monitoring programs, independent of surveyors

The objectives of this project were to use an environmental DNA (eDNA) metabarcoding approach to determine the presence/absence of Blind Cave Eel (*Ophisternon candidum*) a threatened species within the groundwater systems of the Pilbara in Western Australia, specifically the Mesa H area (Rio Tinto). The data is to be incorporated into an environmental impact statement.

2. Methods and Samples

Please refer to report "**eDNA Metabarcoding Report: Blind Cave Eel survey in the Pilbara WA**" issued to RioTinto by the TrEnD lab on 13th July 2018.

3. Results and Discussion

Table 1 list the water samples from each bore and those for which Blind Cave Eel (*Ophisternon candidum*) were detected with the Fish16S, EelFish16S and EelFishCOI metabarcoding assays. DNA sequences obtained for *O. candidum* can be found in the Supplementary Information accompanying this report.

Table 1: Results of eDNA metabarcoding (Fish16S, EelFish16S, EelFishCOI) from groundwater for Blind Cave Eel (*Ophisternon candidum*) detection.

TrEnD Sample ID	Site (bore code)	Field Trip	Ophisternon candidum DNA detected?
AWFS-I17-106	JIMWE003	Jun-17	No
AWFS-I17-107	JW021	Jun-17	Yes
AWFS-I17-108	BC186	Jun-17	No
AWFS-I17-109	JW024	Jun-17	No
AWFS-I17-110	BC276	Jun-17	No
AWFS-I17-111	BC667	Jun-17	No
AWFS-I17-112	BCP001	Jun-17	No
AWFS-I17-113	BC458	Jun-17	No
AWFS-I17-114	Robe River (RR)	Jun-17	Yes
AWFS-I17-115	BUNWO1108	Jun-17	No
AWFS-I17-116	BUNWB13	Jun-17	No
AWFS-I17-117	BUNWB09	Jun-17	No
AWFS-I17-118	BC401	Jun-17	No
AWFS-I17-119	BUNWB08	Jun-17	No
AWFS-I17-120	BC225	Jun-17	No
AWFS-I17-121	JIMWE004	Jun-17	No
AWFS-I17-122	BC292	Jun-17	No
AWFS-I17-123	BUNWO0773	Jun-17	No
AWFS-I17-124	PZ11BUN008	Jun-17	No
AWFS-I18-001	25	Dec-17	Yes
AWFS-I18-002	31	Dec-17	No
AWFS-I18-003	200/Dave Bore	Dec-17	No
AWFS-I18-004	BC186	Dec-17	Yes
AWFS-I18-005	BC401	Dec-17	No
AWFS-I18-006	Budgie Bore	Dec-17	No
AWFS-I18-007	JW023	Dec-17	No
AWFS-I18-008	JW024	Dec-17	Yes
AWFS-I18-009	MB16MEC0009	Dec-17	No
AWFS-I18-010	MB17MEH0008	Dec-17	No
AWFS-I18-011	MB17MEH0010	Dec-17	No
AWFS-I18-012	MB17MEH0015	Dec-17	Yes
AWFS-I18-013	RR1	Dec-17	Yes

AWFS-I18-014	MB16MEC0008	Dec-17	No
AWFS-I18-015	MB17MEH0007	Dec-17	No
AWFS-I18-016	MB17MEH0009	Dec-17	No
AWFS-I18-017	Control (RR)	Dec-17	Yes

4. Findings, Recommendations and Concluding remarks

At the time of report "**eDNA Metabarcoding Report: Blind Cave Eel survey in the Pilbara WA**" issued to RioTinto by the TrEnD lab on 13th July 2018, the water samples identified as positive from the EelFishCOI and Fish16S metabarcoding assays had not been DNA sequenced and bioinformatically processed.

The Fish16S, EelFish16S and EelFishCOI assays utilised on bore water samples collected in June and December 2017 detected Blind Cave Eel (*Ophisternon candidum*) from two sample locations of the Robe River, in addition to bores JW021, JW024, BC186, 25, RR1 and MB17MEH0015. To our knowledge this represents the first time an eDNA based metabarcoding approach, specific for *Ophisternon candidum*, has been applied to samples from ground water system(s) in the Pilbara, Western Australia. Sequencing the mitochondrial genome of *Ophisternon candidum* (WAM P.34817-001) has provided definitive assignments of DNA sequences from eDNA groundwater samples to genus and species.

5. Appendices and additional information

- An electronic file titled; SupplementaryInformation_EelFish16SandCOI_August2018.xlsx is attached to this report.

- Additional information on sampling and methods are available from TrEnD upon request however the exact nature of the assays and workflow are proprietary.

- Below is a list of acronyms, abbreviations and definitions that may apply to aspects of this report.

% value in data	Represents the percentage similarity of a DNA sequence recovered from a sample compared to reference sequences in a database (e.g. compared to DNA databases such as GenBank or references generated in-house)
(x) value in data	Represents the frequency the % value was recorded in the dataset
18S rRNA	The 18S rRNA refers to a conserved gene region of nuclear DNA, which codes for a subunit of the ribosome. 18S rRNA is found in all eukaryotes making it a good candidate for DNA barcoding
18S IMS reference database	Reference 18S rRNA sequences of invasive marine species that are available in DNA databases
Assay	In the context of metabarcoding an assay is a molecular test (using PCR) that is implemented to target a group of taxa within a mixed biological substrate. It is akin to using a magnet to selective enrich for needles (the target) in the context of a haystack (the total DNA from a sample).
COI	The gene region that is being used as the standard barcode for almost all animal groups is a 648 base-pair region of the mitochondrial cytochrome c oxidase 1 gene ("CO1"). COI is proving highly effective in identifying birds, butterflies, fish, flies and many other animal groups. COI is not an effective barcode region in plants because it evolves too slowly, but two gene regions in the chloroplast, matK and rbcL, have been approved as the barcode regions for plants
CO1 IMS reference database	Reference COI sequences of invasive marine species that are available in DNA databases
DNA	Deoxyribonucleic Acid (DNA) is the hereditary material that contains the genetic information of an organism
DNA metabarcoding	Is a genetic technique that simultaneously amplifies and sequences barcode regions (e.g. COI, 18S, 16S) of many different species in parallel
eDNA	Environmental DNA (eDNA) refers to genetic material that is recovered from an environmental substrate (e.g. water, sediment, air)

eukaryotes	An organism where cells contain a nucleus surrounded by a membrane and has the DNA bound together by proteins (histones) into chromosomes. The cells of eukaryotes also contain an endoplasmic reticulum and numerous specialised organelles not present in prokaryotes, especially mitochondria, golgi bodies, and lysosomes
Fisheries	Department of Primary Industries and Regional Development, Fisheries Division, Aquatic Biosecurity Section
GenBank	Publically available repository of genetic information. Contains the barcode information of genes that have previously been sequenced
Genome	A genome is all the genetic material of an organism. It consists of DNA (or RNA in RNA viruses). The genome includes both the genes (the coding regions) and the noncoding DNA. In eukaryotes it refers to the genomes of the nucleus, mitochondria and chloroplasts. In prokaryotes, there is a single genome (as they do not contain mitochondria or chloroplasts)
Illumina MiSeq	Next generation sequencing platform developed by the company Illumina
IMP	Introduced marine pests
IMS	Introduced marine species
Metabarcoding assay	A PCR reaction using a specific set of primers that simultaneously amplifies the same gene target from multiple species
Mitochondria	The mitochondrion (plural mitochondria) is a double membrane-bound organelle found in all eukaryotic organisms, although some cells in some organisms may lack them (e.g. Red blood cells). It contains its own genome
Mitogenomes	Refers to the mitochondrial genome
NGS	Next generation sequencing or second generation sequencing refers to massively parallel sequencing technology, as opposed to first generation sequencing or sanger sequencing where only a single template is sequenced at one time
Nucleotide	A compound consisting of a nucleoside linked to a phosphate group. Nucleotides form the basic structural unit of nucleic acids such as DNA
PCR	Polymerase chain reaction (PCR) is the technique that is used to amplify (akin to photocopying DNA) specific regions of the genome from specific groups of taxa
Primer	A short DNA strand (≈20bp in size) used in PCR to target particular groups of organisms and genes. Two of them are required for PCR (a forward and a reverse)
Primer binding site	A primer-binding site is the target region of a genome where the primer attaches to start replication. The primer binding site is on one of the two complementary strands of a double-stranded nucleotide polymer, in the strand which is to be copied, or is within a single-stranded nucleotide polymer sequence
prokaryote	Any of the typically unicellular microorganisms that lack a distinct nucleus and membrane-bound organelles and that are classified as a kingdom (Prokaryotae syn. Monera) or into two domains (Bacteria and Archaea)
RNA	Ribonucleic acid (RNA) is a polymeric molecule implicated in various biological roles in coding, decoding, regulation, and expression of genes

rRNA	ribosomal ribonucleic acid is the RNA component of the ribosome, and is essential for protein synthesis in all living organisms
Sequence	DNA sequencing is the process of determining the precise order of nucleotides within a DNA molecule. It includes any method or technology that is used to determine the order of the four bases—adenine, guanine, cytosine, and thymine—in a strand of DNA
Shotgun sequencing	Refers to randomly sequencing short pieces of DNA (≈150bp in size) after shearing or cutting DNA (e.g. fragmenting a genome)
TrEnD	Trace and Environmental DNA laboratory, Curtin University

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6 July 2018

Our Reference: 14279-17-BILR-2Rev0_180706

Melinda Brand
Principal Advisor Environmental Approvals
Rio Tinto Iron Ore
Central Park, 152-158 St Georges Terrace
Perth WA 6000

Dear Melinda,

Re: Mesa H – Targeted Night Parrot Fauna Assessment, September 2017

1 Introduction

Rio Tinto Iron Ore Pty Ltd (Rio Tinto), on behalf of Robe River Mining Co. Pty. Ltd, is evaluating the potential development of the Mesa H deposit (survey area) located adjacent to the Mesa J Operation and approximately 13 km to the south-west of Pannawonica. Key components of the pre-feasibility and feasibility studies being undertaken are environmental surveys which are required to inform the environmental assessment process for the potential development of the Mesa H deposit. Due to the recent publication of the *Interim guideline for preliminary surveys of Night Parrot* (*Pezoporus occidentalis*) (Department of Parks and Wildlife 2017) and to ensure all fauna surveys meet current guidelines, Astron was commissioned to undertake a targeted Night Parrot fauna survey in the survey area (Figure A.1, Attachment A).

The possible occurrence of this Matters of National Environmental Significance species within the survey area presents a potential management issue to ground disturbance activities for the development of the Mesa H deposit. In order to gain a comprehensive understanding of Night Parrot occurrence, habitat utilisation and resident population estimates, a more intensive survey was required within the survey area.

2 Scope of Work

The scope of work was to conduct a targeted Night Parrot fauna survey within the survey area in accordance with the scope of works provided by Rio Tinto (dated 17/07/2017), regulatory guidelines (Department of Parks and Wildlife 2017) and industry best practice. Specifically, the following was undertaken:

- a desktop literature review to assess the potential occurrence of the Night Parrot within the local and regional vicinity of the survey area
- a systematic field survey to:
    - verify the results of the desktop study and previous Night Parrot records
    - record potential Night Parrot observations or records and assess the potential for the survey area to support a resident population of this species.

This report details the findings of the desktop and field studies.

3 Night Parrot (*Pezoporus occidentalis*)

3.1 Distribution and Conservation Status

The Night Parrot is listed as Endangered under the *Environmental Protection and Biodiversity Conservation Act 1999* (EPBC Act) and Critically Endangered (Scheduled 1) under the *Wildlife Conservation Act 1950*. Conservation category listings are detailed in Table B.1 and B.2 (Attachment B). The Night Parrot has long been thought extinct in Australia, with only sporadic and sometimes unconfirmed sightings recorded. However the focus on this species has amplified due to a recent sighting near Wiluna in Western Australia (Jones 2017) and from the rediscovery of this species in Queensland near the Pullen Pullen Reserve and at Goneaway and Diamantina National Parks (Palaszczuk and Miles 2017).

The Night Parrot has long been elusive and due to its highly cryptic behaviour has largely gone unnoticed and undetected. Now with the release of the vocal calls made by this species from Queensland, a more informed and targeted survey effort can be undertaken.

3.2 Ecology

Little is known on the ecological requirements of the Night Parrot due to the cryptic behaviour this species has previously shown. With the recent sightings of the Night Parrot and records from certain areas, ecologists have been able to better understand the species' habitat requirements.

Roosting habitat is thought to be long unburnt stands of spinifex hummocks (*Triodia* spp.) particularly large hummocks that are ring forming that would form a certain level of protection from predators. The hummocks that are < 50 cm in height and collapsed are thought not likely to provide enough shelter and/or protection from predators (Department of Parks and Wildlife 2017). Some systematic acoustic monitoring from Murphy (2015, 2016) has shown that Night Parrots in south-western Queensland regularly roosted in the same location even despite exceptionally dry conditions when no *Triodia* seed was available. However, Higgins (1999) reported that the species may be nomadic, have very large home ranges and may only be sedentary under suitable conditions, such as during mass times of seeding and flowering of *Triodia* seed.

Foraging habitat requirements are also largely unknown; however, some favoured sites, particularly in Western Australia, seem to be in close association of chenopod communities, principally the succulents of *Sclerolaena*. These succulents are possibly a source of moisture for the Night Parrot given their preference for the arid regions of Australia and the probable lack of free standing water. Murphy (2016) suggested that Night Parrots may not rely on surface water, and instead may derive sufficient metabolic water from foraging on succulent plants, such as *Sclerolaena*. This indicates that access to water may not be required in some circumstances. It is also assumed that *Triodia* spp. would provide foraging potential particularly during times of mass seeding and flowering (Department of Parks and Wildlife 2017).

It is evident that Night Parrots have a preference for highly selective habitat and this probably explains the low level of records to date.

4 Methodology

The field survey was completed according to the relevant state and federal survey guidelines, particularly the guidelines set out by the state Environmental Protection Authority (EPA) and Parks and Wildlife Service of the Department of Biodiversity, Conservation and Attractions (DBCA):

- EPA Position Statement No. 3, Terrestrial Biological Surveys as an Element of Biodiversity Protection (Environmental Protection Authority 2002)
- Survey Guidelines for Australia's Threatened Birds: Guidelines for Detecting Birds Listed as Threatened Under the EPBC Act (Department of Environment 2010).
- Technical Guidance - Sampling Methods for Terrestrial Fauna (Environmental Protection Authority 2016a)
- Technical Guidance - Terrestrial Fauna Surveys (Environmental Protection Authority 2016b)
- Interim Guideline for Preliminary Surveys of Night Parrot (*Pezoporus occidentalis*) in Western Australia, May 2017 (Department of Parks and Wildlife 2017).

4.1 Desktop Literature Review

Prior to the field assessment a review of publically available databases was conducted. In particular, the desktop review included an examination of the previous Night Parrot records on DBCA's *NatureMap* database. The review focussed on the locations of recent survey records to help obtain an understanding on the distribution of this species from the current literature available.

4.2 Targeted Field Survey

The targeted field survey was conducted by Astron Zoologists Matthew Love and John Trainer on the 14 and 18 September 2017. Matthew and John both have over five years of experience conducting Level 2 vertebrate fauna surveys. The survey was conducted under a "Licence to Take Fauna for Scientific Purposes" (Permit 08-000566-2).

Weather conditions were hot during the survey period. Maximum temperatures recorded at Pannawonica (approximately 13 km north-east of the survey area) ranged from 37.0°C to 39.4°C with minimum temperatures in the mid to upper twenties. As a result of low rainfall prior to the survey, no surface water was present in the vicinity of the survey area, except where dewatering from the Mesa J mine site was occurring.

Conditions were considered to be dry with no seeding spinifex and very little seed remaining in the seed-heads of spinifex and other grasses, indicating that it had been many months since grasses had flowered. No rain-fed surface water was observed within the Robe River and in the immediate vicinity of the survey area. Yerra Bluff (located on the western margin of the survey area), a permanent water pool of the Robe River, was full and was likely to be the only natural source of water in the area at the time of the survey.

Rainfall received (based on Pannawonica weather station 005069) in three months preceding the survey was 0.3 mm, 58.9 mm less than the mean rainfall for the same three months (Bureau of Meteorology 2018). Rainfall was received earlier in the year, with a total of 602.7 mm of rainfall received in the nine months preceding the survey, 208.7 mm more than the mean rainfall for the same nine months (Bureau of Meteorology 2018). These factors are not optimal for Night Parrot occurrence, however, they are not considered to be a major limitation given that:

- this species is generally accepted as an arid and semi-arid specialist and would be adapted to long periods of drought
- habitat assessment is a critical component of a survey, as no available survey technique can irrefutably demonstrate that Night Parrots are absent from a site (Department of Parks and Wildlife 2017).

4.2.1 Habitat Assessment

Previously, Astron conducted a flora, vegetation and fauna assessment within the survey area (Astron Environmental Services 2016a, 2016b). The fauna survey conducted in November 2016 (Astron Environmental Services 2016a) mapped the fauna habitats of the survey area that helped refine the survey effort for potential Night Parrot habitat.

Two fauna habitat assessments were conducted within the survey area (Table C.1, Attachment C). The locations are shown in Figure A.2 (Attachment A) and the following information was collected at each site:

- location – coordinates measured using a handheld GPS (GDA94)
- recorder and date – personnel involved in undertaking the fauna habitat assessment and the survey date
- vegetation type – a broad description of vegetation type and structure
- soils – a brief description of soil type
- microhabitat pertinent to the Night Parrot – potential roosting habitat such as the presence of primarily old large spinifex hummocks (>50 cm), especially hummocks that are ring forming or presence of foraging habitat such as the presence of samphire communities and/or seeding spinifex hummocks, and the presence of permanent or semi-permanent water
- condition – habitat condition was assessed based on the presence of anthropogenic (human-induced) disturbances, and using the condition ratings suggested by Thompson and Thompson (2010) (Table B.3, Attachment B)
- fire age – recorded as either recent (<2 years); young (2 to 5 years); moderate (5 to 10 years); old (>10 years); very old (>50 years)
- disturbance – any disturbance such as clearing, weeds, flooding, vehicular, machinery, tracks or grazing
- photographs – a representative photograph was taken of each habitat assessment site.

The information derived from the fauna habitat assessments, as well as the previous fauna habitat mapping (Astron Environmental Services 2016a) and vegetation mapping (Astron Environmental Services 2016b) from within the survey area, was used to assess the suitability of habitat for the Night Parrot. The habitat was ranked according to the criteria listed in Table 1 and the likelihood of occurrence in the survey area utilising the criteria in Table B.4 (Attachment B).

Table 1: Suitability of habitat ranking criteria for the Night Parrot (*Pezoporus occidentalis*) within the survey area.

Species	Potential shelter and foraging habitat (a)	Suitable foraging and dispersal habitat (b)	Limited foraging and dispersal habitat (c)
Night Parrot (*Pezoporus occidentalis*)	Isolated habitat not subjected to predation pressure, fire pressure, and altered habitat from pastoralism and mining activities. Generally roosting habitat that contains old and large spinifex clumps (>50 years unburnt), particularly ring-forming hummocks **OR** Areas highly suitable for foraging in close association (<10 km) to potential roosting habitat, including Triodia (particularly at times of mass flowering and seeding) and chenopod communities dominated by Sclerolaena	Very little is known on the foraging requirements of the Night Parrot. Habitat within 40 km of potential roosting and nesting sites, potentially important for foraging, including chenopod communities (particularly those dominated by Sclerolaena), Triodia and areas rich in herbs, including forbs, grasses and grass-like plants.	Habitat that has limited roosting and foraging potential for the Night Parrot.

4.2.2 Autonomous Recording Units

Autonomous Recording Units (ARUs) were used to record the potential presence of the Night Parrot by recording the species' vocal call. Two acoustic recording devices (Song Meter 2, SM2BAT+) were positioned in four locations (Figure A.2, Attachment A and Table C.1, Attachment C). The detectors were set for three nights, resulting in a total of 12 recording nights. The ARUs were set to record from 1 hour pre-sunset to 1 hour post-dawn. The recordings were recorded at 44.1 k bits and covered the frequency range 100 kHz to 21,000 kHz that brackets the Night Parrot call frequency range of 1,500 kHz to 3,500 kHz.

The data collected on the SM2BAT+ detectors in the field were analysed by Robert Bullen (Bat Call WA 2017). The reference calls for the Night Parrot were available from Bat Call WA's library and compared against any potential calls made from the survey area (Bat Call WA 2017).

4.2.3 Motion Sensitive Cameras

Two motion sensitive cameras were used during the survey (Moultrie, Reconyx). Cameras were set for four nights each with a combined trapping effort of eight camera trap nights (Figure A.2, Attachment A and Table C.1, Attachment C). The cameras were placed in prospective/suitable habitat aimed at targeting potential foraging Night Parrots in or near prospective roosting habitat.

4.2.4 Aural Listening Surveys/Nocturnal Searching

Two nights (12 person hours) of targeted nocturnal searching was conducted within the survey area. This included six locations of aural listening surveys (Figure A.2, Attachment A and Table C.1, Attachment C). The fauna team targeted the search effort in long unburnt spinifex hummocks and sat and listened for the distinct audio call of the Night Parrot. It is thought that the species' peak calling period is two hours after sunset and two hours before sunrise (Department of Parks and Wildlife 2017). Due to concerns with health, safety and fatigue only the post-sunset calling period was targeted during the fauna assessment.

5 Results

5.1 Desktop Assessment

A review of the DBCA *NatureMap* database in October 2017 for previous records of the Night Parrot reported 15 records within Western Australia. Of these, five records were made within the Interim Biogeographic Regionalisation for Australia Pilbara bioregion and only one record was reported recently or post-2000.

In April 2005 three individuals of the Night Parrot were recorded at the onset of dusk near standing water at Minga Well adjacent to the Fortescue Marsh (Davis and Metcalf 2008). Minga Well is 320 km to the east of the survey area, situated on Mulga Downs pastoral station. Two birds were observed moving towards the water's edge and then drinking; the third bird was only seen briefly and was not resighted (Davis and Metcalf 2008). No vocalisations or noises from their wings were recorded when the individuals departed the site (Davis and Metcalf 2008). The habitat was described as a pastoral bore; however, Minga Well is situated 2 km from the edge of the Fortescue Marsh (a known priority ecological community) where succulents such as *Sclerolaena* are found.

5.2 Targeted Field Survey

No individual sightings, vocal calls or any other signs of the Night Parrot were recorded during the current targeted survey. The Night Parrot was not detected from the 12 nights of ARU recordings (Attachment D). No Night Parrots were recorded on any of the motion sensitive cameras from the combined trapping effort of eight camera trap nights.

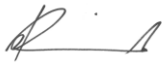
Two habitat assessments in the survey area determined the fire ages to range from young (2 to 5 years) to moderate (5 to 10 years) (Attachment C).

6 Discussion

The survey area is located in the western extent of the Pilbara region of Western Australia, located within an area deemed as 'species or species habitat may occur' by the Department of the Environment and Energy (Department of the Environment and Energy 2017). No individual sightings and/or vocal calls were recorded, nor any prospective calls made on the ARUs set within the survey area. Astron is of the belief that the survey area is not suitable for the Night Parrot as there is limited preferred habitat present and the impacts of regular fire would be too great. The current knowledge of habitat preference of the Night Parrot is limited, with some sources believing a matrix of long unburnt spinifex stands (>50 years) in close association with chenopod communities (samphire) is a key habitat preference. The only recent discovery of the Night Parrot within the Pilbara region was in 2005 in which three individuals were sighted at a pastoral bore close to the Fortescue Marsh, supporting the theory that samphire is of some importance (Davis and Metcalf 2008). Recently the Night Parrot was discovered in March 2017 in the arid region of the Mid-west in which the habitat was also described as long unburnt spinifex in association with a chenopod community (Jones 2017). Given these habitats do not occur in the survey area, the likely predation pressure from cats and dingos (sighted during the survey) and the proximity to active mining infrastructure, the chance of this species being present is considered very low.

This report was prepared by Senior Scientist Matthew Love and technically reviewed by Senior Scientist Dr Jessica Johnston. Should you have any further queries regarding this information, please do not hesitate to contact Melissa Ford (Project Coordinator) on 9421 9600.

Yours sincerely
ASTRON ENVIRONMENTAL SERVICES



Dr Robert Archibald
Principal Scientist

Attachments

Attachment A: Figures

Attachment B: Conservation Fauna Categories, Habitat Condition Scales and Likelihood Criteria

Attachment C: Survey Sampling Locations

Attachment D: Bat Call WA Pty Ltd Report

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Attachment 1: Figures

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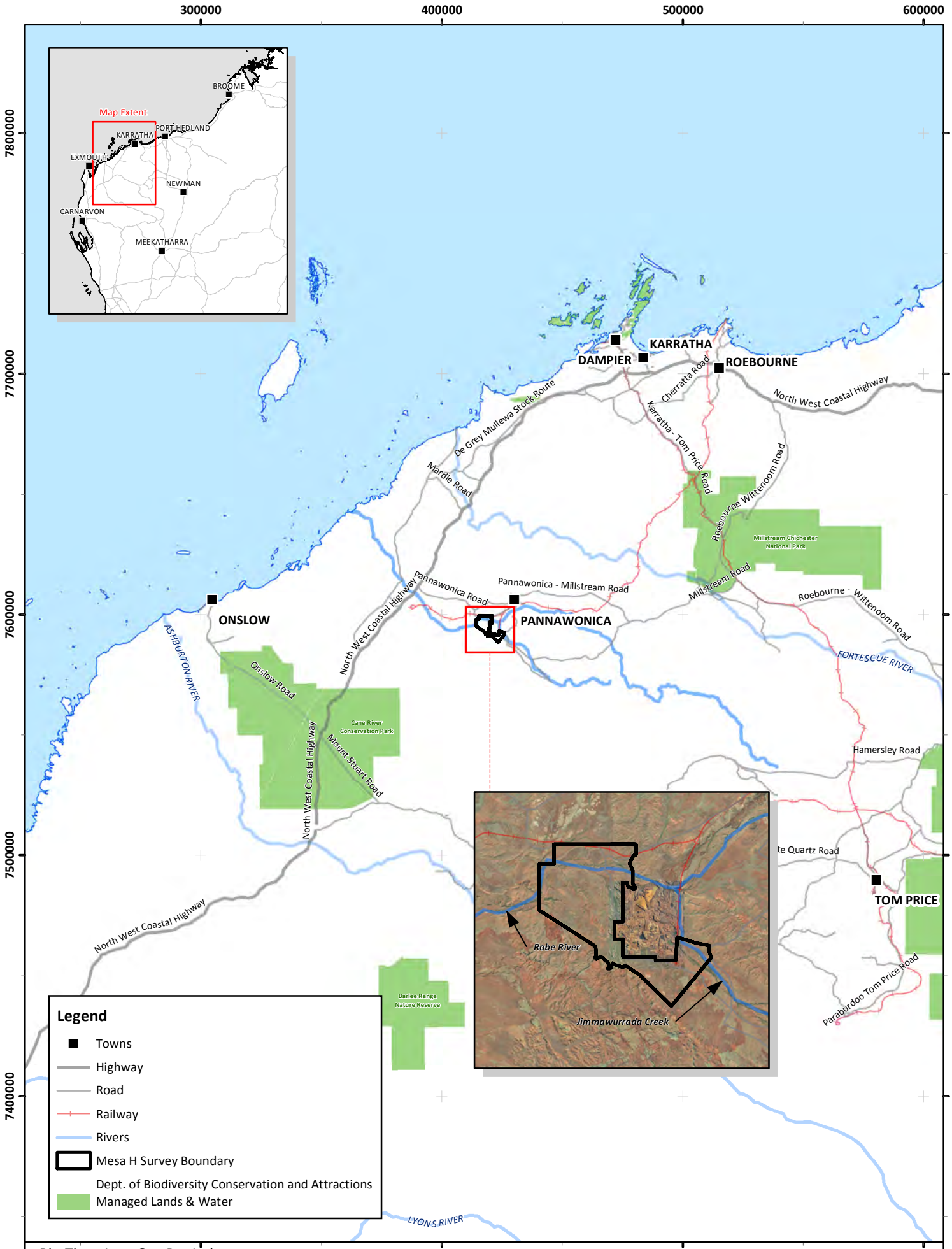

Rio Tinto Iron Ore Pty Ltd

Mesa H – Targeted Night Parrot Fauna Assessment, September 2017

Figure A.1: Location Figure

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Drawn: C. Dyde	Figure Ref: 14279-17-BIDR-1RevA_171110_FigA1_MesaH_Locn

Datum: GDA 1994 - Projection: MGA Zone 50

0 20 40 60 80 100 Km

N

415000 420000 425000

7600000

7595000

7590000

ARU4 AL6 AL5 ARU2 AL4 ROBE RIVER Mesa J Mine Access Road Milkstream Rd CAM2 ARU3 HA2 ARU1 HA1 AL1 CAM1 AL2 AL3 JIMMAWURRADA CREEK

Legend

- Mesa H Survey Boundary
- GPS Tracklogs
- Main Road
- Minor Road
- Railway

Sampling Sites

- Acoustic recording
- Active foraging
- Camera (active)
- Habitat Assessment

Rio Tinto Iron Ore Pty Ltd

Mesa H – Targeted Night Parrot Fauna Assessment, September 2017

Figure A.2: Survey Effort Figure

Coordinate System: GDA 1994 MGA Zone 50

0 1 2 3 4 Km

N

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Author: M. Love | Drawn: C. Dyde | Date: 10-11-2017 | Figure Ref: 14279-17-BIDR-1RevA_171110_FigA2_MesaH_SurvEff

Attachment B: Conservation Fauna Categories, Habitat Condition Scales and Likelihood Criteria

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Table B.1: Categories and definitions for EPBC Act listed fauna species.

Conservation category	Definition
Extinct	Taxa with no reasonable doubt that the last member of the species has died.
Extinct in the wild	Taxa known to survive only in cultivation, in captivity or as a naturalized population well outside its past range; or it has not been recorded in its known and/or expected habitat, at appropriated seasons, anywhere in its past range, despite exhaustive surveys over a time frame appropriate to its life cycle and form.
Critically endangered (CR)	Taxa facing an extremely high risk of extinction in the wild in the immediate future, as determined in accordance with the prescribed criteria.
Endangered (E)	Taxa are not critically endangered; and are facing a very high risk of extinction in the wild in the near future, as determined in accordance with the prescribed criteria.
Vulnerable (V)	Taxa are not critically endangered or endangered; and are facing a high risk of extinction in the wild in the medium-term future, as determined in accordance with the prescribed criteria.
Conservation dependent (CD)	Taxa are the focus of a specific conservation program the cessation of which would result in the species becoming vulnerable, endangered or critically endangered; or the following subparagraphs are satisfied: i) the taxa is a species of fish; ii) the taxa is the focus of a management plan that provides management actions necessary to stop the decline of, and support the recovery of, the taxa so that its chances of long term survival in nature are maximized; iii) the management plan is in force under a law of the Commonwealth or of a State or Territory; iv) Cessation of the management plan would adversely affect the conservation status of the taxa Fish includes all taxa of bony fish, sharks, rays, crustaceans, molluscs and other marine organisms, but does not include marine mammals/reptiles.

Table B.2: Conservation codes for Western Australian fauna (Department of Parks and Wildlife 2015).

Code	Conservation category	Definition
CR	Schedule 1 of the Wildlife Conservation (Specially Protected Fauna) Notice under the Wildlife Conservation Act 1950.	Fauna that is rare or likely to become extinct, as critically endangered fauna.
EN	Schedule 2 of the Wildlife Conservation (Specially Protected Fauna) Notice under the Wildlife Conservation Act 1950.	Fauna that is rare or likely to become extinct, as endangered fauna.
VU	Schedule 3 of the Wildlife Conservation (Specially Protected Fauna) Notice under the Wildlife Conservation Act 1950.	Fauna that is rare or likely to become extinct, as vulnerable fauna.
EX	Schedule 4 of the Wildlife Conservation (Specially Protected Fauna) Notice under the Wildlife Conservation Act 1950.	Fauna that is presumed to be extinct.
IA	Schedule 5 of the Wildlife Conservation (Specially Protected Fauna) Notice under the Wildlife Conservation Act 1950.	Birds that are subject to international agreements relating to the protection of migratory birds.
CD	Schedule 6 of the Wildlife Conservation (Specially Protected Fauna) Notice under the Wildlife Conservation Act 1950.	Fauna that are of special conservation need being species dependent on ongoing conservation intervention.
OS	Schedule 7 of the Wildlife Conservation (Specially Protected Fauna) Notice under the Wildlife Conservation Act 1950.	Declared to be fauna that is in need of special protection, otherwise than for the reasons mentioned.

Reference: Department of Parks and Wildlife 2015, *Conservation Codes For Western Australian flora and fauna*, The Government of Western Australia.

Table B.3: Fauna habitat condition scale (Thompson and Thompson 2010).

Habitat condition	Condition description
High Quality Fauna Habitat (1.0)	These areas closely approximate the vegetation mix and quality that would have been in the area prior to any human induced disturbance. The habitat has connectivity with other habitats and is likely to support the most natural vertebrate fauna assemblage.
Very Good Fauna Habitat (0.8)	These areas show minimal signs of human induced disturbance (e.g. grazing, clearing, fragmentation, weeds) and retain almost all of the characteristics of the habitat had it not been disturbed. The habitat has connectivity with other habitats, and fauna assemblages in these areas are likely to be minimally effected by disturbance.
Good Fauna Habitat (0.6)	These areas show signs of human induced disturbance (e.g. grazing, clearing, fragmentation, weeds) but generally retain many of the characteristics of the habitat had it not been disturbed. The habitat still retains some connectivity with other habitats but fauna assemblages in these areas are likely to be affected by disturbance. Fauna assemblages in these areas are likely to be similar to what might be expected in this habitat.
Disturbed Fauna Habitat (0.4)	These areas show signs of human induced significant disturbance (e.g. mining, clearing, tracks and roads). Many of the trees, shrubs and undergrowth have died or have been cleared. These areas may be in the early succession and regeneration stages. Areas may show signs of significant grazing, contain an abundance of weeds or have been damaged by vehicles or machinery. Habitats are fragmented or have limited connectivity with other fauna habitats. Fauna assemblages in these areas are likely to differ significantly from what might be expected in the area had the disturbance not occurred.
Highly Degraded Fauna Habitat (<0.2)	These areas often have a significant human induced loss of vegetation, and / or a large number of vehicle tracks and / or have been completely cleared, and / or areas have been heavily grazed or farmed. There is limited or no fauna habitat connectivity. Fauna assemblages in these areas are likely to differ significantly from what existed prior to the disturbance, and are often depleted compared to what existed prior to the disturbance.

Reference: Thompson, SA & Thompson, GG 2010, *Terrestrial Vertebrate Fauna Assessments for Ecological Impact Assessment*, Terrestrial Ecosystems, Mt Claremont.

Table B.4: Criteria used to define likelihood occurrence of conservation significant fauna species.

Likelihood of occurrence	Pre-survey	Post-survey
Recorded	N/A	Species or evidence of species recorded during survey.
High	Species has been recorded within the survey area or within 20 km of the survey area and preferred habitat appears to be present.	Core or preferred habitats present in the survey area which are abundant and/or high quality condition. OR Species is known to be cryptic and may not have been detected despite adequate survey effort and suitable habitat present within the survey area. OR Species or evidence of species recorded within the survey area however doubt remains over the taxonomic identification, validity of record.
Moderate	Species has not been recorded from within the survey area, however species has been recorded within 20 km of the survey area and suitable habitat appears to be present.	Core or highly suitable habitats present in the survey area, however, non-cryptic species that was not detected despite adequate survey effort. OR Core or preferred habitats present in the survey area are mainly in poor or modified condition.
Low	Species recorded within 20 km of the survey area but suitable habitat does not appear to be present.	Species has not been recorded in the survey area despite adequate survey effort. OR Species dependent on specific habitats that do not occur in the survey area. OR Species considered locally extinct.

Attachment C: Survey Sampling Locations

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Table C.1: Astron fauna sampling locations.

Site ID	MGA Zone 50K		Sampling method	Date	Habitat	Condition	Disturbance	Microhabitats important to Night Parrot	Photo
	Easting (mE)	Northing (mN)							
ARU1	421585	7591008	Audio Recording Unit	14/09/2017-18/09/2017	Low hills and slopes	0.8	Drill tracks	N/A	No photo
ARU2	415745	7598784	Audio Recording Unit	18/09/2017-21/09/2017	Loamy/stony plain	1.0	None	N/A	No photo
ARU3	422451	7591151	Audio Recording Unit	14/09/2017-18/09/2017	Loamy/stony plain	0.8	Grazing	N/A	No photo
ARU4	416396	7599262	Audio Recording Unit	18/09/2017-21/09/2017	Loamy/stony plain	1.0	None	N/A	No photo
AL1	422179	7590867	Aural Listening Survey	14/09/2017	Low hills and slopes	0.8	Grazing	N/A	No photo
AL2	422491	7590563	Aural Listening Survey	14/09/2017	Loamy/stony plain	1.0	None	N/A	No photo
AL3	422457	7590176	Aural Listening Survey	14/09/2017	Loamy/stony plain	1.0	None	N/A	No photo
AL4	415328	7598566	Aural Listening Survey	18/09/2017	Loamy/stony plain	0.8	Grazing	N/A	No photo
AL5	416163	7599030	Aural Listening Survey	18/09/2017	Loamy/stony plain	1.0	None	N/A	No photo
AL6	418749	7599276	Aural Listening Survey	18/09/2017	Loamy/stony plain	1.0	None	N/A	No photo
CAM1	422485	7590539	Motion Sensitive Camera Recordings	14/09/2017-18/09/2017	Loamy/stony plain	0.8	Grazing	N/A	No photo
CAM2	422058	7591396	Motion Sensitive Camera Recordings	14/09/2017-18/09/2017	Loamy/stony plain	1.0	None	N/A	No photo
HA1	421585	7591008	Habitat Assessment	14/09/2017	Low hills and slopes	0.8	Clearing for drilling; mineral exploration	Moderately sized *Triodia* hummocks <40 cm; no chenopod communities; no refuge from fire; fire age approx. 2 to 5 years	

Site ID	MGA Zone 50K		Sampling method	Date	Habitat	Condition	Disturbance	Microhabitats important to Night Parrot	Photo
	Easting (mE)	Northing (mN)							
HA2	422450	7591151	Habitat Assessment	14/09/2017	Loamy/stony plain	0.8	Clearing for drilling; mineral exploration	Moderately sized *Triodia* hummocks <40 cm; no chenopod communities; no refuge from fire; fire age approx. 5 to 10 years	

Condition

1.0 (Excellent)
0.8 (Very Good)
0.6 (Good)
0.4 (Poor)
0.2 (Very Poor)

Attachment D: Bat Call WA Pty Ltd Report

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Bat Call WA Pty Ltd

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10 October 2017

Rio Tinto CAT 3 Vendor Number 11027089

Matthew Love
Senior Environmental Scientist
Astron Environmental Services
129 Royal St,
East Perth 6004,
Western Australia

Rio Tinto Mesa A and H targeted Night Parrot survey

Astron Environmental Services has provided Bat Call with a series of audio recordings made at Mesa A and Mesa H in September 2017. These recordings were made at eight locations, four at each mesa, and targeted Night Parrot (*Pezoporus occidentalis*) presence. They were made using Songmeter SM2 audio detectors fitted with SMX-II microphones. Reference calls for the Night Parrot for comparison were available from Bat Call's library.

The recoding data and results for each site are summarised in the following tables.

Mesa A	Date	Recording Time & SM2 unit	Easting	Northing	Night Parrot presence detected
SM002468A	13 to 16 September	Detector failed to record	381293	7599064	No
SM002468B	17 to 20 September	Detector failed to record	381262	7599212	No
SM007982A	13 to 16 September	Four overnight recordings using SM2 SN 7982	380088	7608911	No
SM007982B	17 to 19 September	Three overnight recordings using SM2 SN 7982	391731	7602261	No

Mesa H	Date	Recording Time & SM2 unit	Easting	Northing	Night Parrot presence detected
SM004685A	15 to 17 September	Three overnight recordings using SM2 SN 4685	421585	7591008	No
SM004685B	18 to 20 September	Three overnight recordings using SM2 SN 4685	415745	7598784	No
SM004698A	15 to 17 September	Three overnight recordings using SM2 SN 4698	422451	7591151	No
SM004698B	18 to 20 September	Three overnight recordings using SM2 SN 4698	416396	7599262	No

Yours sincerely

Robert Bullen
Managing Director and Principal Ecologist

Mesa H
Ghost Bat, *Macroderma gigas* - Contextual Study
September 2017

Prepared for
Robe River Mining Co. Pty Ltd

astron

Report Reference: 14269-16-BISR-1Rev0_170907

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Mesa H
Ghost Bat, *Macroderma gigas* – Contextual Study

Prepared for
Robe River Mining Co. Pty Ltd

Job Number: 14269-16

Reference: 14269-16-BISR-1Rev0_170907

Revision Status

Rev	Date	Description	Author(s)	Reviewer
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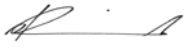
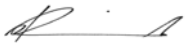
Approval

Rev	Date	Issued to	Authorised by	
			Name	**Signature**
A	29/07/2016	P. Royce	S. Pearse	
B	05/09/2017	M. Brand	R. Archibald	
0	07/09/2017	M. Brand	R. Archibald	

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Abbreviations and Definitions

Abbreviation	Definition
Adit	The entrance to a mine shaft that is horizontal or near horizontal.
Bat Call WA	Bat Call WA Pty Ltd
Biologic	Biologic Environmental Survey
Biota	Biota Environmental Services
BOM	Bureau of Meteorology
cm	Centimetres
Contextual survey area	The survey area between the Mesa A Operation and Mesa H deposit that the contextual field survey was completed within (94,582 ha)
Desktop survey area	A 30 km radius around the Mesa H survey area that the desktop assessment was undertaken
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999*
Fecundity	The reproductive rate of an organism or population
g	Grams
GDA	Geocentric Datum of Australia
GIS	Geographical Information System
HSE	Health, safety and environment
IBRA	Interim Biogeographic Regionalisation for Australia
km	Kilometres
m	Metres
Mesa H survey area	The Mesa H development envelope (4,930 ha)
Midden	A collection of scats and animal remains that indicate a frequently used feed site
mm	Millimetres
MNES	Matter of National Environmental Significance
Mt	Mount
Robe River Mining	Robe River Mining Co Pty Ltd
Scat	Faecal matter
SM2	SM2BAT SongMeter bat detectors (Wildlife Acoustics Inc USA)
WC Act	*Wildlife Conservation Act 1950*
°C	Degrees Celsius

Executive Summary

Astron was commissioned by Robe River Mining Co Pty Ltd to undertake a contextual analysis for the conservation significant Ghost Bat (*Macroderma gigas*) within the vicinity of the Mesa H survey area. The Ghost Bat has recently been upgraded to Vulnerable under the *Environment Protection and Biodiversity Conservation Act 1999* and Schedule 3 under the *Wildlife Conservation Act 1950*. The Mesa H survey area is approximately 4,930 ha and encompasses potential future mine and infrastructure. The contextual survey area is approximately 94,582 ha and encompasses areas west of Mesa H through to the Mesa A Operation. The purpose of this assessment is to identify significant habitats for the Ghost Bat in the vicinity of the Mesa H survey area and to discuss this habitat in a local and regional context.

The first stage of the assessment involved a desktop review. This review combined data from database searches and previous surveys from within a 30 km radius of the Mesa H survey area. The review indicated that 79 Ghost Bat records, including six diurnal roosts (five confirmed and one potential) and three maternal roosts (one confirmed and two potential) have been recorded within 30 km of the Mesa H survey area (the desktop survey area). This includes two diurnal roost sites that have been previously identified within the Mesa H survey area.

The second stage of the assessment was a field survey involving mapping of potential habitat and targeted survey for the Ghost Bat within the contextual survey area. Survey effort was concentrated to the west of Mesa H, specifically along the Robe Valley, as this area lacked recent Ghost Bat records/data and the Robe Valley to the east of Mesa H had been recently surveyed. Habitats of the contextual survey area were assessed and mapped on their ability to support Ghost Bats, in particular the presence of roosting sites, feed cave sites and quality foraging sites. Habitats were mapped as:

- High quality habitat: potential/confirmed roosting habitat.
- Moderate quality habitat: potential/confirmed nocturnal feeding roosts and quality foraging habitat.
- Low quality habitat: widespread foraging habitat.

The vast majority of the contextual survey area (90,425.3 ha and 95.6%) contains habitat considered as being of low quality habitat for Ghost Bats, including approximately 4,716.1 ha within the Mesa H survey area. A total of 2,531.1 ha (2.7%) of the contextual survey area contains habitat considered as being of moderate quality habitat for Ghost Bats, including approximately 270.4 ha within the Mesa H survey area. A total of 256 ha (0.3%) of the contextual survey area contains habitat considered as being of high quality habitat for Ghost Bats, including only 4.1 ha within the Mesa H survey area.

During the field survey an additional 26 nocturnal feeding roosts, four diurnal roosts and two potential maternal roosts were recorded in the contextual survey area; however, no new roost sites were located in the Mesa H survey area. Since the field survey was completed, further targeted cave assessments have reassessed some of theses caves and it is considered that only four diurnal roosts (three confirmed and one potential) and one potential maternal roost occurs within the contextual survey area. No new roosts were recorded within the Mesa H survey area.

Although high quality habitat is present within the Mesa H survey area, the majority of the high quality habitat (98.4%) and roost sites are located in areas outside the Mesa H survey area. The most significant Ghost Bat habitats in the contextual survey area are located within the gorges on the

lower Robe Valley Mesas, Mesa G and the gorge system along the Buckland Hills to the south of Mesa H, although the only confirmed maternal roost occurs at Mesa F. The gorge to the south of Mesa H was too large to properly survey within the scope of this assessment and only received a preliminary assessment. A maternal roost and two diurnal roosts were identified, however based on the geology and size of the gorge system, more roost sites are expected.

The land systems mapping for the contextual survey area shows relationships between the Robe and Newman systems and the presence of both diurnal and maternal roost sites. Within the contextual survey area approximately 96% of the Newman system and 75% of the Robe system are located outside of the Mesa H survey area, indicating that both of these land systems are well represented locally and are widespread throughout the Pilbara.

The number of Ghost Bat records from the desktop assessment and field survey suggest that the Ghost Bat is common and widespread in small numbers within the Robe Valley and the vicinity of Mesa H. The contextual survey area occurs in the Hamersley subregion where Ghost Bats are widespread but occur in small numbers (approximately 350 individuals) and relatively few breeding records exist. Little is known about this species' roost site fidelity, seasonal movements or local population estimates in the Pilbara, let alone in the contextual survey area or the roost sites identified in this assessment.

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1 Introduction

1.1 Project Background

Robe River Mining Co. Pty. Ltd (the Proponent), is evaluating the potential development of the Mesa H deposit (Mesa H) located adjacent to the Mesa J Operation and approximately 13 km to the southwest of the town of Pannawonica. A key component of the pre-feasibility and feasibility studies being undertaken is the environmental surveys which are required to inform the environmental assessment process for the potential development of the Mesa H deposit (Figure 1). Astron Environmental Services (Astron) has been commissioned to undertake a number of these environmental surveys.

This report presents the outcome of a contextual analysis of conservation significant fauna, specifically the Matter of National Environmental Significance (MNES) species the Ghost Bat (*Macroderma gigas*), within the vicinity of the Mesa H survey area. The status of the Ghost Bat has recently been upgraded to Vulnerable under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) and Schedule 3 under the *Wildlife Conservation Act 1950* (WC Act).

1.2 Scope and Objectives

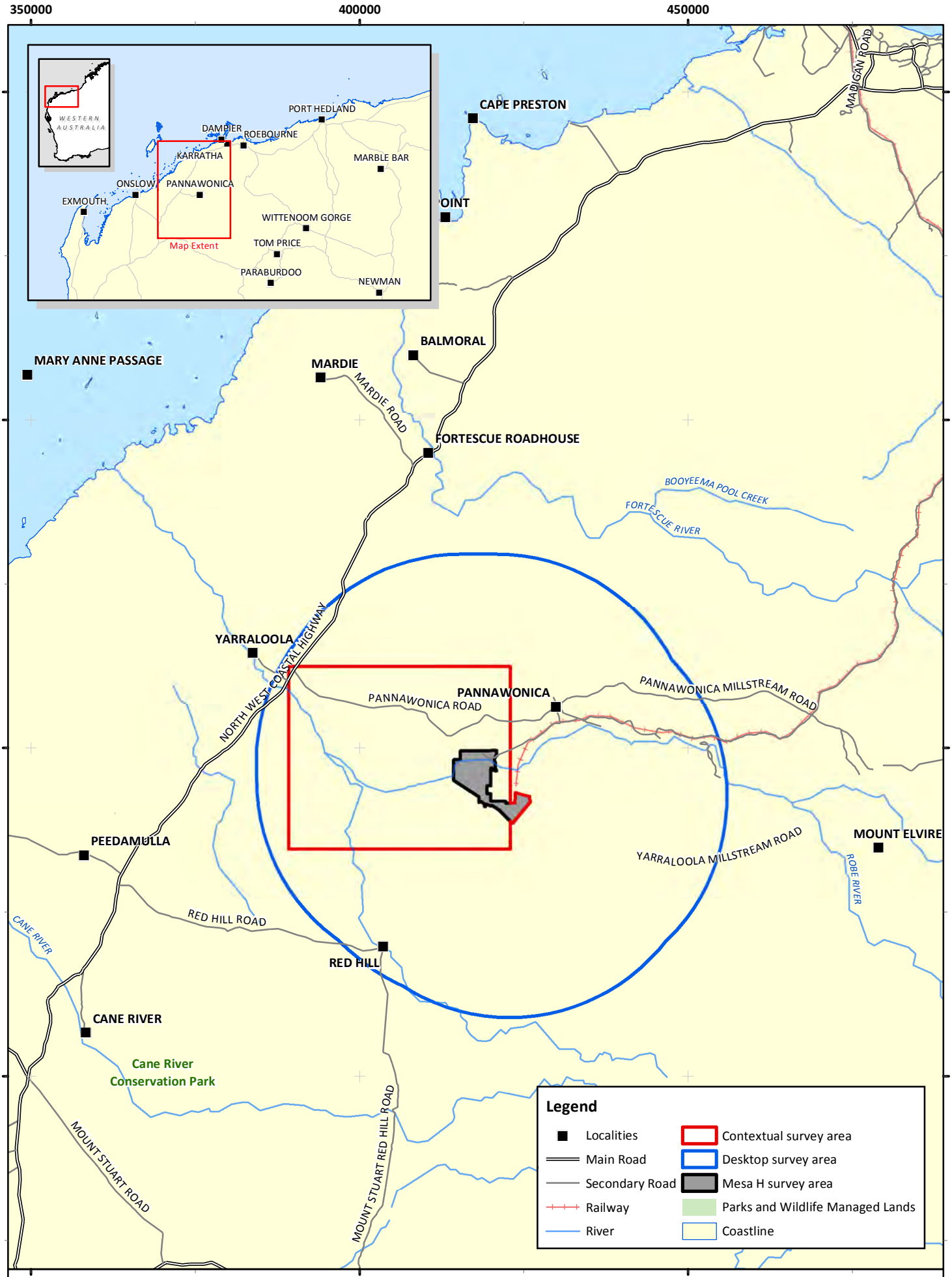
The purpose of this assessment is to identify significant habitats for the Ghost Bat in the vicinity of the Mesa H survey area and to discuss this habitat in a local and regional context.

To obtain a contextual overview of this species within the vicinity of the Mesa H survey area, Astron undertook a desktop review and targeted fauna survey for the Ghost Bat. The desktop assessment combined data from database searches and previous surveys from within a 30 km radius of the Mesa H survey area (desktop survey area; Figure 1).

A number of recent biological surveys have been completed within the Robe Valley, in particular at Mesa H and areas to the east (Bungaroo, Middle Robe). These assessments have provided data on the Ghost Bats presence and habitat within these areas. The field component of this survey concentrated on the Robe Valley to the west of Mesa H (contextual survey area) where recent Ghost Bat specific data were lacking. The contextual survey area is approximately 94,582 ha and covers the Robe Valley between the Mesa A Operation (Mesa A) and Mesa H (Figure 1).

Astron conducted the contextual study in accordance with the following:

- Position Statement No. 3 (Environmental Protection Authority 2002)
- Guidance Statement No. 56 (Environmental Protection Authority 2004)
- Technical Guide – Terrestrial Vertebrate Fauna Surveys for Environmental Impact Assessment (Environmental Protection Authority and Department of Environment and Conservation 2010)
- Survey Guidelines for Australia's Threatened Bats (Department of the Environment, Water, Heritage and the Arts 2010).



Robe River Mining Co. Pty Ltd

Mesa H - Ghost Bat, *Macroderma gigas* - Contextual Study

Figure 1: Survey area regional location

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Author: J. Trainer	Date: 31-08-2017
Drawn: C. Dyde	Figure Ref: 14269-16BIDR-1RevB_170831_Fig01

Datum: GDA 1994 - Projection: MGA Zone 50

0 5 10 15 20 25 Km

N

2 Environmental Context

2.1 Geology and Soils

The contextual survey area occurs on the Hamersley Basin which overlies the Archaean Pilbara Craton and comprises of mafic and felsic volcanics, shale, siltstone, sandstone and conglomerate, as well as dolomite and banded iron formation. The area is extensively deformed with the rocks being folded and faulted (van Vreeswyk et al. 2004). The surface geology of the contextual survey area comprises 13 different geological units (Stewart et al. 2008) (Table 1). Geological mapping of the contextual survey area and surrounds is presented in Figure A.1 (Appendix A).

Table 1: Geological units of the contextual survey area.

Geological name	Label	Area (ha) within the contextual survey area
Marra Mamba Iron Formation: chert, ferruginous chert, jaspilite, banded iron formation, minor shale, siltstone, mudstone	Achm	2,419
Mount McRae Shale and Mount Sylvia Formation: interbedded shale, chert, banded iron-formation	Ashm	4,640
Jeerinah Formation: shale, sandstone, siltstone, mudstone, dolomite, local microbanded chert, jaspilite, conglomerate; fine-grained massive rhyolite; mafic tuff with local accretionary lapilli and agglomerate; thin basalt/dolerite and andesitic basalt flows	Awfj	476
Robe Pisolite: pisolitic, oolitic and massive limonite, goethite and hematite deposits containing fossil wood fragments; iron ore	Czlr	9,777
Nanutarra Formation: shale, ferruginous and glauconitic quartz sandstone, siltstone, micaceous siltstone; poorly sorted conglomerate	Kswn	9,345
Boolgeeda Iron Formation: fine-grained, finely laminated, dark grey-brown to black flaggy iron-formation, minor chert, jaspilite, shale	Lchb	1,445
Brockman Iron Formation: banded iron-formation, chert, mudstone and siltstone	Lchk	7,437
Weeli Wolli Formation: banded iron-formation (commonly jaspilitic), mudstone, siltstone; common interlayered metadoleritic sills	Lchw	87
Woongarra Rhyolite: rhyolite, rhyodacite, rhyolitic volcaniclastic breccia and banded iron formation	Lfhw	1,581
Wyloo Group: shale, sandstone, greywacke, dolomite, phyllite, quartz-mica schist, felsic volcanic rocks, chert, chert breccia, mudstone, siltstone, conglomerate	Lsy	8,449
Ashburton Formation: mudstone interbedded with sandstone and dolomite; intruded by sills	Lsya	1,049
Alluvium 38485: channel and flood plain alluvium; gravel, sand, silt, clay, locally calcreted	Qa	14,524
Colluvium 38491: colluvium, sheetwash, talus; gravel piedmonts and aprons over and around bedrock; clay-silt-sand with sheet and nodular kankar; alluvial and aeolian sand-silt-gravel in depressions and broad valleys in Canning Basin; local calcrete, reworked laterite	Qrc	33,352

Soils of the contextual survey area are typically shallow and of poor quality; soils in the area of the Mesa A Operation are pisolitic limonite gravels, whilst the river landform is characterised by sand, gravel, pebbles and stones. The drainage zones surrounding are red shallow loams (van Vreeswyk et al. 2004).

2.2 Surface Water and Hydrology

The Robe River is considered a seasonal watercourse. It intersects the contextual survey area, flowing in an east-west orientation. A number of permanent pools in the river were observed within the contextual survey area. Numerous creeks and smaller drainage lines stem from the Robe River; drainage lines were also noted down the gullies of the surrounding mesas. There are no regionally significant wetlands in proximity.

2.3 Land Systems

Land systems of the Western Australian rangelands were mapped by the Department of Agriculture and Food to outline their distributions and provide comprehensive descriptions of biophysical resources, including soil and vegetation condition. A total of 102 land systems occur in the Pilbara bioregion covering 181,723 km^2, of which 12 occur in the contextual survey area (Table 2). The distribution of these land systems within the contextual survey area is shown in Figure A.2 (Appendix A).

Table 2: Distribution of land systems within the contextual survey area and Pilbara bioregion (van Vreeswyk et al. 2004).

Land system	Total area within Pilbara bioregion (ha)	Total area within the contextual survey area (ha)	Proportion within the contextual survey area (%)
Boolgeeda: Stony lower slopes and plains below hill systems supporting hard and soft spinifex grasslands and mulga shrublands	961,847	16,779	1.7%
Cane: Alluvial plains and flood plains supporting snakewood shrublands, soft and hard spinifex grasslands and tussock grasslands	81,798	496	0.6%
Capricorn: Rugged sandstone hills, ridges, stony footslopes and interfluves supporting low acacia shrublands or hard spinifex grasslands with scattered shrubs	698,396	3,508	0.5%
Marallina: Sandy surfaced alluvial plains supporting soft spinifex grasslands and minor hard spinifex and tussock grasslands	41,825	1,269	3%
McKay: Hills, ridges, plateaux remnants and breakaways of meta sedimentary and sedimentary rocks supporting hard spinifex grasslands	425,967	1,881	0.4%
Nanutarra: Low mesas and hills of sedimentary rocks supporting soft and hard spinifex shrubby grasslands	77,423	14,198	18.3%
Newman: Rugged jaspilite plateaux, ridges and mountains with hard spinifex	1,994,339	15,898	0.8%
River: Active flood plains, major rivers and banks supporting grassy eucalypt woodlands, tussock grasslands and soft spinifex grasslands	481,994	5,553	1.1%
Robe: Low limonite mesas and buttes supporting soft spinifex (and occasionally hard spinifex) grasslands	128,680	10,967	8.3%
Sherlock: Stony alluvial plains supporting snakewood shrublands with patchy tussock grasses and spinifex grasslands	38,662	10,403	26.9%
Stuart: Gently undulating stony plains supporting hard and soft spinifex grasslands and snakewood shrublands	276,800	4,146	1.5%
Urandy: Stony plains, alluvial plains and drainage lines supporting shrubby soft spinifex grasslands	132,039	9,484	7.2%
TOTAL	**5,339,770**	**94,582**	**N/A**

2.4 Vegetation and Flora

Pre-European vegetation has been mapped across the Pilbara region at a scale of 1:1,000,000 (Beard 1975). The contextual survey area is located in the Stuart Hills and Hamersley Plateau physiographic units of the Fortescue Botanical District (Figure A.3, Appendix A). These physiographic units are described as:

Hamersley: a compact unit defined by the outcropping of jaspilite and dolomite, with some shale, siltstone and volcanics. Vegetation is described as:

- ranges – tree steppe of *Eucalyptus brevifolia* (likely to represent *E. leucophloia*) over *Triodia wiseana* hummock grasslands
- valley plains – mulga (*Acacia aneura* complex) low woodlands, or tussock grasslands on cracking clay soils
- basalt hills – mosaic of mulga low woodland and *Acacia pyrifolia* and *Triodia* species shrub steppe.

Stuart Hills: this unit consists mostly of plains, gently undulating pediplains extending out from Breakaways and residuals capped by Robe pisolites, and stony hills and steeply dissected pediments on fine-grained sandstone, shale and dolomite. Vegetation is described as:

- hills and plains – *Triodia wiseana* and *T. basedowii* hummock grasslands with sparse shrubs, particularly *Acacia bivenosa*
- Drainage lines – *Corymbia hamersleyana* and *C. candida* occur occasionally, with *Senna* species and ephemerals
- major rivers – *Eucalyptus camaldulensis* and *Acacia citrinoviridis* along river and mulga low woodland on river flats and tributaries.

Nine pre-European vegetation units, 29, 82, 93, 157, 583, 603, 605, 609 and 620 (Shepherd, Beeston, and Hopkins 2002), are associated with the contextual survey area:

29: 'Sparse low woodland; mulga, discontinuous in scattered groups,

82: 'Hummock grasslands, low tree steppe; snappy gum over *Triodia wiseana*',

93: 'Hummock grasslands, shrub steppe; kanji over soft spinifex',

157: 'Hummock grasslands, grass steppe; hard spinifex, *Triodia wiseana'*,

583: 'Hummock grasslands, sparse shrub steppe; kanji and *Acacia bivenosa* over hard spinifex *Triodia basedowii* and *T. wiseana*',

603: 'Hummock grasslands, sparse shrub steppe; *Acacia bivenosa* over hard spinifex',

605: 'Hummock grasslands, shrub steppe, *Acacia pachycarpa* and waterwood over soft spinifex',

609: 'Mosaic: Hummock grasslands, open low tree steppe; bloodwood with sparse kanji shrubs over soft spinifex/Hummock grasslands, open low tree steppe; snappy gum over *Triodia wiseana*' and

620: 'Hummock grasslands, shrub steppe; snakewood over soft spinifex.

Table 3 summarises the current and pre-European extent of these nine vegetation units in the Pilbara and the contextual survey area.

Table 3: Extent of pre-European vegetation in the contextual survey area (Government of Western Australia 2014).

Vegetation association	Extent in the contextual survey area (ha)	Current extent in Pilbara bioregion (ha)
29	11,943	1,132,939
82	14,710	2,550,898
93	6,315	3,038,471
157	25	198,409
583	11,793	243,111
603	13,999	55,764
605	24,133	114,115
609	2,278	72,765
620	9,385	15,539

2.5 Ghost Bat, *Macroderma gigas*

2.5.1 Distribution and Conservation Status

The status of the Ghost Bat (*Macroderma gigas*) has been recently upgraded to Vulnerable under the Commonwealth EPBC Act and Schedule 3 under the Western Australian WC Act. This is due to the fact that the Ghost Bat has undergone a substantial decline across its distribution, including an estimated decline greater than 30% in the Pilbara population (Department of the Environment and Energy 2016).

Ghost Bats occur in the Pilbara (Armstrong and Anstee 2000; McKenzie and Bullen 2009), Kimberley including several islands (McKenzie and Bullen 2012), northern sections of the Northern Territory (including Groote Eylandt), and coastal and near coastal eastern Queensland from Cape York to near Rockhampton (Richards et al. 2008). Burbidge et al. (2009), using modern, historical and subfossil data, found that the Ghost Bat occurred in 37 of Australia's 85 bioregions, and that it was extinct in 12 bioregions.

The Pilbara Ghost bat population is estimated at 1,500 to 2,000 based on recently published estimates. This includes estimates of approximately 600 (N.L. McKenzie pers. comm. in McKenzie and Hall 2008); approximately 1,200 (Armstrong and Anstee 2000) and Robert Bullen's unpublished database summarising data from a range of surveys carried out in recent years by Pilbara mining companies, including Rio Tinto and other organisations (summarised in Department of the Environment and Energy (2016)). These recent data (estimates less than 15 years old) cover the entire Pilbara bioregion. Current population estimates in the Hamersley and Chichester subregions are approximately 350 and 1,500 respectively (author's unpublished database summarised in Department of the Environment and Energy (2016)).

Ghost bat breeding populations are known from a small number of maternal roosts in the Pilbara, the largest of these colonies are in abandoned mines in the Chichester subregion and number up to several hundred (Armstrong and Anstee 2000). There is no known large, permanent maternal roost in the Hamersley subregion (Bat Call WA 2016a). Hamersley Range populations are between 5 and 25 individuals in local groups (Bat Call WA 2016a). Multiple records including visual observations and the presence of cave middens of the Ghost bat have been detected on the various mesas within the Robe River valley (Bat Call WA 2016a).

2.5.2 Relevant Biology/Ecology

The Ghost Bat is the largest microchiropteran bat in Australia, weighing up to 150 g and having a wingspan of 60 cm. It is Australia's only carnivorous bat. Its fur is light to dark grey above and paler below (Plate 1). It has long ears which are joined together, large eyes, a simple noseleaf and no tail (Richards et al. 2008). The Ghost Bat occurs in a wide range of habitats from the arid Pilbara to tropical savanna woodlands and rainforests and has a broad diet comprising small mammals including other bats, birds, reptiles, frogs and large insects (Boles 1999; Schulz 1986; Pettigrew et al. 1986).

In the Pilbara, pregnancy in Ghost Bats has been recorded from August until September and births occurred from October until December (Armstrong and Anstee 2000). Hoyle et al. (2001), who studied the southernmost known colony in Queensland, found that female bats gave birth to a single young in late spring and females bred at age two to three years. At Mount Etna, Toop (1985) found that pregnant females congregated in the warmest caves and gave birth over a month commencing in mid-October. As caves became warmer as summer progressed, some mothers shifted the young to other caves. Juvenile bats commenced flying at seven weeks with all young capable of flight by the end of January. Ghost bats disperse widely when not breeding, but concentrate in relatively few maternal roost sites when breeding. Few of these sites are known (Worthington Wilmer 2012; Richards et al. 2008), and most are not protected or managed.

Bat Call WA (2016a) describes the roosting requirements of Ghost Bats: "For Ghost Bats to persist the bats need an 'apartment block' of roosting opportunities, at least one deep cave with characteristics of a maternal roost, multiple caves/shelters and overhangs in close proximity offering nocturnal feeding and refuge opportunities, a productive set of gullies and gorges locally, and a productive foraging area within a 5 km to 10 km radius, usually including a good quality riparian line and appropriate protection from human interference."

Ghost Bats hunt their prey in two primary ways. They hunt birds and bats at cave entrances and elsewhere "air-to-air" by swooping from above or from a perch (Bat Call WA 2016a). They also hunt ground level prey in their target food size range by dropping onto the prey from a perch, either tree branch or rock outcrop (Bat Call WA 2016a). Their diet includes small mammals such as other bats, birds, reptiles, frogs and large insects. The proportion of food items in the diet varies with availability and reported foraging areas vary from a few km to over 10 km from the roost cave (Bat Call WA 2016a).

Roost sites include caves, rock crevices and disused mine adits. In the Hamersley Range in the Pilbara, preferred roosting habitat appears to be caves beneath bluffs of low rounded hills composed of Marra Mamba geology, and larger hills of Brockman Iron Formation; in the eastern Pilbara caves beneath bluffs composed of Gorge Creek Group geology and granite rockpiles are preferred (Armstrong and Anstee 2000). Ghost Bats use three types of roost regularly, these being nocturnal roosts or feeding sites, diurnal or diurnal roosts that may be permanent or semi-permanent sites and maternal roosts that are diurnal roosts with the range of characteristics allowing regular or permanent occupancy:

- Nocturnal roosts or feeding sites are only used at night, either habitually or for transitory visits. They are typically shallow caves and shelters that are well lit during the day. They are often high in the strata and may be well or poorly insulated from the elements. They usually contain guano scatters and/or midden(s) of various sizes containing guano and food scraps.
- Diurnal roosts are generally deep, complex caves or disused mines that contain domed ceilings, fissures or passages which create a stable microclimate. They typically have one or

more large chambers at or beyond the twilight area with additional fissures or chambers at the rear in the fully dark regions. They have a minimum roof height in the chambers of 2 m to 3 m providing protection from attack by terrestrial predators. They are often at mid-levels or lower in the strata and are well insulated overhead providing a stable temperature environment (McKenzie and Bullen 2009; Armstrong and Anstee 2000; Hall et al. 1997; Leitner and Nelson 1967). They typically contain multiple scat piles and middens of guano and food remains that include feathers and skeletal materials.

- Maternal roosts are diurnal roosts that provide additional features listed above that are able to support a reproducing population. These features usually include an interior chamber that is rising toward the rear thereby trapping warmer and more humid air at the top allowing suitable conditions to form during the period when reproductive females and pups are present (Armstrong and Anstee 2000; Churchill 1991; Churchill and Helman 1990; Pettigrew et al. 1986).

2.5.3 Threats

Threats to the Ghost Bat have been outlined by Woinarski et al. (2014) and are summarised in Table 4.

Table 4: Summary of threats to the Ghost Bat (Woinarski, Burbidge, and Harrison 2014).

Threat factor	Consequence rating	Extent over which threat may operate	Evidence base
Disturbance of (human visitation at) maternal roost sites	Severe	Moderate	Ghost Bats easily disturbed and may abandon sites where disturbance occurs (K. Armstrong pers. comm., cited in. Woinarski et al. 2014).
Habitat loss: destruction of, or disturbance to, roost sites (and nearby areas) due to mining	Moderate-severe	Moderate	Mt Etna and surrounding area contains maternal roost sites; some maternal roost sites destroyed; Mt Etna now protected in a national park and visited by tourists; declines reported at Mt Etna following mining (Worthington Wilmer 2012); Mount Consider cave west of Cairns destroyed; other sites still vulnerable; most Pilbara roosts are vulnerable to iron ore mining and the deterioration and disturbance of old underground gold and copper mines.
Collision with fences, especially those with barbed wire	Moderate	Moderate	Ghost Bats have low fecundity and survival (Hoyle et al. 2001), often fly at about fence height and substantial numbers are known to be killed when colliding with fencing wire (McKenzie and Bullen 2009; Armstrong and Anstee 2000).
Collapse or reworking of old mine adits	Minor-moderate	Minor-moderate	Many of the known nursery roosts are in old mine workings that are collapsing, flooding or subject to disturbance (Armstrong 2001; Hall et al. 1997) e.g. the Pine Creek colony roosts in an adit that is in danger of collapse (Richards et al. 2008).
Contamination by mining residue at roost sites	Moderate	Moderate	Several roosting sites in old mines have high levels of pollutants.

Threat factor	Consequence rating	Extent over which threat may operate	Evidence base
Disease	Unknown	Unknown	A possible herpes type virus appears to be affecting the Mt Etna population, but pathology yet to be confirmed (J. Augusteyn pers. comm., cited in Woinarski et al. 2014).

3 Methodology

3.1 Desktop Assessment

Database searches were conducted to identify previous Ghost Bat records within the desktop survey area, a 30 km radius from Mesa H (Table 5). The 30 km radius search area was used as it encompasses all of the recent survey work completed within the Robe Valley including the contextual survey area.

Table 5: Database searches and regional literature.

Source		Information	Administrating agency
Databases	*NatureMap* (Department of Parks and Wildlife 2016a)	List of species recorded, including threatened fauna	Department of Parks and Wildlife
	Threatened Species Database (Department of Parks and Wildlife 2016b)	List and details of conservation significant fauna species recorded in vicinity of survey area	
Regional literature	Stewart, Sweet et al. (2008)	Surface geology of Australia	N/A
	Beard (1975)	Vegetation associations of the Pilbara region	N/A
	Van Vreeswyk, Payne et al. (2004)	Land Systems (geology, soils, and topography) and vegetation associations of the Pilbara region	N/A
	Previous survey reports and GIS data	List of fauna, particularly conservation significant species, previously recorded within or adjacent to study area	Various consultant reports

Relevant fauna surveys that have previously been commissioned by Rio Tinto within the vicinity of the contextual survey area and reviewed as part of this assessment are:

- Astron (2014),'Mesa H Level 1 Flora, Vegetation and Fauna Assessment', unpublished report for Rio Tinto Iron Ore
- Astron (2016a),'Bungaroo Level 2 Fauna Assessment', unpublished report for Rio Tinto Iron Ore
- Astron (2016b),'Mesa H Level 2 Fauna Assessment', unpublished report in prep. for Rio Tinto Iron Ore
- Astron (2016c),'Middle Robe and East Deepdale Level 2 Fauna Assessment', unpublished report for Rio Tinto Iron Ore
- Bat Call WA (2016a). 'Mesa B and C Ghost Bat Roost Cave Assessment, July 2016', unpublished report for Rio Tinto
- Bat Call WA (2017a) 'Robe Valley Mesa A to Mesa 2405A, impact of mining on Ghost bat presence and activity, April 2017, including assessment of caves on Mesas F and G', unpublished report for Rio Tinto

- Bat Call WA (2017b) 'Robe Valley Mesa H, Ghost Bat Roost Assessment, April 2017', unpublished report for Rio Tinto
- Bat Call WA (2017c) 'Robe Valley Mesas A and C, Ghost Bat Roost Cave Assessment, April 2017', unpublished report for Rio Tinto
- Biota Environmental Sciences (Biota) (2005) 'Fauna Habitats and Fauna Assemblage of Mesa A and G, near Pannawonica', unpublished report for Robe River Iron Associates
- Biota (2006), 'Fauna Habitats and Fauna Assemblage of the Mesa A Transport Corridor and Warramboo', unpublished report prepared for Rio Tinto Iron Ore
- Biota (2009), 'Mesa G Baseline Fauna Survey', unpublished report for Rio Tinto Iron Ore
- Biota (2010),'Greater Bungaroo Seasonal Fauna Survey', unpublished report for Rio Tinto Iron Ore
- Biota (2011), 'Robe Valley Mesas Fauna Survey', unpublished report for Rio Tinto Iron Ore
- Biologic Environmental Survey (2014), 'Yarraloola Targeted Fauna Survey', unpublished report for Rio Tinto Iron Ore.
- MWH Australia (2015) 'Level 2 Terrestrial Fauna Surveys: Mesa B-C, Warramboo BWT and Highway to Tod Bore', unpublished report for Rio Tinto Iron Ore.

3.2 Field Survey

3.2.1 Timing and Personnel

Survey effort was concentrated to the west of Mesa H, specifically along the Robe Valley, as this area lacked recent Ghost Bat records/data. The Robe Valley to the east of Mesa H was previously surveyed by Astron in 2015 as part of the Middle Robe/ East Deepdale and Bungaroo fauna surveys and the presence of Ghost Bat activity and potential roost sites assessed. The current field survey was undertaken by John Trainer and Matthew Love, both of whom have over five years of experience conducting Level 2 fauna surveys, including bat monitoring surveys. The field survey was conducted from 3 to 9 June 2016.

Daily weather observations recorded from the Mesa J Operation were used to describe local rainfall and temperatures during the survey. During the survey 39.6 mm rain was received (between 5 and 8 June, with heavy rain occurring between 5 and 7 June) and daily maximum temperatures ranged between 20.5°C and 32.5°C. Night time minimum temperatures varied greatly with warm temperatures experienced from 3 to 6 June (19.4°C to 21.8°C) and cooler temperatures from 7 to 9 June (7.7°C to 14.6°C). A total of 271 mm rainfall was recorded at Mesa J in the 12 months preceding the survey; 133 mm below the annual average of 404 mm at Pannawonica (Station 5069) (Figure 2). Rainfall in the 12 weeks preceding the survey was less than half of the long-term mean for the same period, with 56 mm recorded (Bureau of Meteorology 2016).

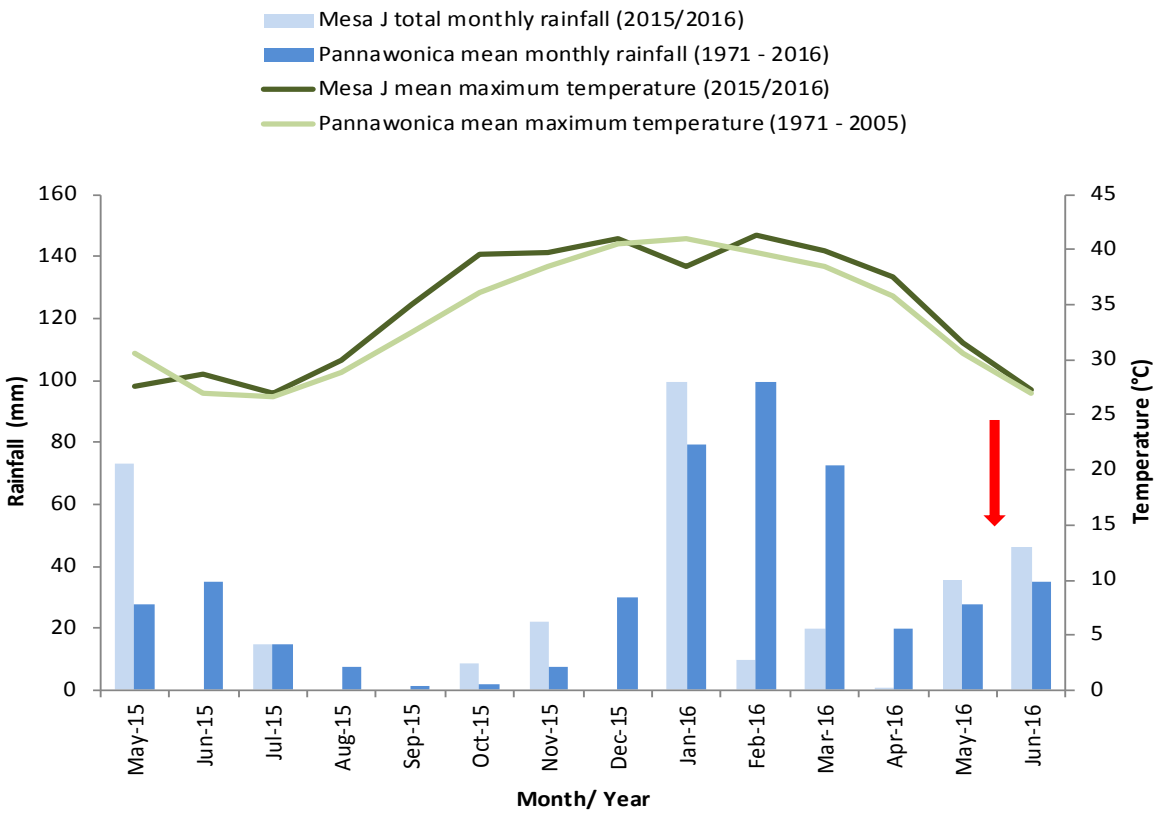


Figure 2: Pannawonica mean monthly rainfall (1971 – 2015) and Mesa J total recorded rainfall (2015/2016), and Pannawonica mean monthly maximum temperatures (1971 – 2016), and Mesa J mean monthly maximum temperatures in the 12 months preceding the survey. Red arrow indicates field survey timing. Pannawonica data from Bureau of Meteorology (2016) and Rio Tinto (2015, 2016).

3.2.2 Acoustic Bat Survey

A total of eight SM2BAT SongMeter (Wildlife Acoustics Inc USA) bat detectors were used at 12 locations completing 35 nights of overnight bat acoustic recordings. The units were situated at the entrance of caves or overhangs or permanent water sources where Ghost Bats were considered likely to forage or roost (Plate 2). One SM2 unit and the associated data for two locations was lost when the unit was crushed under a rock collapse following heavy rain, resulting in only 34 nights of bat recordings at 10 locations (Figure 3).

Due to the unique call characteristics of the Ghost Bat the SM2 units were set up to provide the best chance of recording and identifying Ghost Bat calls and reduce interference/feedback caused by the recording of Pilbara Leaf-nosed Bat (*Rhinonicteris aurantia*) calls. This included the use of both ultrasonic and audio microphones to record the inaudible echolocation calls and the audible social calls used by the Ghost Bat. Analysis of recordings was undertaken by Robert Bullen (Bat Call WA 2016b, Appendix B).

3.2.3 Habitat Assessment

Habitats of the contextual survey area were assessed and mapped on their ability to support Ghost Bats, in particular the presence of roosting sites, feeding sites and quality foraging sites. In this report unless otherwise stated the term 'roost sites' is the collective term for both maternal and diurnal roosts. Significant rocky habitats such as gorges, cliffs and breakaways were identified from aerial photographs or visual inspection during the field survey. If accessible, these habitat features

were traversed by foot during the day and any caves or overhangs were inspected for signs of Ghost Bats and assessed on their suitability as roost caves or feeding sites.

Any cave or overhang that contained Ghost Bat scats and/or feeding remnants (typically feathers and small animal bones) were classified as nocturnal roosts/feeding sites and had their location recorded. The overall concentration of nocturnal roosts/feeding sites is used to indicate the key locations where Ghost Bats forage (given their methods of hunting discussed in Section 2.5.2) and their distribution through the contextual survey area. The focus of the survey was to find and assess the presence of diurnal roosts and maternal roosts. Diurnal roosts were identified by the presence of Ghost Bats (visual observation, presence of scats or low call numbers from acoustic recordings) within or at a complex cave. Maternal roosts were identified by the presence of multiple Ghost Bats (visual observation or high call numbers from acoustic recordings) within or at a complex cave. For this assessment, a complex cave is defined as one which contains domed chambers, internal passages or fissures and is deep enough to provide a different microclimate (stable temperature and elevated humidity) to the ambient.

Cave assessment datasheets were completed at each roost site to document the caves' physical characteristics and their potential to support Ghost Bats. The following details were recorded on each datasheet:

- location – coordinates measured using a handheld GPS (GDA94)
- location on slope – the position of the cave on the slope relative to the top of the slope
- local foraging habitat – broad vegetation description, approximate distance to any nearby water
- entrance description – including aspect and approximate dimensions
- internal description (if visible) – cave depth and height; presence of features such as rear passages, domed chambers
- evidence of bats
- photographs of the cave entrance.

Habitats were rated and mapped as high, moderate or low quality based on the significance each habitat has within the Ghost Bat's ecological requirements. The Ghost Bat habitats were classified according to the criteria detailed in Table 6 and a summary of survey effort is provided in Figure 3.

Table 6: Suitability/significance of habitat criteria for Ghost Bats.

Species	High quality habitat *Potential/confirmed roosting habitat*	Moderate quality habitat *Potential/confirmed feeding sites and quality foraging habitat*	Low quality habitat *Widespread foraging habitat*
Ghost Bat *Macroderma gigas*	Rocky habitats containing, or classified as likely to contain, maternal roosts and/or diurnal roosts.	Habitats containing or likely to contain shallow feeding sites/nocturnal roosts; areas of permanent water sources and gorges suitable for foraging and are likely to be used on a regular basis.	Widespread habitat providing foraging potential only.

380000 390000 400000 410000 420000

7610000

7600000

7590000

North West Coastal Highway

Bat 7

Bat 6

Bat 3

Pannawonica Road

Bat 4

Old Pannawonica Road

ROBE RIVER

MANGAMMADOMA CREEK

Bat A5

Bat A1

Bat A2

Bat A3

Bat A4

Legend

- Bat Detector Locations
- GPS Tracklogs
- Road
- Railway
- River
- Mesa H development envelope and survey area
- Contextual survey area
- Desktop survey area

Robe River Mining Co. Pty Ltd

Mesa H - Ghost Bat, *Macroderma gigas* - Contextual Study

Figure 3: Survey effort

Coordinate System: GDA 1994 MGA Zone 50

0 1 2 3 4 5 Kilometres

N

astron delivering environmental intelligence™

Author: J. Trainer | Drawn: C. Dyde | Date: 05-09-2017 | Figure Ref: 14269-16BIDR-1RevB_170905_Fig03_SurvEff

3.3 Survey Limitations

To identify how complete the contextual survey was, it was assessed against the potential limitations suggested in Guidance Statement 56 for fauna surveys (Environmental Protection Authority 2004). Table 7 lists the key limitations of the targeted Ghost Bat survey.

Heavy rainfall was experienced on three of the six survey nights (5 to 7 June 2016) which affected the SM2 unit's ability to record Ghost Bats. The noise of the rain drowns out all frequency ranges including those where the SM2 unit record bat calls. Additionally, the heavy rain may have reduced the activity levels of Ghost Bats. The survey guidelines for Australia's threatened bats suggest that surveys not be conducted on windy, cold or rainy nights (Department of the Environment, Water, Heritage and the Arts 2010). While not preferred conditions, the rain did not fall during all post dusk and pre-dawn periods and that allowed an adequate chronology of the emergence of the bat species to be recorded (Bat Call WA 2016b).

Data was lost from two locations when the rockfall crushed one of the SM2 units. Although relative abundance data were lost, the occurrence of Ghost Bats at both sites could still be confirmed due to the presence of scats. The occurrence of Ghost Bats in the area is well documented in previous biological reports and as this survey focused on the identification of roost sites rather than the presence/absence of this species it is not deemed a significant limitation.

The heavy rain also created issues with access as many of the tracks were unable to be safely driven on for three of the survey days. As such, on these days access was limited to areas surrounding sealed roads or well used tracks. Overall, this did not impact the survey effort as it just adjusted the areas of focus to sites closer to the main tracks during those days.

Many of the roost caves could not be assessed properly due to the health and safety limitations that did not allow field personnel to enter caves. Internal dimensions were limited to what could be identified visually from the entrance of each cave. To properly assess the size and significance of each roost site, an internal assessment of each cave is required.

Although Mesa H has been extensively surveyed for fauna, only a fraction of the surrounding area has been directly assessed for Ghost Bat presence/suitability. Due to the size of the contextual survey area and the survey effort (two personnel for six survey days) not all areas could be ground-truthed. The contextual survey area was mapped based on the topography identified in the field survey and from aerial photographs and as such it provides an assessment of the likelihood of roost sites. The only way to confirm the presence of roost sites is to walk the gorge/breakaway habitats and assess each cave individually; this was outside of the designated scope for this project. The survey effort and breakaway/gorge locations assessed are displayed in Figure 3. However, the intensity of both the current survey and historical surveys undertaken in the vicinity of Mesa H was considered adequate to identify and assess potential areas of significance.

Table 7: Statement of limitations for the targeted Ghost Bat survey.

Potential limitation	Statement regarding potential limitations
(i) Competency/experience	The ecologists responsible for conducting the survey have extensive experience in conducting Level 2 vertebrate surveys, including targeted bat surveys in the Pilbara.
(ii) Scope What faunal groups were sampled and were some sampling methods not able to be employed because of constraints such as weather conditions.	The survey scope was able to be completed with a total of 35 nights of SM2 acoustic recording and cave assessments undertaken in significant habitats. Internal cave inspections could not be undertaken due to HSE issues. Harp trapping or thermal imaging was not required as part of the scope of this survey.
(iii) Proportion of fauna identified, recorded and/or collected	This was a targeted Ghost Bat survey and did not record any other species or assemblages. It is not possible to determine Ghost Bat abundance/population number from echolocation records; Ghost Bat activity levels provide a relative measure of the population within the contextual survey area.
(iv) Sources of information Previously available information (whether historic or recent) as distinct from new data.	Adequate information was available from database searches and previous studies in the Mesa H survey area and desktop survey area and region.
(v) Proportion of task achieved Further work which might be needed?	The field survey and the desktop assessment were undertaken and considered complete. Any further data required such as population estimates and numbers using each maternal roost are outside of the scope of this assessment and would require a more detailed work program.
(vi) Timing/weather/season/ cycle	The heavy rain experienced during much of the survey period limited the recording ability of the SM2 units and potentially the activity levels of the Ghost Bats. The presence of Ghost Bats in the area is well documented in previous biological reports and as this survey focused on the identification of roost sites rather than the presence/absence of this species it is not deemed a significant limitation.
(vii) Disturbances e.g. fire, flood, accidental human intervention which affected results of survey	A rockfall caused by heavy rain crushed a SM2 unit, losing four nights of data from two separate locations. The data lost were from feeding sites that contain Ghost Bat scats. Although relative abundance data was lost, the presence of Ghost Bats at both sites could still be confirmed. Therefore, the loss of the SM2 unit did not significantly affect the results of the survey.
(viii) Intensity In retrospect, was the intensity adequate?	The intensity of the surveys was considered adequate to ground-truth the desktop assessment and to assess potential areas of significance.
(xi) Completeness Was the relevant area fully surveyed?	Due to the large survey area and the fact that assessments had to be completed on foot, not all breakaways/gorges could be assessed. The points of interest identified during the desktop assessment were suitably covered with all other areas mapped via aerial photographs.
(x) Resources Degree of expertise available in animal identification to taxon level.	All personnel involved in identification have extensive experience in conducting bat monitoring surveys in the Pilbara. All bat call identifications were conducted by Robert Bullen (Bat Call WA) who is considered an expert in this field.
(xi) Remoteness and/or access problems	The majority of significant habitats were able to be accessed by vehicle or on foot. There were two areas classified as high quality

Potential limitation	Statement regarding potential limitations
	habitat that were not able to be assessed due to lack of access. Due to safety and heritage related constraints, internal inspections of caves were not permitted. Ghost Bat roost caves were assessed by external visual observation only, with the internal structure beyond visual boundaries unknown. Cave assessments were used to provide an indication as to whether Ghost Bats were recorded or may utilise the caves as habitat.
(xii) Availability of contextual information e.g. biogeographic information on the region.	Database searches and previous fauna surveys in the desktop survey area provided by Rio Tinto provided contextual information.

4 Results

4.1 Desktop Assessment

The database searches and literature review indicate that 79 Ghost Bat records (not including records from the current survey) exist within 30 km of the Mesa H survey area (Figure 4). The majority of these records (approximately 53%) are from the identification of scats (42 records) or acoustic records (15 records). These types of records provide information on the presence of this species at the location but do not provide the relative abundance or habitat context (i.e. foraging individual vs roost site).

Where Ghost Bat records were identified as occurring at a cave, but its dimensions or habitat context were not stated, some inferences were used to classify the record. Unless specifically stated, any caves that contain scats or feeding material are classified as nocturnal feeding roosts, that have a visual record of a single Ghost Bat are classified as a potential diurnal roost, and caves with visual records of multiple Ghost Bats are classified as a potential maternal roost. Only records of roost sites that are supported by cave assessments and/or visual sightings or high call readings from acoustic recordings are stated as confirmed roost locations. For many of the potential roost sites, the consultant's reports provided limited information on the cave dimensions, habitat context or use by Ghost Bats; as such, little can be inferred from these records.

From the desktop assessment (not including records from the current survey) a total of seven diurnal roost sites (six confirmed and one potential) and two maternal roost sites (one confirmed and one potential) have been previously recorded in the wider desktop survey area. A summary of the Ghost Bat records from previous ecological surveys is presented in Table 8 and the comprehensive data from the desktop assessment is detailed in Appendix C. The numbers of diurnal and maternal roosts are high for some earlier surveys; however, more recent targeted assessments have reassessed these caves, and fewer maternal and diurnal roosts have been confirmed. A summary of diurnal and maternal roosts confirmed following the current survey and more recent targeted caves assessments is presented in Table 9.

The most significant record from the desktop assessment was a potential maternal roost (reference number 11, Appendix C) on Mesa F where 24 Ghost Bats were captured in harp traps at a cave (Biota Environmental Sciences 2009). This cave was confirmed as a permanent maternal roost (MF01) in 2017 when 70 individuals were found to be present (Bat Call WA 2017a). This cave had two entrances opening into a mid-size chamber. It had multiple internal chambers between 2.5 m and 7 m high. The cave was located approximately 4 km from the Robe River.

One cave on Mesa B (MBC-05) was determined to be a diurnal roost with the ability to support a maternity colony (Bat Call WA 2016a). This cave included an internal shape adequately deep and dark along with a high domed chamber at the rear, multiple nocturnal roost opportunities, multiple daytime refuge opportunities, multiple early evening observation sites and a major productive riparian zone within 5 km (Bat Call WA 2016a).

Table 8: Summary of Ghost Bat records from biological surveys in the vicinity of Mesa H.

Report title	Company	Year of report	Distance from Mesa H	Ghost Bat records
Mesa H Level 1 Flora, Vegetation and Fauna Assessment	Astron	2014	Within Mesa H	7 diurnal roosts 4 acoustic records 2 remains
Middle Robe and East Deepdale Level 2 Fauna	Astron	2016	4 km to 35 km	1 maternal roost 4 diurnal roosts 12 nocturnal feeding roosts 4 acoustic records
Bungaroo Level 2 Fauna Assessment	Astron	2016	12 km to 35 km	12 nocturnal feeding roosts
Mesa H Level 2 Flora, Vegetation and Fauna Assessment	Astron	2016	Within Mesa H	1 nocturnal feeding roost 1 acoustic record
Fauna Habitats and Fauna Assemblage of Mesa A and G, near Pannawonica	Biota	2005	3 km to 32 km	1 diurnal roost (1visual sighting)
Fauna Habitats and Fauna Assemblage of the Mesa A Transport Corridor and Warramboo	Biota	2006	22 km to 29 km	1 nocturnal feeding roost
Mesa G Baseline Fauna Survey	Biota	2010	4 km	1 maternal roost 1 individual caught
Greater Bungaroo Seasonal Fauna Survey	Biota	2010	13 km	1 diurnal roost
Robe Valley Mesas Fauna Survey	Biota	2011	16 km to 22 km	1 maternal roost 1 acoustic record
Yarraloola Targeted Fauna Survey	Biologic	2014	6 km to 18 km	2 visual sightings 1 nocturnal feeding roost
Mesa B and C Ghost Bat Roost Cave Assessment, July 2016	Bat Call WA	2016	25 km to 32 km	1 diurnal roost (possible maternal roost) 1 probable diurnal roost 18 nocturnal feeding roosts
Robe Valley Mesas A and C, Ghost Bat Roost Cave Assessment, April 2017	Bat Call WA	2017	25 km to 35 km	3 nocturnal feeding roosts (1 potential diurnal roost)

Report title	Company	Year of report	Distance from Mesa H	Ghost Bat records
Robe Valley Mesa A to Mesa 2405A, impact of mining on Ghost bat presence and activity, April 2017, including assessment of caves on Mesas F and G	Bat Call WA	2017	3 km to 18 km	1 maternal roost (70 individuals sighted) 1 diurnal roost 1 nocturnal feeding roost
Robe Valley Mesa H, Ghost Bat Roost Assessment, April 2017	Bat Call WA	2017	Within Mesa H	2 diurnal roosts (possible maternal roosts) 9 nocturnal feeding roosts
Level 2 Terrestrial Fauna Surveys: Mesa B-C, Warramboo BWT and Highway to Tod Bore	MWH Australia	2015	25 km to 45 km	2 nocturnal feeding roosts 1 acoustic record

Table 9: Summary of Ghost Bat records from the literature and current survey within the desktop, contextual and Mesa H survey areas.

Roost sites	Literature reviewed			Current survey		All sources			
	Mesa H survey area	Contextual survey area	Desktop survey area	Mesa H survey area	Contextual survey area	Mesa H survey area	Contextual survey area	Desktop survey area	Total
Maternal	0	1	0	0	0	0	1	0	**1**
Potential maternal	0	1	0	0	1	0	2	0	**2**
Diurnal	2	0	3	0	3	2	3	3	**8**
Potential diurnal	0	0	1	0	1	0	1	1	**2**

390000 400000 410000 420000 430000 440000 450000

7610000 7600000 7590000 7580000 7570000

Pannawonica Road

Pannawonica - Millstream Road

Old Pannawonica Road

Bungaroo Access Road

Millstream Yarraloola Road

ROBE RIVER

MUNGARATHOONA CREEK

MBC-05 16 indiv.

DRJT1 (MGG-02)

MGT1 (G02) 12 indiv.

Cave 1 (MH16-34) 1 indiv.

Cave 4 (A004)

DRML2

DRML1

Bat A4 30 indiv.

RVM04 (MF01) 70 indiv.

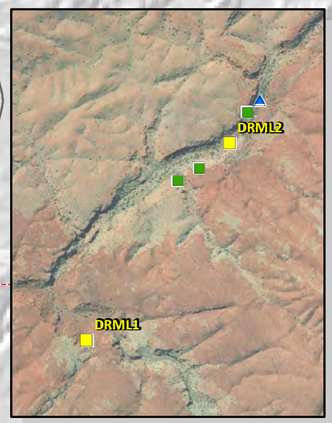
SF09

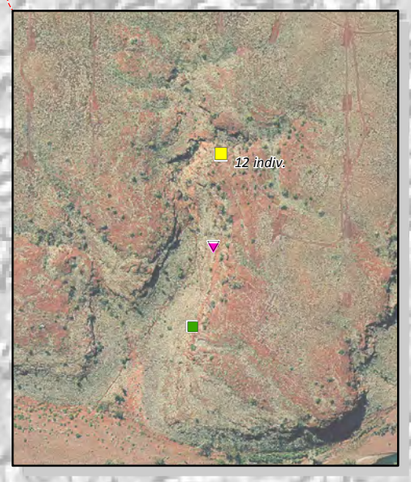
SM10

OPP 1 indiv.

GBNbat02

12 indiv.





Legend

- Road
- Railway
- River
- Mesa H development envelope and survey area
- Contextual survey area
- Desktop survey area

Contextual Ghost bat records

- Maternal roost
- Potential maternal roost
- Diurnal roost
- Potential diurnal roost
- Acoustic recording
- Scat
- Other (e.g. remains, feeding middens, visual sightings)

Robe River Mining Co. Pty Ltd

Mesa H - Ghost Bat, *Macroderma gigas* - Contextual Study

Figure 4: Ghost Bat records in the desktop survey area

Coordinate System: GDA 1994 MGA Zone 50

0 2 4 6 8 10 Kilometres

N

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Author: J. Trainer | Drawn: C. Dyde | Date: 05-09-2017 | Figure Ref: 14269-16BIDR-1RevB_170905_Fig04_Desktop

4.2 Field Survey

4.2.1 Habitat Assessments

Habitats were classified as high, moderate or low corresponding to the resources they provide to the Ghost Bat's ecological requirements (Table 10). Data collected from the cave assessments undertaken during the survey are detailed in Appendix C and the habitat mapping presented in Figure 5.

High quality habitats correspond to the locations where diurnal roosts or maternal roosts were identified or areas where aerial photography showed the topography corresponded to significant gorges or landforms likely to contain suitable caves for roost sites. High quality habitat was restricted to the gorge system located directly south of the Mesa H survey area (Plate 3), the gorges located within Mesa G (Plate 4), gorges on the western side of Mesa H, and the area surrounding the potential maternal roost in Mesa F to the south-west of the contextual survey area. A total of 248.7 ha (0.3%) of the contextual survey area and 4.1 ha (0.1%) of the Mesa H survey area contain habitat considered as being high quality habitat for Ghost Bats.

Moderate quality habitats correspond to rocky breakaways and cliffs where feeding sites were recorded or considered likely to occur and sites where permanent/semi-permanent water sources occur. These areas were mapped based on the type of geology identified in the field visit or from the topography identified from aerial photographs. The areas mapped as moderate quality habitat lack the significant gorges and gullies likely to contain suitable caves for roost sites (Plate 5). Permanent/semi-permanent water sources were classified as moderate quality habitat due to the fact they are likely to be important foraging sites used on a regular basis. A total of 2,531.1 ha (2.7%) of the contextual survey area and 270.4 ha (6.3%) of the Mesa H survey area contain habitat considered as being moderate quality habitat for Ghost Bats.

Low quality habitats correspond to areas of rocky hills, low hills, stony/clay plain and drainage lines where caves were not recorded or considered unlikely to occur. Ghost Bats forage over a variety of habitat types, as such all natural habitats within the contextual survey area provide foraging habitat for this species. Besides foraging these areas do not provide another biological function such as roosting or breeding sites. The vast majority of the contextual survey area (90,425.3 ha and 95.6%) and the Mesa H survey area (4,624.8 ha and 93.6%) contain habitat considered as being low quality habitat for Ghost Bats.

Table 10: Summary of habitat quality in the contextual survey area.

Habitat quality	Area in the contextual survey area (ha)	Proportion in the contextual survey area	Area in the Mesa H survey area (ha)	Proportion in the Mesa H survey area
High quality habitat	248.7	0.3%	4.1	0.1%
Moderate quality habitat	2,531.1	2.7%	270.4	6.3%
Low quality habitat	90,425.3	95.6%	4264.8	93.6%
No potential habitat (disturbed)	1,376.3	1.4%	0	0

390000 400000 410000 420000

7620000 7610000 7600000 7590000 7580000

North West Coastal Highway

Yarraloola Road

Deepdale Yarraloola Road

Pannawonica Road

Old Pannawonica Road

ROBE RIVER

MUNGARATHOONA CREEK

MBC-05

DRJT1 (MCC-02)

MCJT1 (G02)

Cave 1 (MH16-34)

Cave 4 (AC04)

RVM04 (MF01)

DRML2

DRML1

Bat A4

Legend

- Road
- Track
- Railway
- River
- Survey area
- Desktop survey area
- Mesa H development envelope and survey area

Fauna Habitat Mapping

- High quality habitat
- Moderate quality habitat
- Low quality habitat
- Disturbed

Contextual Ghost bat records

- Maternal roost
- Potential maternal roost
- Diurnal roost
- Potential diurnal roost
- Acoustic recording
- Scat
- Other (e.g. remains, feeding middens, visual sightings)

Robe River Mining Co. Pty Ltd

Mesa H - Ghost Bat, *Macroderma gigas* - Contextual Study

Figure 5: Ghost Bat habitat mapping

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Author: J. Trainer	Date: 05-09-2017	Coordinate System: GDA 1994 MGA Zone 50
Drawn: C. Dyde	Figure Ref: 14269-16BIDR-1RevB_170905_Fig05_HabMap	Kilometres 0 1 2 3 4 5

N

4.2.2 Nocturnal Feeding Roosts

During the field survey a total of 26 nocturnal feeding roosts were identified by the presence of Ghost Bat scats and feeding debris. The nocturnal feeding roosts were typically open overhangs along breakaway habitat or in small caves. Scats and feed debris were usually concentrated on the ground under the domed sections of caves/overhangs, indicating a favoured foraging area and feeding location. Sites frequently used often have a large build-up of scats (midden) indicating prolonged use (Plate 6 and Plate 7).

Although foraging evidence is associated with rocky habitats and nocturnal feeding roosts, Ghost Bats forage over all habitat types only returning to nocturnal feeding roosts to eat their prey. Nocturnal feeding roosts were recorded across the contextual survey area in all rocky habitats surveyed indicating the foraging habitat for this species is widespread. Nocturnal feeding roosts are not mapped as part of this assessment.

4.2.3 Significant Roost Sites

During the field survey, four diurnal roosts and two potential maternal roosts were recorded (Table 11). With the exception of the diurnal roost site on the northern side of Mesa C, the roost sites were all located in either side gorges of the southern face of Mesa G or in the large gorge system located directly south of Mesa H. Both potential maternal roosts were large complex caves that were located on the southward facing sections of gorge systems. Based on observations from the field survey, the gorges with southward facing walls generally contained the most suitable geology and conditions to form complex, deep caves.

Since the field survey was completed, further targeted cave assessments have assessed one of the diurnal roosts (DRJT1) as a nocturnal feeding roost and possibly a diurnal roost (MCC02) (Bat Call WA 2017c) and one of the potential maternal roosts (MCJT1) with 12 individual Ghost Bats sighted as only a diurnal roost (G02) (Bat Call WA 2017a).

Plate 1: Ghost Bat (photo credit Gina Barnet).

Plate 2: Typical SM2 unit set up.

Plate 3: Large gorge south of Mesa H 'high quality habitat'.

Plate 4: Gorge in Mesa G 'high quality habitat'.

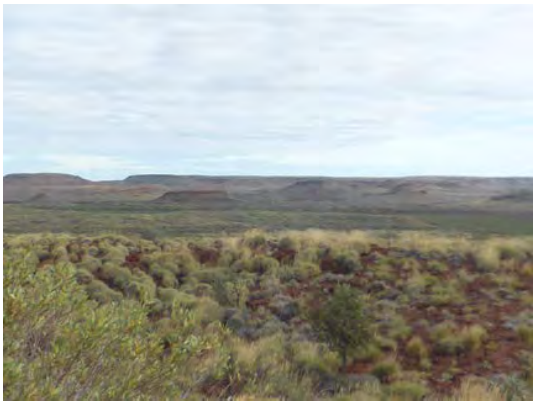

Plate 5: Mesas show typical 'moderate quality habitat'.

Plate 6: Ghost Bat scats.

Plate 7: Ghost Bat feeding debris.

Table 11: Ghost Bat roost locations recorded during the current survey.

Ghost Bat evidence	Site code	Location	Entrance description (H x W)	Internal description (H x W)	Photo
Diurnal roost - Ghost Bat scats present	DRJT1*	Mesa C	Tight (1.5 m x2 m)	Domed cavern (3 m x 8 m) on top of cave entrance	
Diurnal roost - no scats but presence expected due to cave dimensions	DRML1	Gorge south of Mesa H	Open, adit like (35 m x 15 m)	Multiple caverns (20 m x 20 m) and rear passages	
Diurnal roost - no scats but presence expected due to cave dimensions	DRML2	Gorge south of Mesa H	Open (6 m x 12 m)	Large, narrow crevices approx. 15 m high, small domed cavern	

Ghost Bat evidence	Site code	Location	Entrance description (H x W)	Internal description (H x W)	Photo
Potential maternal roost- 3 individuals sighted	A4	Gorge south of Mesa H	Open and large (20 m x 40 m)	60 m deep with 3 large domed chambers and 2 rear passages	
Potential maternal roost - 12 individuals sighted	MCJT1^	Gorge in Mesa G	Complex with multiple tight entrances	40 m deep with multiple domed caverns and rear passages	
Diurnal roost - no scats but presence expected due to cave dimensions	RCML1	Gorge in Mesa G	Open (15 m x 30 m)	25 m deep with 3 rear passages and an open domed cavern	

*since survey, roost confirmed as a nocturnal feeding roost, possible diurnal roost (MCC-02) (Bat Call WA 2017c)

^since survey, roost confirmed as a diurnal roost only (G02) (Bat Call WA 2017a)

4.3 Environmental Context and Ghost Bat Records

The habitat mapping and Ghost Bat records from both the desktop assessment and the field survey in the contextual survey area were compared against the geological mapping (Stewart et al. 2008), land systems (van Vreeswyk et al. 2004) and the pre-European vegetation mapping (Beard 1975). The mapping data that most consistently correlated to the Ghost Bat habitat mapping and records were the land systems mapping.

Land systems mapping is a comprehensive description of biophysical resources including soil and vegetation condition across the Pilbara. As the Ghost Bat requires caves for its important ecological requirements (feeding, roosting and breeding), land systems that contain critical habitat were identified and mapped. The associations of each land system with Ghost Bat habitats and records are detailed in Table 12 and mapped in Figure 6.

The Newman and Robe land systems contain the most significant Ghost Bat habitat and they coincide with the majority of the high quality habitat (99%), diurnal roosts and maternal roosts (both potential and confirmed). The Newman land system is the most important of these as it supports the high quality habitat and roost sites at Mesa B, C, G and the gorge system south of Mesa H. The only exception to this is the maternal roost (RVM04/MF01) at Mesa F (reference number 11 in Appendix C) that occurs in the Boolgeeda system. However, this site occurs only 60 m from the boundary of the Boolgeeda land system and the Robe system suggesting some association with the Robe land system.

Moderate quality Ghost Bat habitat and nocturnal feeding roosts are strongly associated with the Newman, Robe and Nanutarra land systems with 92.5% of the moderate habitat and all but three of the nocturnal feeding roosts in the contextual survey area occurring in these three land systems. The Newman, Robe and Nanutarra land systems (Van Vreeswyk et al. 2004) are described below.

Newman system: extensive high plateaux, mountains and strike ridges with vertical escarpments and steep scree slopes and more gently inclined lower slopes; moderately spaced dendritic and rectangular tributary drainage patterns of narrow valleys and gorges with narrow drainage floors and channels. The system contains iron ore deposits which are currently being mined and deposits which are likely to be mined in the future. Approximately 14,580 km² of this Land system occurs in the Pilbara and is widespread between Pannawonica and Newman.

Robe system: erosional surfaces; formed by partial dissection of old Tertiary surfaces, dissected plateaux and long lines of low mesas along present and past river valleys, indented near vertical breakaway faces and steep slopes with limonite outcrop and pisolitic gravelly mantles, restricted gravelly lower slopes and closely to moderately spaced narrow tributary drainage floors. The system contains iron deposits which are currently being mined or which may be mined in the future. Approximately 850 km² of this Land system occurs in the Pilbara and is widespread between Pannawonica, Port Hedland and Newman, with a concentration south of Pannawonica.

Nanutarra system: erosional surfaces; formed by partial dissection of an old plateau of marine sediments - low plateaux, dissected plateaux, mesas, buttes and low hills with rounded crests, short stony footslopes with parallel and radial drainage patterns, narrow dendritic drainage zones and creeklines between dissected plateaux and mesas. Approximately 697 km² of this Land system occurs in the Pilbara and is concentrated to the west of Pannawonica.

Table 12: Ghost Bat habitat compared against land system mapping within the contextual and Mesa H survey areas.

Land System	Mesa H survey area		Contextual survey area		
	Moderate quality habitat (ha)	High quality habitat (ha)	Moderate quality habitat (ha)	High quality habitat (ha)	Ghost Bat records
Boolgeeda	0	0	118.2	2.1	1 maternal roost
Capricorn	0	0	33.2	0	Nil
Nanutarra	0	0	880.4	0	6 nocturnal feeding roosts 1 visual sighting record
Newman	20.7	0	583.1	234.6	1 potential maternal roost 3 diurnal roosts 18 nocturnal feeding roosts 2 acoustic records 2 visual sighting records
River	38.3	0	109.8	0.04	3 nocturnal feeding roosts 1 acoustic record
Robe	211.4	4.1	878.2	11.9	1 potential maternal roost 2 diurnal roosts 1 potential diurnal roost 33 nocturnal feeding roosts 4 acoustic records 3 visual sighting/remains records
Sherlock	0	0	9.5	0	Nil
Stuart	0	0	4	0	Nil
Urandy	0	0	14.7	0	Nil
Total	**270.4**	**4.1**	**2,531.1**	**248.7**	**82 records**

380000 390000 400000 410000 420000

7610000 7600000 7590000

Yarraloola Road

Deepdale Yarraloola Road

Panawonica Road

Deepdale Yarraloola Road

MBC-05

DRJT1 (MCC-02)

MCJT1 (C02)

Cave 1 (MH16-34)

Cave 4 (AC04)

RVM04 (MF01)

DRML2

DRML1

Bat A4

Legend

- Road
- Track
- Mesa H development envelope and survey area
- Contextual survey area
- Desktop survey area

Contextual Ghost bat records

- Maternal roost
- Potential maternal roost
- Diurnal roost
- Potential diurnal roost
- Acoustic recording
- Scat
- Other (e.g. remains, feeding middens, visual sightings)

Fauna Habitat Mapping

- High quality habitat
- Moderate quality habitat

Land System

- Boolgeeda System
- Cane System
- Capricorn System
- Mallina System
- McKay System
- Nanutarra System
- Newman System
- River System
- Robe System
- Sherlock System
- Stuart System
- Urandy System

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Mesa H - Ghost Bat, *Macroderma gigas* - Contextual Study

Figure 6: Ghost Bat habitat mapping and land systems

Coordinate System: GDA 1994 MGA Zone 50

0 1 2 3 4 5 Kilometres

N

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Author: J. Trainer | Drawn: C. Dyde | Date: 05-09-2017 | Figure Ref: 14269-16BIDR-1RevB_170905_Fig06_LSHabMap

5 Discussion and Conclusions

Mesa H has been extensively surveyed with four biological surveys conducted within the last five years (the current survey; Astron Environmental Services 2014, 2016b; Bat Call WA 2017b; Biota Environmental Sciences 2011). As such, the presence and habitat for the Ghost Bat in the Mesa H survey area is well documented. The Mesa H survey area contains 22 Ghost Bat records (including caves, individuals and acoustic recordings) accounting for approximately 28% of all Ghost Bat records from the desktop survey area. Following recent targeted cave assessments, a total of two confirmed diurnal roosts occur within the Mesa H survey area. Significant habitat for Ghost Bats in the Mesa H survey area occur in the small sections of a gorge/breakaway habitat (approximately 4.1 ha mapped as high quality habitat) located along the western side of Mesa H and a small portion of a gorge system to the south (and outside) of the Mesa H survey area (Figure 5). The number of records is to be expected given the geology of the Mesa H survey area and the fact it has been extensively surveyed in recent years.

Although high quality habitat is present within the Mesa H survey area, the majority of roost sites (including the more important one maternal and two potential maternal roosts) and high quality habitat (98.4%) are located in areas outside of the Mesa H survey area boundary. The most significant Ghost Bat habitats in the contextual survey area are located within the gorges on the lower Robe Valley Mesas, Mesa G and the gorge system to the south of (and outside) Mesa H, although the only confirmed maternal roost occurs on Mesa F. The gorges on Mesa G contained one diurnal roost, one potential maternal roost on Mesa B and one potential diurnal roost on Mesa C. The gorge to the south of Mesa H was too large to properly survey in the time available and only received a preliminary assessment. One potential maternal roost and two diurnal roosts (all confirmed) were identified; however, based on the geology and size of the gorge system more roost sites are expected.

In the Chichester subregion Ghost Bats are more numerous (approximately 1,500 to 2,000 individuals) and are focused in medium to large groups around roosts in abandoned mine shafts and adits. The contextual survey area occurs in the Hamersley subregion where Ghost Bats are more widespread, occur in smaller numbers (approximately 350 individuals) and where relatively few breeding records exist (Department of the Environment and Energy 2016). Observations from the survey and the desktop components support this statement with all roost sites containing a small numbers of individuals (1 to 70 individuals).

All of the records obtained through the desktop assessment were collected by environmental consultants and were therefore biased towards mining tenements in the area, specifically along the Robe Valley. The majority of records are from scats and acoustic recordings; although a number of targeted cave assessments have been conducted in recent years, and therefore do not reflect the location of roost sites (Bat Call WA 2016a, 2017a, 2017b, 2017c). The number of Ghost Bat records from the desktop assessment and field survey suggest that the Ghost Bat is well distributed across the Robe Valley and within the vicinity of the Mesa H survey area but in small numbers.

Armstrong and Anstee (2000) stated that roost sites in the Hamersley Ranges are associated with the Marra Mamba Iron and Brockman Iron formations. In the contextual survey area, roost sites were associated with the Robe Pistolite and Brockman Iron formations but not with the Marra Mamba Iron formations. However, the geological formation mapping does not correlate as strongly with potential Ghost Bat habitat as the land systems mapping does. In the contextual survey area, the land systems mapping shows relationship between the Robe and Newman systems and the presence of both diurnal and maternal roost sites. Within the contextual survey area approximately 96% of the Newman system and 75% of the Robe system are located outside of the Mesa H survey area, indicating that both of these land systems are well represented locally and are widespread

throughout the Pilbara (Table 2). Nocturnal feeding roosts are expected to occur across all rocky habitats in all of the land systems; however, during the field survey they were not found in some land systems due to the fact that survey effort focused on likely roost locations rather than a broad scale assessment. As such, the habitat mapping gives a clearer indication of potential presence of nocturnal feeding roosts (moderate quality habitat) rather than the feeding site records.

The key threat to the Ghost Bat is the habitat loss and degradation due to mining activities (McKenzie and Hall 2008). The species' slow reproductive rate, and the lack of suitable habitat which restricts its movement, renders it vulnerable to threats and localised extinctions (Queensland Department of Environment and Heritage Protection 2015). The Pilbara population is genetically distinct at both a regional and local scale (Armstrong et al. in prep). The genetic isolation of each subpopulation suggests areas are unlikely to be recolonised if a local extinction occurs (Queensland Department of Environment and Heritage Protection 2015). In the Pilbara, most known breeding sites of the Ghost Bat are confined to underground gold/copper mines that are now collapsing or being open cut, and to caves in banded ironstone strata that may be mined out over the next 30 to 50 years. On current trends, most of its Pilbara roost sites may be destroyed over the next 30 years (Woinarski et al. 2014). Numbers are likely to decline by over 30% in Western Australia in the future with local extinction in areas such as the central and eastern Hamersley Range, with the extent of occupancy likely to decline by over 10,000 km² (Bullen pers. comm., Department of the Environment and Energy 2016). However, barbed wire fences are being replaced in crucial areas and breeding sites are being identified for protection (Department of Parks and Wildlife 2015), which may reduce the current rate of decline.

The survey was completed prior to the known breeding period of this species in the Pilbara and the survey methods employed, specifically the lack of harp trapping, mist netting or thermal tracking cameras means that maternal roosts were identified on the presence of multiple Ghost Bats rather than breeding records. Relatively little is known about this species' roost site fidelity, seasonal movements or local population estimates in the Pilbara, let alone in the contextual survey area or the roost sites identified in this assessment.

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Appendix A: Environmental Context Figures

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Legend

- Mesa H survey area
- Contextual survey area
- Desktop survey area

Geological Unit

- Ashburton Formation
- Boolgeeda Iron Formation
- Brockman Iron Formation
- Jeerinah Formation
- Marra Mamba Iron Formation
- Mt McRae Shale & Mt Sylvia Formation
- Nanutarra Formation
- Robe Pisolite
- Weeli Wolli Formation
- Woongarra Rhyolite
- Wyloo Group
- alluvium 38485
- colluvium 38491

Robe River Mining Co. Pty Ltd

Mesa H - Ghost Bat, *Macroderma gigas* - Contextual Study

Figure A.1: Geological Units of the contextual survey area

Coordinate System: GDA 1994 MGA Zone 50

0 1 2 3 4 5 Kilometres

N

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Legend

- Mesa H survey area
- Contextual survey area
- Desktop survey area

Land System

- Boolgeeda System
- Cane System
- Capricorn System
- Mallina System
- McKay System
- Nanutarra System
- Newman System
- River System
- Robe System
- Sherlock System
- Stuart System
- Urandy System

Robe River Mining Co. Pty Ltd

Mesa H - Ghost Bat, *Macroderma gigas* - Contextual Study

Figure A.2: Land Systems of the contextual survey area

Coordinate System: GDA 1994 MGA Zone 50

0 1 2 3 4 5 Kilometres

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STUART HILLS-603
STUART HILLS-603
STUART HILLS-605
STUART HILLS-82
STUART HILLS-82
STUART HILLS-605
STUART HILLS-82
STUART HILLS-605
STUART HILLS-29
STUART HILLS-605
STUART HILLS-29
STUART HILLS-29
HAMMERSLEY-609
STUART HILLS-603
STUART HILLS-93
STUART HILLS-29
HAMMERSLEY-82
HAMMERSLEY-82
HAMMERSLEY-609
STUART HILLS-583
STUART HILLS-620
STUART HILLS-29
HAMMERSLEY-82
HAMMERSLEY-82
STUART HILLS-157

Legend

- Mesa H survey area
- Contextual survey area
- Desktop survey area

Pre-European Vegetation

- HAMMERSLEY-609
- HAMMERSLEY-82
- STUART HILLS-29
- STUART HILLS-82
- STUART HILLS-93
- STUART HILLS-157
- STUART HILLS-583
- STUART HILLS-603
- STUART HILLS-605
- STUART HILLS-620

Robe River Mining Co. Pty Ltd

Mesa H - Ghost Bat, *Macroderma gigas* - Contextual Study

Figure A.3: Pre-European Vegetation of the contextual survey area

Coordinate System: GDA 1994 MGA Zone 50

0 1 2 3 4 5 Kilometres

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Author: J. Trainer | Drawn: C. Dyde | Date: 14-07-2016 | Figure Ref: 14269-16BIDR-1RevA_160714_FigA3_PreEuroVeg

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Appendix B: Bat Call WA Report

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Mesa H contextual fauna survey, Pilbara WA, June 2016

Echolocation Survey of Bat Activity.

Prepared for Astron Environmental Services

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Issue 2
29 August 2017

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Document Revision History

Issue	Date	Revision History
A	16 June 2016	Initial draft prepared for Astron
1	23 July 2016	First issue incorporating client comments
2	29 Aug 2017	Second issue incorporating client comments

Summary
Bat species presence, with an estimate of activity level, is presented for ten sites near Mesa H along the Robe River valley in the Pilbara, WA. Astron Environmental Services (Astron) carried out an echolocation based survey during June 2016. Bat Call WA has reviewed the recordings made and provided species lists for the bats present.

Nine species of echolocating bats were recorded including the two EPBC Act listed species from the Pilbara, the Orange Leaf-nosed Bat, Pilbara form (*Rhinonicteris aurantia*) (PLNb) and the Ghost bat (*Macroderma gigas*). Ghost bat calls were detected at four sites, all cave entrances or overhangs. PLNb calls were detected foraging in medium numbers at one site and in low numbers at five sites. A summary of call numbers and timing is provided. Activity levels for the common species are provided by site. No previously unidentified PLNb roost is indicated by these data

Habitats
The sites for the survey were chosen by Astron. Details of the sites are presented in Table 1. Three were in cave entrances, six under overhangs and one was on a semi-permanent pool within a gorge. The locations are shown in relation to Robe River valley features in Figure 1.

Characteristics of the calls recorded are presented in Table 2.

Bat Fauna
An assemblage of nine echolocating species was confirmed as present at the study sites, Tables 2 and 3. Species activity levels were low to high, which is expected for the study area habitat and the time of year, see criteria below.

Multiple Ghost bat calls were detected at four sites, Bat A1, ‘A4, ‘2 and ‘7 although the patterns of calls at these sites were interrupted by nights with extensive rainfall and also probably impacted by two nights with low temperatures, see below. The pattern though is adequate to show that Ghost bats are using most well defined caves and some overhangs in the district.

PLNb were detected at six of the sites. One site, Bat A4 had a medium activity level with a total of 140 calls being recorded over six nights. Five sites had low activity levels. Detections within 60 minutes of dusk civil twilight (CT) were recorded at the three southern sites. The earliest time differentials from dusk CT were at site ‘A4, 30 minutes on the 6th June (overcast night with rainfall periods), 35 minutes at ‘A2 and 50 minutes at ‘A3. The latest calls were between 25 and 45 minutes before CT, on the 6th June at ‘A4, and at sites ‘A3 and ‘A1, Figure 1. The closest call to CT at Bat 2 was 90 minutes and the single call at Bat 7 was close to midnight. These time differentials, together with the progressively increasing time differentials from south to north, indicate that the PLNb probably originated from a known roost approximately10 km south of the study area.

Taxonomy presented herein is after Reardon *et al.* (2014) and Jackson and Groves (2015).

Survey Timing, Moon Phase and Weather
The echolocation survey was conducted between 3rd and 8th June 2016.

The first four sampling evenings were warm with minimum overnight temperatures between 15 and 20^{O}C while the last two were cold with temperatures around 10^{O}C. Rain fell on the nights of 4th , 5th and 6th June. The moon in this period was new.

During the survey, sunset, sunrise, dusk and dawn CT were within two minutes of 17:39, 06:49, 18:03 and 06:25 respectively.

Survey Team
Sites were chosen and detectors placed by Astron ecologists. Bob Bullen of Bat Call WA completed analysis of echolocation recordings.

Sampling
The survey consisted of completing a total of 34 overnight bat sound recordings, beginning at twilight, at ten locations within the survey area. The recordings were "continuous" (Hyder *et al.* 2010) made using SM2BAT+ SongMeter (Wildlife Acoustics Inc., USA) detectors. The jumper and audio settings used followed the manufacturer's recommendations for bat detection contained in the user manual (Wildlife Acoustics 2010).

For the recordings, once reformatted as .wav files, COOL EDIT 2000 (now available as AUDITION from Adobe Systems Inc.) was used to display each sequence for identification. Calls were identified manually. Only good quality call sequences were used. Details of calls analysed are provided in Table 2 as recommended by Australasian Bat Society (ABS 2006). Reference data for the species identified are available in Bullen and McKenzie 2002, McKenzie and Bullen 2003 and McKenzie and Bullen 2009.

Bat activity was then characterised as "Low", "Medium" or "High" based on the rate of call sequences recorded.

- Low species activity is referred when a species is recorded with call spacing less often than ten minutes.
- Medium species activity refers to call recordings more often than 10 minutes but less often than two minutes apart for at least an hour followed by sporadic records for the remainder of the session.
- High species activity refers to call recording more often than two minutes apart for at least two hours followed by reasonably regular records for the remainder of the session.

Survey Limitations
The sites surveyed were accessible on foot and the SM2, using an omnidirectional microphone, was set on the ground with the microphone horizontal. Species are unlikely to be under-represented as a result.

Bat species density away from cave or adit entrances is impossible to estimate from echolocation records. Bat activity is therefore substituted as an approximate guide to the relative numbers of each species using the study area.

Heavy rain on three nights and cold temperatures on two nights have resulted in lower than typical bat call numbers for the time of year.

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Table 1 Site Specific details.

	Date	Recording Time	Habitat	Easting	Northing
Bat A1	3-6 June	Four overnight recordings using SM2 SN 15289	Overhang in gorge	417714	7591311
Bat A2	3-8 June	Four overnight recordings using SM2 SN 13947	Semi-permanent pool in gorge	417078	7590311
Bat A3	3-8 June	Six overnight recordings using SM2 SN 14909	Overhang in gorge	417723	7589676
Bat A4	3-8 June	Six overnight recordings using SM2 SN 15281	Cave entrance	419326	7588792
Bat A5	7-8 June	Two overnight recording using SM2 SN 15289	Cave entrance	417641	7591471
Bat 2	4-8 June	Five overnight recordings using SM2 SN 15337	Cave entrance	411741	7595774
Bat 3	4 June	One overnight recording using SM2 SN 8027	Overhang	397545	7607340
Bat 4	4-5 June	Two overnight recordings using SM2 SN 7634	Overhang	405894	7606227
Bat 6	6-7 June	Two overnight recordings using SM2 SN 7634	Overhang	399978	7608691
Bat 7	6-7 June	Two overnight recordings using SM2 SN 8027	Overhang	391468	7608781

Note 1: Coordinates are Zone 50K

Table 2: Summary of Echolocation call characteristics for microbat species present.

Genus species Authority	Common name	Typical F_{peak} kHz Note 1	Ave. Q Note 1	Typical Duration msec	Typical Call Shape
Austronomus australis (Gray 1838) Note 2	White-striped free-tailed bat	12	7	12 - 23	CF– shallow FM
Chaerephon jobensis (Miller 1902)	Northern free-tailed bat	22	5	8 - 15	Shallow FM
Chalinolobus gouldii (Grey 1841)	Gould's wattled bat	32	10	7 - 11	FM
Macroderma gigas (Dobson 1880)	Ghost bat	20 – 52 variable	2 – 20 variable	variable	Complex FM
Rhinonicteris aurantia (Gray 1845)	Pilbara leaf-nosed bat	120	30	5 - 8	CF
Saccolaimus flaviventris (Peters 1867)	Yellow-bellied sheath-tailed bat	18	9	12 - 21	CF - FM
Scotorepens greyii (Gray 1843)	Little broad-nosed bat	38	10	7 - 13	FM
Taphozous georgianus Thomas 1915	Common sheath-tailed bat	24.5	14	9 - 18	CF– shallow FM
Vespadelus finlaysoni (Kitchener, Jones and Caputi 1987)	Inland cave bat	55	14	4 - 8	FM

Note 1: *Fpeak* and *Q* are defined in McKenzie and Bullen 2003, 2009.
Note 2: Taxonomy follows Jackson and Groves (2015). *A. australis* was known until recently as *Tadarida australis*.

Table 3. Survey microbat lists presented by site.

Site	*Austronomus australis*	*Chaerephon jobensis*	*Chalinolobus gouldii*	*Macroderma gigas*	*Rhinonicteris aurantia* Note 1	*Saccolaimus flaviventris*	*Scotorepens greyii*	*Taphozous georgianus*	*Vespadelus finlaysoni*
Bat A1	Low	Low	Low	Low (Multiple calls detected)	Low (23 calls)	Low	Low	High	High
Bat A2	Low		Low		Low (20 calls)		Low	High	High
Bat A3	Low				Low (18 calls)	Low	Low	High	Low
Bat A4	Low	Low	Low	Low (Multiple calls detected)	Med (140 calls)		Low	High	High
Bat A5		Low					Low	Low	Low
Bat 2	Low	Low	Low	Med (Multiple calls detected)	Low (17 calls)		Low	High	Med
Bat 3		Low	Low					High	Low
Bat 4		Low	Low					Med	Low
Bat 6								Low	
Bat 7	Low	Low	Low	Low (two calls detected)	Low (1 call)			Med	Med

Note 1: Total number of calls detected during the recording period at the site

Figure 1. Detector sites in relation to features in the study area. White pins denote sites where Ghost bats were detected.

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Appendix C: Summary of Ghost Bat Records

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Table C.1: Summary of Ghost Bat records

Ref #	Report	Author	Year	Easting	Northing	Site code	Record type	Assessment	Assessment	Updated assessment	Within		Land system	Distance to Robe River or tributary	Cave dimensions (H x W)		Distance to Mesa H
											Contextual survey area	Desktop survey area			Entrance	Internal	
1	Fauna Habitats and Fauna Assemblage of Mesa A and G	Biota Environmental Sciences	2005	386106	7603985	MEA06 (MAI06-SH17)	Visual sighting	Cave	Potential diurnal roost - 1 individual sighted	Nocturnal feeding roost (MAI06-SH17; Bat Call WA 2017c)	No	Yes	Robe	5 km	Unknown	Unknown	29 km
2	Mesa H - Ghost Bat, *Macroderma gigas* - Contextual study	Astron Environmental Services	2016	391440	7608686	FCML8	Scat	Cave	Nocturnal feeding roost	-	Yes	Yes	Nanutarra	2 km	N/A	N/A	25 km
3	Mesa H - Ghost Bat, *Macroderma gigas* - Contextual study	Astron Environmental Services	2016	391468	7608781	BAT 7	Acoustic recording	Breakaway	Nocturnal feeding roost	-	Yes	Yes	Nanutarra	2 km	N/A	N/A	25 km
4	Robe Valley Mesas Fauna Survey	Biota Environmental Sciences	2011	392301	7596831	RVM03	Acoustic recording	Cave	-	-	Yes	Yes	Robe	3 km	N/A	N/A	22 km
5	Mesa H - Ghost Bat, *Macroderma gigas* - Contextual study	Astron Environmental Services	2016	392440	7602769	DRJT1 (MCC-02)	Scat	Large cave	Diurnal roost - cave assessment	Potential diurnal roost (MCC-02; Bat Call WA 2017c)	Yes	Yes	Robe	1 km	Tight (1.5 m x 2 m)	Domed cavern on top of entrance (3 m x 8 m)	22 km
6	Mesa H - Ghost Bat, *Macroderma gigas* - Contextual study	Astron Environmental Services	2016	392445	7602780	FCJT14	Scat	Cave	Nocturnal feeding roost	-	Yes	Yes	Robe	1 km	N/A	N/A	22 km
7	Mesa H - Ghost Bat, *Macroderma gigas* - Contextual study	Astron Environmental Services	2016	392577	7602375	FCJT16	Scat	Cave	Nocturnal feeding roost	-	Yes	Yes	Robe	1 km	N/A	N/A	22 km
8	Mesa H - Ghost Bat, *Macroderma gigas* - Contextual study	Astron Environmental Services	2016	392585	7600245	FCJT13	Scat	Cave	Nocturnal feeding roost	-	Yes	Yes	Robe	1 km	N/A	N/A	22 km
9	Fauna Habitats and Fauna Assemblage of the Mesa A Transport Corridor and Warramboo	Biota Environmental Sciences	2006	392718	7603137	MATHARP1 and 2	Scat	Breakaway	Nocturnal feeding roost	-	Yes	Yes	Robe	1 km	N/A	N/A	22 km
10	Mesa H - Ghost Bat, *Macroderma gigas* - Contextual study	Astron Environmental Services	2016	397502	7607326	FCJT3 (BAT 3)	Scat	Cave	Nocturnal feeding roost	-	Yes	Yes	Nanutarra	5 km	N/A	N/A	20 km

Ref #	Report	Author	Year	Easting	Northing	Site code	Record type	Assessment	Assessment	Updated assessment	Within		Land system	Distance to Robe River or tributary	Cave dimensions (H x W)		Distance to Mesa H
											Contextual survey area	Desktop survey area			Entrance	Internal	
11	Robe Valley Mesas Fauna Survey	Biota Environmental Sciences	2011	398218	7591036	RVM04 (MF01)	Harp trap and acoustic recording	Cave	Potential maternal roost - 24 individuals caught	Maternal roost – 70 individuals sighted (MF01; Bat Call WA 2017a)	Yes	Yes	Boolgeeda	4 km	Unknown	Unknown	16 km
12	Mesa H - Ghost Bat, *Macroderma gigas* - Contextual study	Astron Environmental Services	2016	398672	7611567	FCML7	Scat	Cave	Nocturnal feeding roost	-	Yes	Yes	Nanutarra	10 km	N/A	N/A	20 km
13	Mesa H - Ghost Bat, *Macroderma gigas* - Contextual study	Astron Environmental Services	2016	399979	7608691	FCML6 (BAT6)	Scat	Cave	Nocturnal feeding roost	-	Yes	Yes	Nanutarra	10 km	N/A	N/A	18 km
14	Yarraloola - Northern Quoll, Pilbara Olive Python and Pilbara Leaf-nosed Bat Targeted Survey	Biologic Environmental Survey Pty Ltd	2014	405774	7606714	1	Visual sighting	Unknown	-	-	Yes	Yes	Nanutarra	12 km	N/A	N/A	12 km
15	Mesa H - Ghost Bat, *Macroderma gigas* - Contextual study	Astron Environmental Services	2016	405895	7606227	FCJT4 (BAT4)	Scat	Cave	Nocturnal feeding roost	-	Yes	Yes	Nanutarra	12 km	N/A	N/A	12 km
16	Mesa H - Ghost Bat, *Macroderma gigas* - Contextual study	Astron Environmental Services	2016	409835	7595814	FCJT5	Scat	Cave	Nocturnal feeding roost	-	Yes	Yes	Newman	< 1 km	N/A	N/A	4 km
17	Mesa H - Ghost Bat, *Macroderma gigas* - Contextual study	Astron Environmental Services	2016	410059	7595897	FCJT6	Scat	Cave	Nocturnal feeding roost	-	Yes	Yes	Newman	< 1 km	N/A	N/A	4 km
18	Mesa H - Ghost Bat, *Macroderma gigas* - Contextual study	Astron Environmental Services	2016	410078	7595957	FCJT7	Scat	Cave	Nocturnal feeding roost	-	Yes	Yes	Newman	< 1 km	N/A	N/A	4 km
19	Mesa H - Ghost Bat, *Macroderma gigas* - Contextual study	Astron Environmental Services	2016	410143	7595939	FCML5	Scat	Cave	Nocturnal feeding roost	-	Yes	Yes	Newman	< 1 km	N/A	N/A	4 km
20	Mesa H - Ghost Bat, *Macroderma gigas* - Contextual study	Astron Environmental Services	2016	410151	7595728	FCML4	Scat	Cave	Nocturnal feeding roost	-	Yes	Yes	Newman	< 1 km	N/A	N/A	4 km

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21	Mesa H - Ghost Bat, *Macroderma gigas* - Contextual study	Astron Environmental Services	2016	410174	7595941	FCJT10 (BAT5)	Scat	Cave	Nocturnal feeding roost	-	Yes	Yes	Newman	< 1 km	N/A	N/A	4 km
22	Mesa H - Ghost Bat, *Macroderma gigas* - Contextual study	Astron Environmental Services	2016	410176	7595921	FCJT9	Scat	Cave	Nocturnal feeding roost	-	Yes	Yes	Newman	< 1 km	N/A	N/A	4 km
23	Mesa H - Ghost Bat, *Macroderma gigas* - Contextual study	Astron Environmental Services	2016	410440	7595459	FCJT2	Scat	Cave	Nocturnal feeding roost	-	Yes	Yes	Newman	< 1 km	N/A	N/A	4 km
24	Mesa G Baseline Fauna Survey	Biota Environmental Sciences	2009	410531	7595661	MSG06E (G01)	Harp trap	Breakaway	Potential maternal roost - 11 individuals caught	Foraging habitat (cave G01; Bat Call WA 2017a)	Yes	Yes	Newman	< 1 km	Unknown	Unknown	4 km
25	Mesa G Baseline Fauna Survey	Biota Environmental Sciences	2009	410688	7595388	MSGBAT01	Harp trap	Breakaway	1 individual caught	-	Yes	Yes	Newman	< 1 km	Unknown	Unknown	4 km
26	Mesa H - Ghost Bat, *Macroderma gigas* - Contextual study	Astron Environmental Services	2016	410826	7595410	FCML3	Scat	Cave	Nocturnal feeding roost	-	Yes	Yes	River	< 1 km	N/A	N/A	4 km
27	Mesa H - Ghost Bat, *Macroderma gigas* - Contextual study	Astron Environmental Services	2016	410869	7595409	FCML2	Scat	Cave	Nocturnal feeding roost	-	Yes	Yes	River	< 1 km	N/A	N/A	4 km
28	Mesa H - Ghost Bat, *Macroderma gigas* - Contextual study	Astron Environmental Services	2016	410886	7595414	FCML1	Scat	Cave	Nocturnal feeding roost	-	Yes	Yes	River	< 1 km	N/A	N/A	4 km
29	Mesa H - Ghost Bat, *Macroderma gigas* - Contextual study	Astron Environmental Services	2016	411696	7595502	FCJT1	Scat	Cave	Nocturnal feeding roost	-	Yes	Yes	Newman	< 1 km	N/A	N/A	3 km
30	Mesa H - Ghost Bat, *Macroderma gigas* - Contextual study	Astron Environmental Services	2016	411727	7595625	RCML1	Cave assessment	Large cave	Diurnal roost - cave assessment	-	Yes	Yes	Newman	< 1 km	Open (15 m x 30 m)	25 m deep with 3 rear passages and 1 open domed cavern	3 km
31	Mesa H - Ghost Bat, *Macroderma gigas* - Contextual study	Astron Environmental Services	2016	411740	7595774	MCJT1 (G02)	Acoustic recording and visual sighting	Large cave	Potential maternal roost - 12 individuals sighted	Diurnal roost (G02; Bat Call WA 2017a)	Yes	Yes	Newman	< 1 km	Complex with multiple tight entrances	40 m deep with multiple domed caverns and rear passages	3 km

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32	Yarraloola - Northern Quoll, Pilbara Olive Python and Pilbara Leaf-nosed Bat Targeted Survey	Biologic Environmental Survey Pty Ltd	2014	413118	7588574	4	Visual sighting	Unknown	-	-	Yes	Yes	Robe	6 km	N/A	N/A	6 km
33	Mesa H - Ghost Bat, *Macroderma gigas* - Contextual study	Astron Environmental Services	2016	413766	7600738	FCJT11	Scat	Cave	Nocturnal feeding roost	-	Yes	Yes	Newman	3 km	N/A	N/A	3 km
34	Mesa H Level 1 Flora, Vegetation and Fauna Assessment	Astron Environmental Services	2014	414408	7597657	Anabat 8	Acoustic recording	Robe River	Foraging habitat	-	Yes	Yes	River	< 1 km	N/A	N/A	Within Mesa H
35	Mesa H Level 1 Flora, Vegetation and Fauna Assessment	Astron Environmental Services	2014	414643	7597665	Anabat 7	Acoustic recording	Robe River	Foraging habitat	-	Yes	Yes	Robe	< 1 km	N/A	N/A	Within Mesa H
36	Mesa H Level 1 Flora, Vegetation and Fauna Assessment	Astron Environmental Services	2014	414995	7595902	Anabat 1	Acoustic recording	Breakaway	-	-	Yes	Yes	Robe	< 1 km	N/A	N/A	Within Mesa H
37	Mesa H Level 1 Flora, Vegetation and Fauna Assessment	Astron Environmental Services	2014	415149	7596502	Cave 2 (H18)	Scat, remains and visual sighting	Cave	Diurnal roost - 1 individual sighted	Nocturnal feeding roost (H18; Bat Call WA 2017b)	Yes	Yes	Robe	< 1 km	Complex with multiple tight entrances	Unknown	Within Mesa H
38	Mesa H Level 1 Flora, Vegetation and Fauna Assessment	Astron Environmental Services	2014	415159	7596483	OPP	Remains	Gorge/gully/ cave	-	-	Yes	Yes	Robe	< 1 km	N/A	N/A	Within Mesa H
39	Mesa H Level 1 Flora, Vegetation and Fauna Assessment	Astron Environmental Services	2014	415162	7596482	OPP	Remains	Gorge/gully/ cave	-	-	Yes	Yes	Robe	< 1 km	N/A	N/A	Within Mesa H
40	Mesa H Level 1 Flora, Vegetation and Fauna Assessment	Astron Environmental Services	2014	415168	7596492	Cave 3 (H18)	Visual sighting	Gorge/gully/ cave	Diurnal roost - 1 individual sighted	Nocturnal feeding roost (H18; Bat Call WA 2017b)	Yes	Yes	Robe	< 1 km	Unknown	Unknown	Within Mesa H
41	Mesa H Level 1 Flora, Vegetation and Fauna Assessment	Astron Environmental Services	2014	415265	7596486	Cave 6	Scat	Cave	Potential diurnal roost - cave assessment	-	Yes	Yes	Robe	< 1 km	Complex with multiple tight entrances		Within Mesa H

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42	Yarraloola - Northern Quoll, Pilbara Olive Python and Pilbara Leaf-nosed Bat Targeted Survey	Biologic Environmental Survey Pty Ltd	2014	415676	7579617	"Stone"	Scat	Unknown	Nocturnal feeding roost	-	No	Yes	Rocklea	16 km	N/A	N/A	Within Mesa H
43	Mesa H Level 1 Flora, Vegetation and Fauna Assessment	Astron Environmental Services	2014	415739	7598526	Anabat 6	Acoustic recording	Riverine	Foraging habitat	-	Yes	Yes	Robe	< 1 km	N/A	N/A	Within Mesa H
44	Mesa H Level 1 Flora, Vegetation and Fauna Assessment	Astron Environmental Services	2014	415802	7595656	Cave 1 (MH16-34)	Visual sighting and scat	Cave	Diurnal roost – 1 individual sighted	Diurnal roost (MH16-34; Bat Call WA 2017b)	Yes	Yes	Robe	< 1 km	Complex with multiple tight entrances	Unknown	Within Mesa H
45	Mesa H - Ghost Bat, *Macroderma gigas* - Contextual study	Astron Environmental Services	2016	416948	7590247	DRML1	Cave assessment	Large cave	Diurnal roost - cave assessment	-	Yes	Yes	Newman	6 km	Open, adit like (35 m x 15 m)	Multiple caverns (20 m x 20 m) and rear passages	2 km
46	Mesa H Level 1 Flora, Vegetation and Fauna Assessment	Astron Environmental Services	2014	417109	7593285	Cave 5 (AC05)	Scat	Gorge cave	Potential diurnal roost- cave assessment	Nocturnal feeding roost (AC05; Bat Call WA 2017b)	Yes	Yes	Newman	5 km	Tight	Unknown	Within Mesa H
47	Mesa H - Ghost Bat, *Macroderma gigas* - Contextual study	Astron Environmental Services	2016	417354	7590957	FCML9	Scat	Cave	Nocturnal feeding roost	-	Yes	Yes	Newman	5 km	N/A	N/A	1 km
48	Mesa H - Ghost Bat, *Macroderma gigas* - Contextual study	Astron Environmental Services	2016	417447	7591014	FCML10	Scat	Cave	Nocturnal feeding roost	-	Yes	Yes	Newman	5 km	N/A	N/A	1 km
49	Mesa H - Ghost Bat, *Macroderma gigas* - Contextual study	Astron Environmental Services	2016	417580	7591118	DRML2	Cave assessment	Large cave	Diurnal roost - cave assessment	-	Yes	Yes	Newman	5 km	Open (6 m x 12 m)	Large, narrow crevices approx. 15 m high, small domed cavern	1 km
50	Mesa H Level 1 Flora, Vegetation and Fauna Assessment	Astron Environmental Services	2014	417586	7594896	Cave 3/ Anabat 9	Scat	Large cave	Potential diurnal roost	Diurnal roost (AC04; Bat Call WA 2017b)	Yes	Yes	Robe	3 km	Large open entrance	Unknown	Within Mesa H
51	Mesa H - Ghost Bat, *Macroderma gigas* - Contextual study	Astron Environmental Services	2016	417662	7591258	FCJT15	Scat	Cave	Nocturnal feeding roost	-	Yes	Yes	Newman	5 km	N/A	N/A	1 km

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52	Mesa H - Ghost Bat, *Macroderma gigas* - Contextual study	Astron Environmental Services	2016	417714	7591311	Bat A1	Acoustic recording	Breakaway	Foraging habitat	-	Yes	Yes	Newman	5 km	N/A	N/A	1 km
53	Mesa H Level 1 Flora, Vegetation and Fauna Assessment	Astron Environmental Services	2014	418068	7592683	Cave 5	Scat	Gorge/gully/ cave	Potential diurnal roost	Nocturnal feeding roost (Bat Call WA 2017b)	Yes	Yes	Newman	5 km	Tight	Unknown	Within Mesa H
54	Mesa H Level 2 Flora, Vegetation and Fauna Assessment	Astron Environmental Services	2016	419092	7591197	SN12791	Acoustic recording	Gorge	-	-	Yes	Yes	Newman	6 km	N/A	N/A	Within Mesa H
55	Mesa H - Ghost Bat, *Macroderma gigas* - Contextual study	Astron Environmental Services	2016	419326	7588792	Bat A4	Acoustic recording and visual sighting	Large cave	Potential maternal roost - 3 individuals sighted		Yes	Yes	Newman	8 km	Open and large (20 m x 40 m)	60 m deep with 3 large domed chambers and 2 rear passages	2 km
56	Mesa H Level 2 Flora, Vegetation and Fauna Assessment	Astron Environmental Services	2016	419408	7596586	OPP02	Scat	Breakaway	Nocturnal feeding roost	-	Yes	Yes	Newman	< 1 km	N/A	N/A	Within Mesa H
57	Mesa H - Ghost Bat, *Macroderma gigas* - Contextual study	Astron Environmental Services	2016	420680	7589526	FCJT12	Scat	Cave	Nocturnal feeding roost	-	Yes	Yes	Newman	7 km	N/A	N/A	1 km
58	Middle Robe East Deepdale Level 2 Fauna Assessment	Astron Environmental Services	2015	424651	7599195	SM12	Acoustic recording	Breakaway	-	-	No	Yes	Robe	< 1 km	N/A	N/A	4 km
59	Middle Robe East Deepdale Level 2 Fauna Assessment	Astron Environmental Services	2015	426240	7600597	OPP	Scat	Breakaway	Nocturnal feeding roost	-	No	Yes	Robe	< 1 km	N/A	N/A	6 km
60	Middle Robe East Deepdale Level 2 Fauna Assessment	Astron Environmental Services	2015	429041	7600905	Sf33	Scat	Breakaway cave	Nocturnal feeding roost	-	No	Yes	Robe	< 1 km	N/A	N/A	8 km
61	Bungaroo Level 2 Fauna Assessment	Astron Environmental Services	2015	432041	7581397	M17	Scat	Breakaway cave	Nocturnal feeding roost	-	No	Yes	Newman	< 1 km	N/A	N/A	13 km
62	Greater Bungaroo Seasonal Fauna Survey	Biota Environmental Sciences	2010	432484	7581130	GBNbat02	Harp trap	Cave	Potential diurnal roost	-	No	Yes	Boolgeeda	< 1 km	Unknown	Unknown	13 km
63	Middle Robe East Deepdale Level 2 Fauna Assessment	Astron Environmental Services	2015	434094	7603463	HA6	Scat	Breakaway	Nocturnal feeding roost	-	No	Yes	Robe	< 1 km	N/A	N/A	14 km
64	Bungaroo Level 2 Fauna Assessment	Astron Environmental Services	2015	437393	7575997	M14c	Scat	Breakaway	Nocturnal feeding roost	-	No	Yes	Newman	< 1 km	N/A	N/A	20 km

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65	Bungaroo Level 2 Fauna Assessment	Astron Environmental Services	2015	439477	7577992	MJ1	Acoustic recording	Breakaway	Nocturnal feeding roost	-	No	Yes	Newman	< 1 km	N/A	N/A	20 km
66	Middle Robe East Deepdale Level 2 Fauna Assessment	Astron Environmental Services	2015	439619	7603530	HA7	Scat	Breakaway	Nocturnal feeding roost	-	No	Yes	Robe	< 1 km	N/A	N/A	19 km
67	Middle Robe East Deepdale Level 2 Fauna Assessment	Astron Environmental Services	2015	440541	7603393	SM10	Acoustic recording	Breakaway	Diurnal roost – low call number	-	No	Yes	Robe	< 1 km	Open (1 m x 8 m)	10 m deep	19 km
68	Middle Robe East Deepdale Level 2 Fauna Assessment	Astron Environmental Services	2015	440543	7603387	SF09	Acoustic recording	Cave	Diurnal roost - low call number	-	No	Yes	Robe	< 1 km	Narrow entrance (1 m x 1 m)	6 m deep with a domed chamber	19 km
69	Middle Robe East Deepdale Level 2 Fauna Assessment	Astron Environmental Services	2015	441635	7601956	OPP	Scat	Breakaway	Nocturnal feeding roost	-	No	Yes	Robe	< 1 km	N/A	N/A	19 km
70	Bungaroo Level 2 Fauna Assessment	Astron Environmental Services	2015	441772	7573032	MJ19	Scat	Gorge	Nocturnal feeding roost	-	No	Yes	Newman	< 1 km	N/A	N/A	25 km
71	Middle Robe East Deepdale Level 2 Fauna Assessment	Astron Environmental Services	2015	443673	7600605	HA26	Scat	Stony hills and slopes	Nocturnal feeding roost	-	No	Yes	Robe	< 1 km	Shallow overhang	Two rear passages	20 km
72	Middle Robe East Deepdale Level 2 Fauna Assessment	Astron Environmental Services	2015	443675	7600570	SM14	Acoustic recording	Breakaway	-	-	No	Yes	Robe	< 1 km	N/A	N/A	20 km
73	Bungaroo Level 2 Fauna Assessment	Astron Environmental Services	2015	443690	7572830	M14b	Scat	Breakaway cave	Nocturnal feeding roost	-	No	Yes	Newman	< 1 km	N/A	N/A	26 km
74	Middle Robe East Deepdale Level 2 Fauna Assessment	Astron Environmental Services	2015	443694	7600663	HA26	Scat	Stony hills and slopes	Nocturnal feeding roost	-	No	Yes	Robe	< 1 km	Overhang 6 m deep	Tight rear passage dimensions unknown	20 km
75	Middle Robe East Deepdale Level 2 Fauna Assessment	Astron Environmental Services	2015	445777	7600412	OPP	Scat	Breakaway	Nocturnal feeding roost	-	No	Yes	Rocklea	< 1 km	Shallow overhang	Tight rear passage dimensions unknown	23 km
76	Middle Robe East Deepdale Level 2 Fauna Assessment	Astron Environmental Services	2015	446229	7598184	HA9	Scat	Breakaway	Nocturnal feeding roost	-	No	Yes	Robe	< 1 km	N/A	N/A	23 km
77	Middle Robe East Deepdale Level 2 Fauna Assessment	Astron Environmental Services	2015	447006	7601602	OPP	Scat	Breakaway	Nocturnal feeding roost	-	No	Yes	Robe	< 1 km	N/A	N/A	23 km
78	Middle Robe East Deepdale Level 2 Fauna Assessment	Astron Environmental Services	2015	447043	7601535	OPP	Visual sighting	Breakaway	Diurnal roost - 1 individual sighted	-	No	Yes	Robe	< 1 km	Unknown	8 m deep	25 km

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79	Bungaroo Level 2 Fauna Assessment	Astron Environmental Services	2015	447125	7572647	MJ30	Scat	Gorge cave	Nocturnal feeding roost	-	No	Yes	Newman	< 1 km	N/A	N/A	29 km
80	Middle Robe East Deepdale Level 2 Fauna Assessment	Astron Environmental Services	2015	447185	7601770	SF05	Scat	Cave	Nocturnal feeding roost	-	No	Yes	Robe	< 1 km	N/A	N/A	25 km
81	Middle Robe East Deepdale Level 2 Fauna Assessment	Astron Environmental Services	2015	447192	7601783	HA12	Scat	Breakaway	Nocturnal feeding roost	-	No	Yes	Robe	< 1 km	N/A	N/A	25 km
82	Bungaroo Level 2 Fauna Assessment	Astron Environmental Services	2015	448668	7569097	sm7634a	Acoustic recording	Large cave	Nocturnal feeding roost	-	No	No	Unknown	< 1 km	N/A	N/A	32 km
83	Bungaroo Level 2 Fauna Assessment	Astron Environmental Services	2015	448687	7569055	JO-BAT-2	Acoustic recording	Large cave	Nocturnal feeding roost	-	No	No	Unknown	< 1 km	N/A	N/A	32 km
84	Bungaroo Level 2 Fauna Assessment	Astron Environmental Services	2015	449452	7571114	M14	Scat	Breakaway cave	Nocturnal feeding roost	-	No	No	Unknown	< 1 km	N/A	N/A	32 km
85	Bungaroo Level 2 Fauna Assessment	Astron Environmental Services	2015	449703	7568370	M08	Scat	Breakaway cave	Nocturnal feeding roost	-	No	No	Unknown	< 1 km	N/A	N/A	34 km
86	Middle Robe East Deepdale Level 2 Fauna Assessment	Astron Environmental Services	2015	449948	7601179	Sf24	Scat	Cave	Nocturnal feeding roost	-	No	Yes	Robe	< 1 km	N/A	N/A	29 km
87	Bungaroo Level 2 Fauna Assessment	Astron Environmental Services	2015	450747	7568576	M08s	Scat	Cave	Nocturnal feeding roost	-	No	No	Unknown	< 1 km	N/A	N/A	34 km
88	Bungaroo Level 2 Fauna Assessment	Astron Environmental Services	2015	451025	7570122	Jt GB Cave 1	Scat	Gorge cave	Nocturnal feeding roost	-	No	No	Unknown	< 1 km	N/A	N/A	34 km
89	Middle Robe East Deepdale Level 2 Fauna Assessment	Astron Environmental Services	2015	455741	7594808	Sf12	Scat	Cave	Nocturnal feeding roost	-	No	Yes	Robe	< 1 km	N/A	N/A	35 km
90	Middle Robe East Deepdale Level 2 Fauna Assessment	Astron Environmental Services	2015	455987	7595300	SF13	Scat	Cave	Diurnal roost - cave assessment	-	No	No	Unknown	< 1 km	Open (25 m wide)	25 m deep	35 km
91	Middle Robe East Deepdale Level 2 Fauna Assessment	Astron Environmental Services	2015	456013	7595266	Sm20	Acoustic recording	Cave	Maternal roost - high call number	-	No	No	Unknown	< 1 km	Open (20 m wide)	20 m deep	35 km
92	Mesa B-C Cave Assessment, July 2016	Bat Call WA Pty Ltd	2016	389239	7604270	MBC-02	Cave assessment	Cave	Nocturnal feeding roost	-	No	Yes	Robe	2 km	Single entrance, 23.2 x 4.0	Cave 19.3 m deep with low domed roof 2.0m high.	25 km

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93	Mesa B-C Cave Assessment, July 2016	Bat Call WA Pty Ltd	2016	389341	7604165	MBC-06	Cave assessment	Cave	Nocturnal feeding roost	-	Yes	Yes	Robe	3 km	Single entrance, 5.0 x 1.0	Cave10.7 m deep with domed ceiling in rear chamber 1.7m high.	25 km
94	Mesa B-C Cave Assessment, July 2016	Bat Call WA Pty Ltd	2016	389368	7603890	MBS-04	Cave assessment	Cave	Nocturnal feeding roost	-	Yes	Yes	Robe	3 km	Single entrance, 1.9 x 1.0	Shelter 1.5 m deep with domed ceiling 1.5m high.	25 km
95	Mesa B-C Cave Assessment, July 2016	Bat Call WA Pty Ltd	2016	389387	7604070	MBS-05	Cave assessment	Cave	Nocturnal feeding roost	-	Yes	Yes	Robe	3 km	Two entrance, 11.1 x 2.0 and 9.2 x 2.0	Shelter chambers 6.8and 5.5 m deep, both with domed ceilings ~1.6m high.	25 km
96	Mesa B-C Cave Assessment, July 2016	Bat Call WA Pty Ltd	2016	390541	7604402	MBS-03	Cave assessment	Cave	Nocturnal feeding roost	-	Yes	Yes	Robe	2 km	Single entrance, 2.3 x 2.3	Shelter 7.2 m deep.	25 km
97	Mesa B-C Cave Assessment, July 2016	Bat Call WA Pty Ltd	2016	390791	7604400	MBC-05	Cave assessment	Cave	**Diurnal roost (possible maternal roost) - 16 individuals sighted**	-	Yes	Yes	Robe	2 km	Single entrance, Not measured due to presence of Ghost bats	Cave approx. 20 m deep. Not measured due to presence of Ghost bats	25 km
98	Mesa B-C Cave Assessment, July 2016	Bat Call WA Pty Ltd	2016	390809	7604425	MBC-04	Cave assessment	Cave	Nocturnal feeding roost	-	Yes	Yes	Robe	2 km	Single entrance, 7.6 x 2.5	Cave 13.3 m deep with domed roof 3.0m high and low rear chamber.	25 km
99	Mesa B-C Cave Assessment, July 2016	Bat Call WA Pty Ltd	2016	391009	7604273	MBS-01	Cave assessment	Cave	Nocturnal feeding roost	-	Yes	Yes	Robe	2 km	Single entrance, 14.3 x 2.5	Shelter 10.5 m deep with low domed roof 1.5m high.	25 km
100	Mesa B-C Cave Assessment, July 2016	Bat Call WA Pty Ltd	2016	391348	7604205	MBS-07	Cave assessment	Cave	Nocturnal feeding roost	-	Yes	Yes	Robe	2 km	Single entrance, 7.2 x 4.1	Cave with 12.2m deep with domed ceiling 2.7 high.	25 km

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101	Mesa B-C Cave Assessment, July 2016	Bat Call WA Pty Ltd	2016	391643	7604682	MBS-08	Cave assessment	Cave	Nocturnal feeding roost	-	Yes	Yes	Robe	< 1 km	Single entrance, 13.0 x 3.0	Shelter 11.0m deep with domed ceiling 2.0 high.	25 km
102	Mesa B-C Cave Assessment, July 2016	Bat Call WA Pty Ltd	2016	391999	7604441	MBC-01	Cave assessment	Cave	Nocturnal feeding roost	-	Yes	Yes	Robe	1 km	Single entrance 7.1 x 2.8 m	Internal domed chamber 1.5 m high	25 km
103	Mesa B-C Cave Assessment, July 2016	Bat Call WA Pty Ltd	2016	392498	7602976	MCC-04	Cave assessment	Cave	Nocturnal feeding roost	-	Yes	Yes	Robe	< 1 km	Two entrances, both 1.5 x 1.0	Internal domed chamber 2.5 m high	25 km
104	Mesa B-C Cave Assessment, July 2016	Bat Call WA Pty Ltd	2016	392569	7602798	MCC-05	Cave assessment	Cave	Nocturnal feeding roost	-	Yes	Yes	Robe	< 1 km	Single entrance, 4.7 x 2.7	Cave approx. 30 m deep	25 km
105	Mesa B-C Cave Assessment, July 2016	Bat Call WA Pty Ltd	2016	392587	7603154	MCS-14	Cave assessment	Cave	Nocturnal feeding roost	-	Yes	Yes	Robe	< 1 km	Single entrance, 4.3 x 2.4	Shelter 8.1 m deep with internal chamber with low ceiling.	25 km
106	Mesa B-C Cave Assessment, July 2016	Bat Call WA Pty Ltd	2016	392711	7600078	MCS-05	Cave assessment	Cave	Nocturnal feeding roost	-	Yes	Yes	Robe	< 1 km	Single entrance, 9.3 x 3.0	Shelter 9.7m deep	25 km
107	Mesa B-C Cave Assessment, July 2016	Bat Call WA Pty Ltd	2016	393014	7599998	MCS-03	Cave assessment	Cave	Nocturnal feeding roost	-	Yes	Yes	Robe	< 1 km	Single entrance, 15.1 x 3.3	Shelter 8.9 m deep	25 km
108	Mesa B-C Cave Assessment, July 2016	Bat Call WA Pty Ltd	2016	393017	7601019	MCS-11	Cave assessment	Cave	Nocturnal feeding roost	-	Yes	Yes	Robe	< 1 km	Single entrance, 11.0 x 2.5	Shelter 7.5 m deep	25 km
109	Mesa B-C Cave Assessment, July 2016	Bat Call WA Pty Ltd	2016	393067	7600967	MCS-10	Cave assessment	Cave	Nocturnal feeding roost	-	Yes	Yes	Robe	< 1 km	Single entrance, 12.1 x 3.2	Shelter 7.5 m deep with rear chamber with domed ceiling, not entered due to presence of snake	25 km
110	Mesa B-C Cave Assessment, July 2016	Bat Call WA Pty Ltd	2016	393071	7599984	MCS-02	Cave assessment	Cave	Nocturnal feeding roost	-	Yes	Yes	Robe	< 1 km	Single entrance, 11.3 x 2.0	Shelter 12.3 m deep	25 km
111	Mesa A-C Cave Assessment, April 2017	Bat Call WA Pty Ltd	2017	386122	7604019	A5	Cave assessment	Cave	Nocturnal feeding roost	-	No	Yes	Robe	6 km	Single wide entrance 5.3 x 3.6 m	Internal domed chamber 2.5 to 4.5 m high	28 km

Ref #	Report	Author	Year	Easting	Northing	Site code	Record type	Assessment	Assessment	Updated assessment	Within		Land system	Distance to Robe River or tributary	Cave dimensions (H x W)		Distance to Mesa H
											Contextual survey area	Desktop survey area			Entrance	Internal	
112	Mesa H Cave Assessment, April 2017	Bat Call WA Pty Ltd	2017	415625	7595659	MH-Opp 1S	Cave assessment	Cave	Nocturnal feeding roost	-	Yes	Yes	Robe	2 km	A small entrance among a group of overhangs. Entrance 1.5 x 1.5 m	Deep shelter with a two low domes	Within Mesa H
113	Mesa H Cave Assessment, April 2017	Bat Call WA Pty Ltd	2017	415782	7595640	MH16-35	Cave assessment	Cave	Nocturnal feeding roost	-	Yes	Yes	Robe	3 km	A shallow shelter among a group of overhangs	Shallow shelter ~5 m deep.	Within Mesa H
114	Mesa H Cave Assessment, April 2017	Bat Call WA Pty Ltd	2017	416587	7596590	H27	Cave assessment	Cave	Nocturnal feeding roost	-	Yes	Yes	Robe	2 km	Two entrances, one 8.6 x 3.8 m and another very small entrance to the north.	Shelter is 10.5 m deep with low roof and a low dome with a sinuous vertical pipe	Within Mesa H
115	Mesa H Cave Assessment, April 2017	Bat Call WA Pty Ltd	2017	416948	7596585	MH-Opp 2S (H26)	Cave assessment	Cave	Nocturnal feeding roost	-	Yes	Yes	Robe	2 km	small constricted entrance 0.7 x 1.5 m.	Shelter with small entrance and a low dome	Within Mesa H
116	Mesa H Cave Assessment, April 2017	Bat Call WA Pty Ltd	2017	417252	7594383	MH15-13 MH15-14	Cave assessment	Cave	Nocturnal feeding roost	-	Yes	Yes	Robe	4 km	Single entrance 2.7 x 2.5 m	Shelter is 9.0 m deep with low roof and a high pipe in the roof at the rear	Within Mesa H
117	Mesa H Cave Assessment, April 2017	Bat Call WA Pty Ltd	2017	417270	7595276	H01-A01 MH15-44	Cave assessment	Cave	Nocturnal feeding roost	-	Yes	Yes	Robe	3 km	Single wide entrance 9.0 x 1.5 m.	Shelter is 8 m deep with low roof and one low dome.	Within Mesa H
118	Mesa H Cave Assessment, April 2017	Bat Call WA Pty Ltd	2017	417330	7595332	MH-Opp 3S (H23)	Cave assessment	Cave	Nocturnal feeding roost	-	Yes	Yes	Robe	3 km	A large entrance among a group of overhangs. Entrance 8.0 x 4.0 m	Deep shelter with a two levels. Upper level accessed by three pipes ~1.0 m high.	Within Mesa H

Ref #	Report	Author	Year	Easting	Northing	Site code	Record type	Assessment	Assessment	Updated assessment	Within		Land system	Distance to Robe River or tributary	Cave dimensions (H x W)		Distance to Mesa H
											Contextual survey area	Desktop survey area			Entrance	Internal	
119	Level 2 Terrestrial Fauna Surveys: Mesa B-C, Warramboo BWT and Highway to Tod Bore	MWH Australia	2015	391022	7604299	B1	Cave assessment	Cave	Nocturnal feeding roost	-	Yes	Yes	Robe	2 km	Unknown	Unknown	25 km
120	Level 2 Terrestrial Fauna Surveys: Mesa B-C, Warramboo BWT and Highway to Tod Bore	MWH Australia	2015	392004	7604437	SM2-BC06	Cave assessment	Cave	Nocturnal feeding roost	-	Yes	Yes	Robe	2 km	Unknown	Unknown	25 km

Mesa H
Level 2 Fauna Assessment
May 2016

Prepared for
Robe River Mining Co. Pty Ltd

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Report Reference: 14269-16-BISR-3Rev2_170927

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Mesa H
Level 2 Fauna Assessment

Prepared for
Robe River Mining Co. Pty Ltd

Job Number: 14269-16

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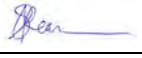
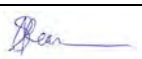
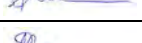
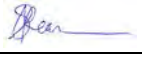
			Name	**Signature**
A	15/08/2016	P. Royce	S. Pearse	
B	16/02/2017	M. Brand	S. Pearse	
0	26/07/2017	M. Brand	S. Pearse	
1	17/08/2017	M. Brand	S. Pearse	
2	27/09/2017	M. Brand	S. Pearse	

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Abbreviations

Abbreviation	Definition
ANOSIM	Analysis of Similarity
Bat Call WA	Bat Call WA Pty Ltd
Biota	Biota Environmental Sciences
BOM	Bureau of Meteorology
DEC	Department of Environment and Conservation (now DER and Parks and Wildlife)
EN	Endangered
EPA	Environmental Protection Authority (State)
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999* (Commonwealth)
ESA	Environmentally Sensitive Areas
GDA94	Geocentric Datum of Australia 1994
IBRA	Interim Biogeographic Regionalisation for Australia
Mi	Migratory
MNES	Matters of National Environmental Significance (under the EPBC Act)
Parks and Wildlife	Department of Parks and Wildlife (State)
PEC	Priority Ecological Community
sp.	Species (singular)
SRE	Short Range Endemic
TEC	Threatened Ecological Community
The 'survey area'	Mesa H survey area (4,930 ha)
VU	Vulnerable
WA	Western Australia
WC Act	*Wildlife Conservation Act 1950* (State)
WAM	Western Australian Museum

Executive Summary

Rio Tinto on behalf of Robe River Mining Co. Pty. Ltd is evaluating the potential development of the Mesa H deposit located adjacent to the Mesa J Operation and approximately 13 kilometres to the south-west of the town of Pannawonica. Astron Environmental Services has been commissioned to undertake a two-phase Level 2 vertebrate and Short Range Endemic invertebrate fauna assessment in the Mesa H survey area which is approximately 4,930 hectares in size.

Vertebrate Fauna

Seven broad fauna habitat types were recorded in the survey area: Riverine, Drainage Line, Gorge, Breakaway, Rocky Hills, Low Hills and Slopes, and Loamy/Stony Plain. Areas of disturbed habitat were prevalent in the Low Slopes and Hills habitats on the top of Mesa H and the Loamy/Stony Plains habitat in the form of drill pads and associated tracks. The Gorge, Riverine and Breakaway habitats in the survey area are considered important for fauna due to the microhabitats they provide such as caves and water pools. The Gorges and Breakaways in particular contain a high diversity of microhabitats; it represents an important site of refuge due to its location close to the Robe River and as habitat for conservation listed fauna.

There were 169 vertebrate fauna species recorded within the survey area, including two amphibian species, 55 reptile species, 85 bird species and 27 mammal species (including four introduced species). The faunal assemblage recorded is considered typical of the Hamersley Range subregion extending from near Pannawonica to Mt Brockman.

Eight conservation listed fauna species have been recorded in the survey area: Pilbara Olive Python (VU; S3) (*Liasis olivaceus barroni*), Northern Quoll (EN; S2) (*Dasyurus hallucatus*), Pilbara Leaf-nosed Bat (VU; S3) (*Rhinonicteris aurantia*), Ghost Bat (VU; S3) (*Macroderma gigas*), Rainbow Bee-eater (Mi; S5) (*Merops ornatus*), Eastern Great Egret (Mi; S5) (*Ardea modesta*), Lined Soil-crevice Skink (P4) (*Notoscincus butleri*) and Western Pebble-mound Mouse (P4) (*Pseudomys chapmani*).

Four of the eight recorded conservation listed species are classified under the *Environment Protection and Biodiversity Act 1999* as 'Matters of National Environmental Significance' species: the Pilbara Olive Python; Northern Quoll; Ghost Bat; and Pilbara Leaf-nosed Bat. A single juvenile Pilbara Olive Python was recorded within the Riverine habitat and two Pilbara Olive Python scats were recorded within the Breakaway habitat type of the survey area. The Northern Quoll was recorded 32 separate times during the survey comprising: six capture records (four confirmed individuals); 22 remote camera records from 14 different locations; and from four scats within the Breakaway, Riverine and Gorge habitat types. The Pilbara Leaf-nosed Bat was recorded at eight of the 14 SM2 bat detector locations, all at low activity levels apart from BAT 14 (located in the mouth of a Gorge) which recorded 257 calls. Further data and analysis of the BAT 14 sites suggests that the Pilbara Leaf-nosed Bats likely originated from a known roost site approximately 10 kilometres south of the survey area. No diurnal or maternal roost sites suitable for the Pilbara Leaf-nosed Bat were recorded in the survey area. The Ghost Bat was recorded twice through scat collections and acoustic recordings. Seven caves were previously identified in the Astron 2014 survey of Mesa H, two of which were deemed to be diurnal roosts (possible maternal roosts) following a targeted cave assessment conducted by Bat Call WA Pty Ltd. Another three of the caves (two caves part of one system) were determined to be nocturnal feeding roosts and the other two caves were considered to not be used. An additional seven sites identified by Bat Call WA Pty Ltd during the targeted cave assessment were deemed to be nocturnal feeding roosts.

The results from the survey suggest that the survey area supports a diverse and representative vertebrate fauna assemblage with a varied array of microhabitats for fauna species to exploit. The

microhabitats of the Gorge, Riverine and Breakaway habitat types contain ecological features important to conservation listed fauna such as the Pilbara Olive Python, Northern Quoll, Ghost Bat and Pilbara Leaf-nosed Bat.

Short Range Endemic Invertebrate Fauna

The fauna habitats most suited to Short Range Endemic species, namely the Breakaway, Gorge and Riverine habitats, did not support rich Short Range Endemic communities. Conversely, the Loamy/Stony Plains habitat supported some Short Range Endemic species but this habitat type is widespread and has little prospect to restrict dispersal in Short Range Endemic fauna. Prospective Short Range Endemic habitats within the survey area are not restricted at the local, sub-regional or regional scale.

A total of 36 specimens belonging to at least 14 invertebrate morphospecies were collected from the survey area. Scorpions were the most diverse group with six species and 12 specimens, followed by slaters (three species; 16 specimens), pseudoscorpions (two species; four specimens) and spiders (three species; four specimens). No centipedes, harvestmen, millipedes or snail specimens (aquatic or terrestrial) were collected during the current survey. No listed invertebrate species were collected during the survey. Based on these results, nine of the species (64%) were not considered to be, or are unlikely to be, Short Range Endemics. No confirmed Short Range Endemic species were collected; however, five species (36%) were classified as potential Short Range Endemic species, principally in the scorpion (two species), spider (two species) and slater (one species) faunas. These species are:

- slaters – *Buddelundia* '61'
- scorpions – *Lychas* 'sp. nov. 1' and *Lychas* 'sp. nov. 2'
- spiders – *Karaops feedtime* and *Karaops* sp. indet.

The identity and distribution of these potential Short Range Endemic species is uncertain, primarily due to a lack of taxonomic resolution. Some of the potential Short Range Endemic species are likely to be more widespread but remain poorly documented. Molecular analyses were undertaken on the arachnid specimens because they were either juvenile specimens or from complex family groups that have a cryptic morphology. The four potential Short Range Endemic arachnid species were identified using genetic data and are classified as potential Short Range Endemics in the Western Australian Museum sub-category 'Molecular Evidence'. The potential Short Range Endemic slater species was identified using morphology and was classified as a potential Short Range Endemic in the sub-category 'Data deficient'.

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1 Introduction

1.1 Project Background

Rio Tinto, on behalf of Robe River Mining Co. Pty. Ltd (the Proponent), is evaluating the potential development of the Mesa H deposit located adjacent to the Mesa J Operation and approximately 13 km to the south-west of the town of Pannawonica. Key components of the pre-feasibility and feasibility studies being undertaken are the environmental surveys which are required to inform the environmental assessment process for the potential development of the Mesa H deposit. Astron Environmental Services (Astron) has been commissioned to undertake some of these environmental surveys. This report presents the outcome of the Level 2 vertebrate and Short Range Endemic (SRE) invertebrate fauna assessment at the Mesa H deposit (the survey area). The survey area is 4,930 ha (Figure 1).

1.2 Scope and Objectives

The objective of the assessment was to undertake a two-phase Level 2 assessment of vertebrate fauna and targeted SRE invertebrate fauna through a desktop assessment and field survey, and to incorporate data from previous biological surveys. The resultant data has been utilised to produce this report which is intended to support and inform the environmental assessment process in accordance with the requirements of the Environmental Protection Authority (EPA). Astron completed the first phase of the assessment in 2015 (Astron Environmental Services 2015). The scope of works was to undertake a:

- **desktop assessment**, including database searches and literature review of available resources
- **two-phase vertebrate fauna** field survey, including:
  - fauna sampling
  - targeted Matters of National Environmental Significance (MNES) species sampling and searches
  - fauna habitat mapping
- **targeted SRE field survey**, including:
  - targeted survey and searches
  - dry pitfall trap sampling
  - SRE fauna habitat mapping.

Astron conducted the fauna survey in accordance with the following:

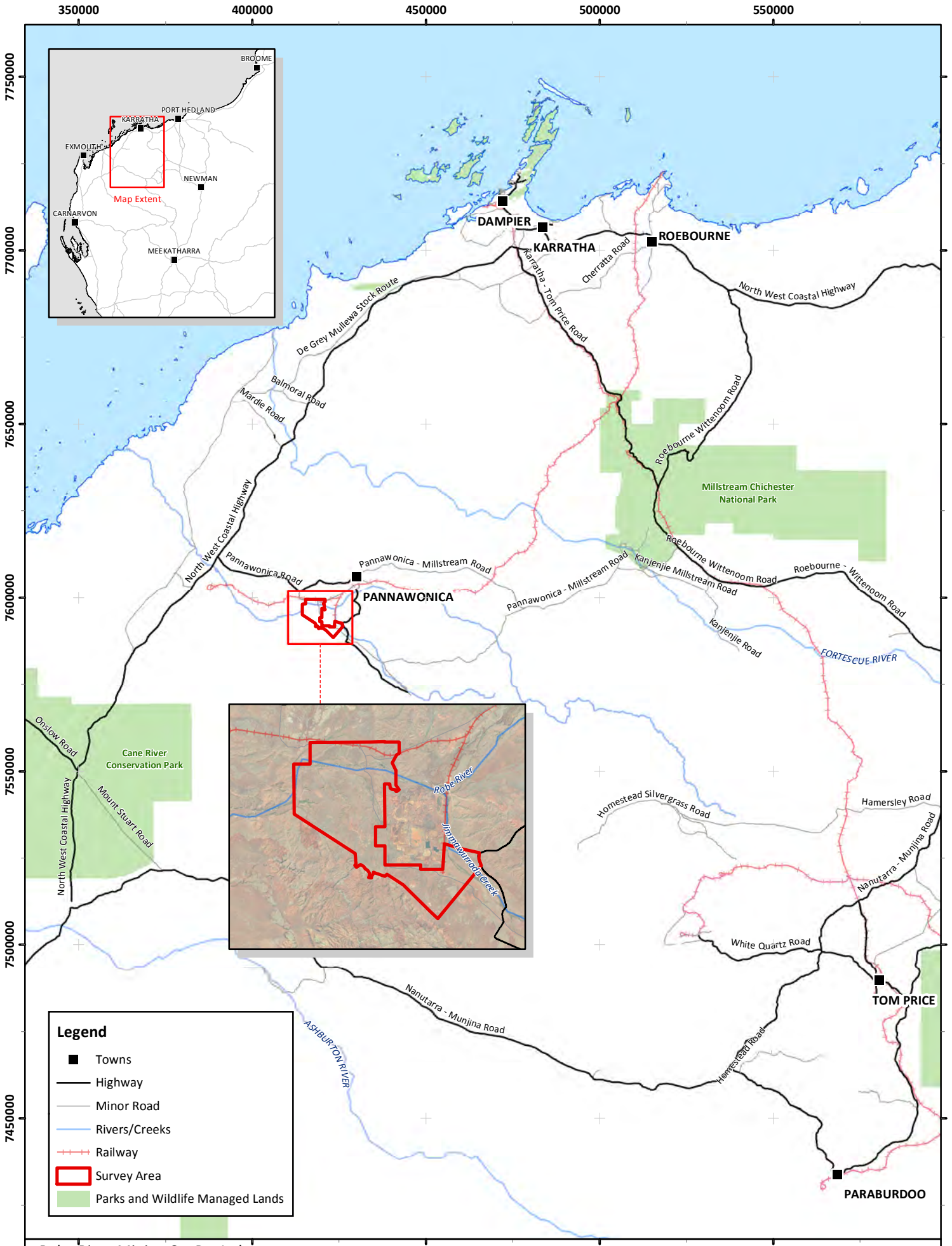
- Position Statement No. 3 (Environmental Protection Authority 2002)
- Technical Guidance - Terrestrial Fauna Surveys (Environmental Protection Authority 2016a)
- Technical Guidance - Subterranean Fauna Surveys (Environmental Protection Authority 2016b)
- Technical Guidance - Sampling Methods for Terrestrial Fauna (Environmental Protection Authority 2016c)

- *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) referral guideline for the Endangered Northern Quoll *Dasyurus hallucatus* (Department of the Environment and Energy 2016)
- Rio Tinto data standards (Rio Tinto Iron Ore 2016a, 2016b, 2016c, 2016d, 2016e).

The scope and key limitations of the survey are outlined in Table 1. Section 3.5 of this report provides more detail on the limitations of the survey.

Table 1: Summary of Astron's vertebrate fauna and SRE invertebrate fauna assessment.

Level of survey	Survey area size	Survey timing	Relevant regulatory guidance documents	Key survey limitations
Level 2 two-phase survey	4,930.2 ha	24 September to 3 October 2015 27 April to 9 May 2016	• Position Statement No. 3 (Environmental Protection Authority 2002) • Technical Guidance - Terrestrial Fauna Surveys (Environmental Protection Authority 2016a) • Technical Guidance - Subterranean Fauna Surveys (Environmental Protection Authority 2016b) • Technical Guidance - Sampling Methods for Terrestrial Fauna (Environmental Protection Authority 2016c) • *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) referral guideline for the Endangered Northern Quoll *Dasyurus hallucatus* (Department of the Environment and Energy 2016)	• Rainfall preceding both phase 1 and phase 2 of the fauna surveys was below average. • Large portions of the Low Hills and Slopes and Loamy/Stony Plains habitat on top of Mesa H were affected by exploration drilling pads and their associated tracks. • These are classified as minor limitations only and are not expected to have a major effect on survey outcomes.



Robe River Mining Co. Pty Ltd

Mesa H – Level 2 Fauna Assessment, May 2016

Figure 1: Survey area location

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Author: J. Trainer	Date: 15-08-2017	Datum: GDA 1994 - Projection: MGA Zone 50
Drawn: C. Dyde	Figure Ref: 14269-16-BIDR-3Rev1_170815_Fig01_Locn	0 10 20 30 40 50 Km

N

2 Environmental Context

2.1 Physical Environment

2.1.1 Climate

The climate of the Pilbara region of Western Australia is classified as arid tropical with two distinct seasons: a hot, wet summer (October – April) and a mild, dry winter (May – September) (Bureau of Meteorology 2016).

Based on long-term climatic data from the nearest Bureau of Meteorology (BOM) weather station at Pannawonica (Station 5069) (approximately 13 km north-east of the survey area) the mean annual rainfall since 1971 is 403.5 mm (Bureau of Meteorology 2016). The mean maximum daily temperatures range between 28°C and 41°C, and range above 30°C for much of the year (Bureau of Meteorology 2016) (Figure 2).

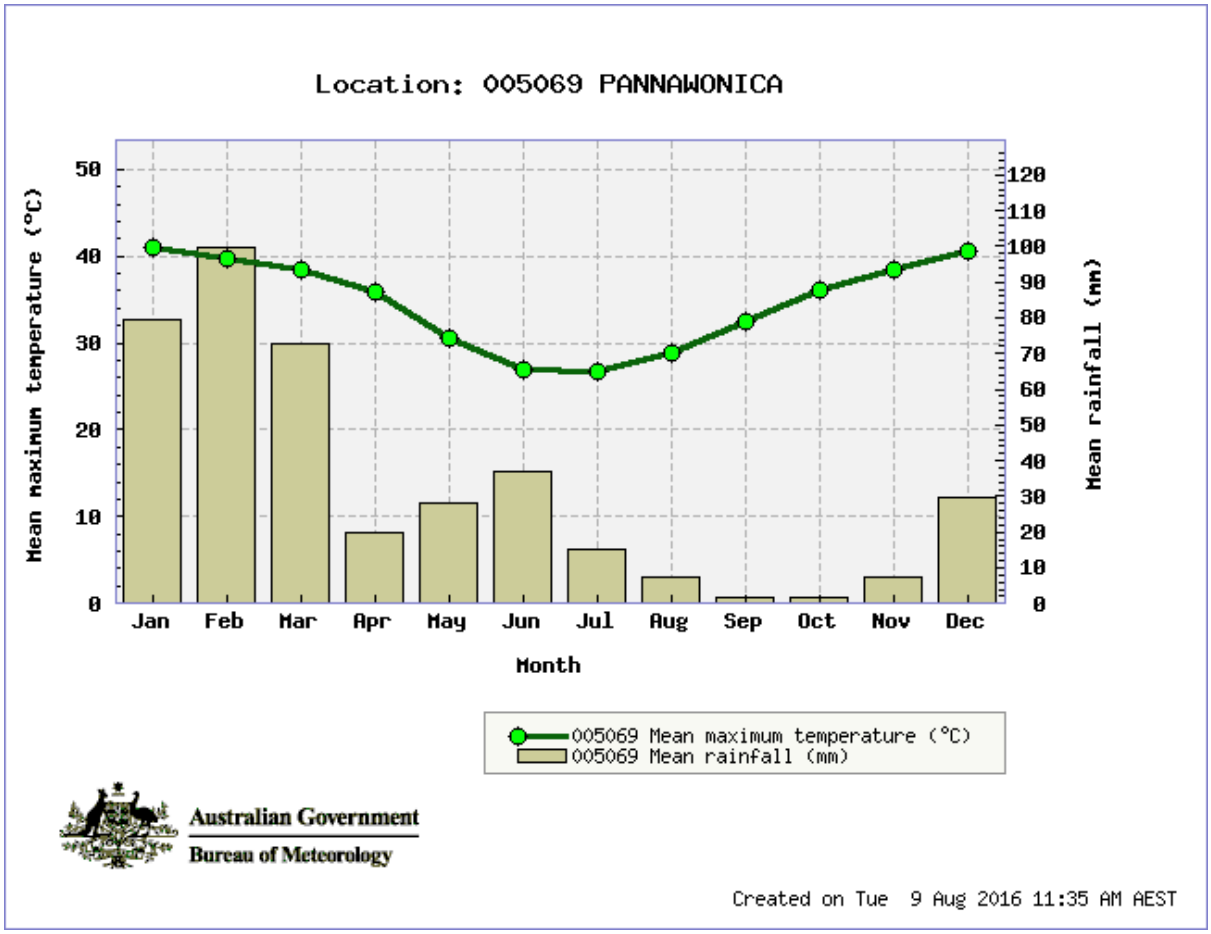

Figure 2: Climate data for Pannawonica (Station 5069). Mean annual rainfall data has been calculated from 1971 – 2016 and mean maximum temperature has been calculated from 1971 – 2005 (Bureau of Meteorology 2016).

2.1.2 Geology and Soils

The survey area occurs on the Hamersley Basin which overlies the Archaean Pilbara Craton and comprises of mafic and felsic volcanics, shale, siltstone, sandstone and conglomerate, as well as dolomite and banded iron formation. The area is extensively deformed with the rocks being folded and faulted (van Vreeswyk et al. 2004). The surface geology of the survey area is comprised of seven

units (Stewart et al. 2008), with Robe Pisolite the most dominant (Table 3). Geological mapping of the survey area and surrounds is presented in Figure A.1 (Appendix A).

Table 2: Geological units of the survey area (Stewart et al. 2008).

Geological name	Label	Area within survey area (ha)
Woongarra Rhyolite: rhyolite, rhyodacite, rhyolitic volcaniclastic breccia and banded iron formation	Lfhw	88.5
Marra Mamba Iron Formation: chert, ferruginous chert, jaspilite, banded iron formation, minor shale, siltstone, mudstone	Achm	635.9
Mount McRae Shale and Mount Sylvia Formation: interbedded shale, chert, banded iron-formation	Ashm	289.7
Brockman Iron Formation: banded iron-formation, chert, mudstone and siltstone	Lchk	114.0
Colluvium 38491: colluvium, sheetwash, talus; gravel piedmonts and aprons over and around bedrock; clay-silt-sand with sheet and nodular kankar; alluvial and aeolian sand-silt-gravel in depressions and broad valleys in Canning Basin; local calcrete, reworked laterite	Qrc	778.2
Robe Pisolite: pisolitic, oolitic and massive limonite, goethite and hematite deposits containing fossil wood fragments; iron ore	Czlr	2,261.7
Alluvium 38485: channel and flood plain alluvium; gravel, sand, silt, clay, locally calcreted	Qa	762.3

The survey area is mapped as soil landscape zone 285 – Hamersley Plateaux in the Fortescue Province and soil landscape zone 296 – Stuart Plains and Hills Zone of the Ashburton Province (Tille 2006).

The Hamersley Plateaux soil unit is described as hills and dissected plateaux with some stony plains and hardpan wash plains on volcanic and sedimentary rocks. It is comprised predominately of stony soils with red shallow loams and some red-brown non-cracking clays and red loamy earths (Tille 2006). Some drainage habitats occur and these are characterised by sand, gravel, pebbles and stones (van Vreeswyk et al. 2004).

The Stuart Plains and Hills Zone consists of hills and ranges with some floodplains and stony plains on sandstone, shale and conglomerate of the Ashburton Basin. Soils are typically stony with red loamy earth and red shallow loams (Tille 2006).

2.1.3 Surface Water and Hydrology

The Robe River is considered a seasonal watercourse and intersects the northern section of the survey area, flowing in an east-west orientation. A number of permanent pools in the river were observed within the survey area. Numerous creeks and smaller drainage lines stem from the Robe River; drainage lines also occur down the gullies of the surrounding mesas. Springs and pools of the Robe River are listed as 'Wetlands of Subregional Significance' (Kendrick 2001) and are in proximity to the survey area. These wetland ecosystems are distributed from 40 km east of Pannawonica downstream to the North West Coastal Highway. Approximately 998 ha in the south-eastern corner of the survey area is within a Public Drinking Water Source Area: the Bungaroo Water Reserve (Department of Water 2008).

2.2 Biological Environment

2.2.1 Interim Biogeographic Regionalisation of Australia

The Interim Biogeographic Regionalisation for Australia (IBRA version 7) divides the Australian continent into 89 bioregions and 419 subregions (Department of the Environment and Energy 2016a). The IBRA regions represent a landscape-based approach to classifying the land surface, including attributes of climate, geomorphology, landform, lithology, and characteristic flora and fauna. The survey area occurs in the Pilbara Bioregion, of which 5% to 10% is represented in the national reserve system (Department of the Environment and Energy 2016b).

The biodiversity of the 53 subregions recognised in Western Australia was documented as part of a national audit to provide priorities for conservation action (Department of Conservation and Land Management 2002). The survey area occurs within the Hamersley subregions of the Pilbara region. The Hamersley subregion is described in the audit as:

> Hamersley PIL3 – dissected bold plateaux and ranges of flat lying, moderately folded sandstone and quartzite with vegetation described as Mulga low woodland over tussock grasses occurring on fine textured soils in valley floors, with scattered Snappy gum (*Eucalyptus leucophloia*) over *Triodia brizoides* on skeletal soils of the ranges (Kendrick 2001).

2.2.2 Land Systems

Land systems of the Western Australian rangelands have been mapped and described by the Department of Agriculture and Food outlining the distributions and providing descriptions of biophysical resources including soil and vegetation condition. A total of 102 land systems occur in the Pilbara bioregion covering 181,723 km^2. Six land systems occur in the survey area, with Robe being the most dominant (Table 3). The layout of these land systems within the survey area is shown in Figure A.2 (Appendix A).

Table 3: Distribution of land systems within the survey area and Pilbara bioregion (van Vreeswyk et al. 2004).

Land system	Total area within Pilbara bioregion (ha)	Total area within survey area (ha)	Proportion within survey area (%)
Boolgeeda - stony lower slopes and plains below hill systems supporting hard and soft spinifex grasslands and mulga shrublands	961,847	559.8	<0.1
McKay - hills, ridges, plateaux remnants and breakaways of meta sedimentary and sedimentary rocks supporting hard spinifex grasslands	425,967	0.2	<0.1
Newman - rugged jaspilite plateaux, ridges and mountains with hard spinifex	1,994,339	673.5	<0.1
River - active flood plains, major rivers and banks supporting grassy eucalypt woodlands, tussock grasslands and soft spinifex grasslands	481,994	816.7	0.2
Robe - low limonite mesas and buttes supporting soft spinifex (and occasionally hard spinifex) grasslands	128,680	2,758	2.1
Urandy - stony plains, alluvial plains and drainage lines supporting shrubby soft spinifex grasslands	132,039	121.8	<0.1
TOTAL	**4,124,866**	**4,390**	-

2.2.3 Pre-European Vegetation

Pre-European vegetation was mapped across the Pilbara region at a scale of 1:1,000,000 (Beard 1975). The survey area is located in the Stuart Hills and Hamersley Plateau physiographic units of the Fortescue Botanical District (Figure A.3, Appendix A). These physiographic units are described as:

Hamersley: a compact unit defined by the outcropping of jaspilite and dolomite, with some shale, siltstone and volcanics. Vegetation is described as:

- ranges – tree steppe of *Eucalyptus brevifolia* (likely to represent *E. leucophloia*) over *Triodia wiseana* hummock grasslands
- valley plains – mulga (*Acacia aneura* complex) low woodlands, or tussock grasslands on cracking clay soils
- basalt hills – mosaic of mulga low woodland and *Acacia pyrifolia* and *Triodia* species shrub steppe.

Stuart Hills: this unit consists mostly of plains, gently undulating pediplains extending out from Breakaways and residuals capped by Robe pisolites, and stony hills and steeply dissected pediments on fine-grained sandstone, shale and dolomite. Vegetation is described as:

- hills and plains – *Triodia wiseana* and *T. basedowii* hummock grasslands with sparse shrubs, particularly *Acacia bivenosa*
- drainage lines – *Corymbia hamersleyana* and *C. candida* occur occasionally, with *Senna* species and ephemerals
- major rivers – *Eucalyptus camaldulensis* and *Acacia citrinoviridis* along river and mulga low woodland on river flats and tributaries.

Four pre-European vegetation units, 82, 603, 605 and 609 (Shepherd, Beeston, and Hopkins 2002), are associated with the survey area:

> 82: 'Hummock grasslands, low tree steppe; snappy gum over *Triodia wiseana*'
>
> 603: 'Hummock grasslands, sparse shrub steppe; *Acacia bivenosa* over hard spinifex'
>
> 605: 'Hummock grasslands, shrub steppe; *Acacia pachycarpa* and waterwood over soft spinifex'
>
> 609: 'Mosaic: Hummock grasslands, open low tree steppe; bloodwood with sparse kanji shrubs over soft spinifex/Hummock grasslands, open low tree steppe; snappy gum over *Triodia wiseana*'.

Table 4 summarises the current and pre-European extent of these four vegetation units in the Pilbara and the survey area.

Table 4: Extent of pre-European vegetation in the survey area (Government of Western Australia 2014).

Vegetation association	Mapping unit (Beard 1975)	Extent in survey area (ha)	Current extent in Pilbara bioregion (ha)	Pre-European extent (ha)	Proportion of pre-European extent remaining (%)
82	e16Lr t3Hi	2,023.7	2,550,898.98	2,563,583.23	99.51
603	a6Sb t3Hi	534.0	55,764.00	56,726.87	98.30
605	a5,11Sr t1Hi	965.5	114,115.85	114,115.85	100.00
609	e24Lr a2Sp t1Hi /e16Lr t3Hi	1407.0	72,765.18	74,186.11	98.08

2.3 State and Commonwealth Conservation Categories and Management

Commonwealth and State regulatory authorities maintain databases of the locations and conservation status of significant flora, fauna and ecological communities in Western Australia. The EPBC Act provides a legal framework to protect and manage MNES including listed flora, fauna and ecological communities. These listed flora, fauna and ecological communities are allocated conservation categories, which are outlined in Tables B.1-B.6 (Appendix B).

Ecological communities may be subject to processes that threaten to destroy or significantly modify it across much of its range. These communities are identified as Threatened Ecological Communities (TECs) and are listed at both the State level by the Western Australian Minister for Environment and the Commonwealth level under the EPBC Act (Tables B.1-B.2, Appendix B). The Department of Parks and Wildlife (Parks and Wildlife) maintains a list of Priority Ecological Communities (PECs), which may also be under threat and are assigned one of four priority rankings according to the criteria outlined in Table B.3 (Appendix B).

Under Western Australian legislation, all native fauna is protected and it is an offence to 'take' protected fauna. The *Wildlife Conservation Act 1950* (WC Act) also provides for native fauna species to be specially protected when they are considered rare, threatened with extinction, or have a high conservation value (Table B.4, Appendix B). In addition, due to the diversity of Western Australia's fauna, many species are known from only a few collections or locations, but have not been adequately surveyed. Such fauna may be rare or threatened, but cannot be considered for declaration as Threatened fauna until adequate surveys have been undertaken. These fauna species are included on a supplementary conservation list managed by Parks and Wildlife called the *Priority*

Fauna List. Priority fauna are categorised according to level of threat and other information and the conservation categories are described in Table B.5 (Appendix B).

2.4 Land Use and Tenure

The survey area is located within the Shire of Ashburton. The majority of the survey area is on the Yalleen Station pastoral lease, with 100 ha (<1% of the survey area) on the Yarraloola Station pastoral lease. The local area is used for pastoralism, mineral exploration and mining activity.

The Millstream-Chichester National Park is the nearest conservation reserve to the survey area, located approximately 79 km to the north-east. The Cane River Conservation Park is located approximately 48 km to the south-west, Murujuga National Park is approximately 120 km north and Karijini National Park is approximately 180 km south-east of the survey area (refer to Figure 1).

3 Methodology

3.1 Desktop Assessment

A desktop assessment was undertaken to assess whether any conservation listed vertebrate and invertebrate species, SRE invertebrate species or communities, or PECs/TECs were likely to occur within the survey area. For vertebrate species, the review focused on key habitats for conservation listed fauna and species of MNES. For SRE invertebrates, the review focused on key habitats for SRE fauna and the eight invertebrate groups with a known high proportion of SRE species (the SRE groups): centipedes (Chilopoda), harvestmen (Opiliones), millipedes (Diplopoda), non-marine snails (Gastropoda), pseudoscorpions (Pseudoscorpiones), scorpions (Scorpiones), terrestrial slaters (Isopoda) and spiders (Araneae).

3.1.1 Database Searches

A search for Environmentally Sensitive Areas (ESAs) in the vicinity of the survey area was conducted using the WA Atlas (Landgate 2015) and Register of the National Estate spatial database (Department of the Environment and Energy 2008). In addition, database searches were conducted with search details summarised in Table 5. Conservation categories for fauna are provided in Appendix B.

Table 5: Database searches requested.

Database name	Date search results received	Search focus	Search area
NatureMap (Department of Parks and Wildlife 2015a)	22/09/2015	Terrestrial fauna and fauna of conservation significance	40 km radius from an approximate survey area centre point, defined by the coordinates: 21°44’47 S, 116°12’02 E
Threatened and Priority Fauna Database (Department of Parks and Wildlife 2015b)	30/09/2015	Threatened and Priority fauna species	20 km radius from a point defined by the coordinates: -21.738899, 116.205782 (MGA50, GDA94)
Protected Matters Search Tool (Department of the Environment 2015)	21/09/2015	Threatened and Priority fauna species	40 km buffer from the central coordinates: -21.738899, 116.205782 (MGA50, GDA94)
BirdLife Australia (Birdlife Australia 2015)	30/09/2015	Bird species	1 degree from a point defined by the coordinates: -21.74617, 116.20118 (MGA50, GDA94)
Western Australian Museum Invertebrate Database (Western Australian Museum 2015)	20/04/2015	Arachnids, Myriapods, Crustaceans, and Molluscs	100 km buffer from survey area bounded by the coordinates: -21.338898, 115.636173 and -22.548142, 116.805241 (MGA50, GDA94)
Atlas of Living Australia (Atlas of Living Australia 2015)	20/04/2015	All fauna species	10 km radius from a point defined by the coordinates: 21°53’21 S, 116°22’37 E

3.1.2 Literature Review

Fauna surveys have previously been commissioned by Rio Tinto within the vicinity of the survey area and supplied to Astron for the desktop assessment. The previous survey areas in relation to the current survey area are shown in Figure 3. The reports reviewed as part of this assessment include:

- Mesa J Tail Track Extension Vegetation, Flora and Fauna Survey (Astron Environmental Services 2011)
- Mesa H Level 1 Flora, Vegetation and Fauna Assessment (Astron Environmental Services 2014)
- Mesa H Flora, Vegetation and Fauna Survey – Phase 1 Summary (Astron Environmental Services 2015)
- Bungaroo Iron Ore Mine and Infrastructure Project, Level 2 Fauna Survey (Astron Environmental Services 2016a)
- Middle Robe and East Deepdale Level 2 Fauna Assessment (Astron Environmental Services 2016b)
- Yarraloola Targeted Fauna Survey (Biologic Environmental Survey 2014)
- Fauna Habitats and Fauna Assemblage of Mesa A and G (Biota Environmental Sciences 2005)
- Fauna Habitats and Fauna Assemblage of the Mesa A Transport Corridor and Warramboo (Biota Environmental Sciences 2006)
- Bungaroo Trial Pit and Transport Corridor to Mesa J, near Pannawonica (Biota Environmental Sciences 2007)
- Mesa G Baseline Fauna Survey (Biota Environmental Sciences 2009)
- Greater Bungaroo Seasonal Fauna Survey (Biota Environmental Sciences 2010)
- Robe Valley Mesas Fauna Survey (Biota Environmental Sciences 2011)
- Middle Robe and East Deepdale Flora, Vegetation, Vertebrate and Invertebrate Fauna Survey (ecologia Environment 2013).

3.1.3 Habitat Characterisation

Using orthophotos provided by Rio Tinto and the available literature, the survey area was split into distinct landform types that were evaluated further for their likelihood of conservation listed vertebrate or SRE species occurrence. The assessment followed several criteria, such as the availability of moisture, extent of shade and shelter, and soil and vegetation types. Emphasis was given to landforms (and associated habitats) that may contain 'relict' species (surviving in sheltered and moist conditions) and those that may support habitat specialists (i.e. species restricted to rocky outcrops).

3.1.4 Conservation Assessment

Conservation listed vertebrate fauna species returned from the database searches were categorised for likelihood of occurrence within the survey area prior to the field survey, according to the criteria listed in Table B.7 (Appendix B). Post survey, the likelihood table was re-assessed utilising the information obtained during the field survey. The additional criteria used for the assessment are outlined in Table B.7 (Appendix B). The likelihood table was then updated to reflect an improved understanding of the likelihood that a species would actually occur in the survey area.

SRE invertebrates are species with distributions of less than 10,000 km^2 and their occurrence within their distribution is usually fragmented and highly localised (Harvey 2002; Ponder and Colgan 2002). However, it is often difficult to determine whether or not a species in one of the target SRE groups actually has a range < 10,000 km^2. For the purpose of desktop review, SRE status was determined by the staff of the Western Australian Museum (WAM) through providing the results of SRE filtered searches of the WAM databases. This assessment was reviewed and supplemented with information contained in previous environmental reports, the published literature and online databases. For morphospecies collected during the survey, the criteria outlined in Table B.8 (Appendix B) were used to determine SRE status. The SRE categories of the WAM (confirmed SRE, potential SRE and widespread species) were used to assess the status of species, with sub-categories applied in accordance with the WAM-TS guidelines.

380000 390000 400000 410000 420000 430000 440000 450000 460000 470000

7620000 7610000 7600000 7590000 7580000 7570000 7560000

Yarraloola Rd
North West Coastal Hwy
Pannawonica
PANNAWONICA
Millstream - Pannawonica Rd
Millstream Rd

Legend

- Towns
- Roads

Previous surveys

- Mesa J Tail Track Extension (Astron 2011)
- Mesa H Level 1 Flora, Vegetation and Fauna Assessment (Astron 2014)
- Bungaroo Iron Ore Mine and Infrastructure Project, Level 2 Fauna Survey (Astron 2016a)
- Mesa H Flora, Vegetation and Fauna Survey – Phase 1 Summary (Astron 2015)
- Middle Robe and East Deepdale Level 2 Fauna Assessment (Astron 2016b)
- Yarraloola Targeted Fauna Survey (Biologic 2014)
- Fauna Habitats and Fauna Assemblage of Mesa A and G, near Pannawonica (Biota 2005)
- Fauna Habitats and Fauna Assemblage of the Mesa A Transport Corridor and Warramboo (Biota 2006)
- Bungaroo Trial Pit and Transport Corridor to Mesa J, near Pannawonnica (Biota 2007)
- Mesa G Baseline Fauna Survey (Biota 2009)
- Greater Bungaroo Seasonal Fauna Survey (Biota 2010)
- Robe Valley Mesas Fauna Survey (Biota 2011)
- Middle Robe and East Deepdale Flora, Vegetation, Vertebrate and Invertebrate Fauna Survey (ecologia Environment 2013)

Robe River Mining Co. Pty Ltd

Mesa H – Level 2 Fauna Assessment, May 2016

Figure 3: Previous surveys conducted over the Mesa H survey area

Datum: GDA 1994 - Projection: MGA Zone 50

0 2 4 6 8 10 km

N

astron delivering environmental intelligence™

Author: J. Trainer | Drawn: C. Dyde | Date: 15-08-2017 | Figure Ref: 14269-16-BIDR-3Rev1_170815_Fig03_PrevSurv

3.2 Field Survey

3.2.1 Survey Timing and Personnel

The phase 1 field survey (dry season) was undertaken by Matthew Johnston and John Trainer and the phase 2 field survey (post wet season) was undertaken by Matthew Love and John Trainer. All survey personnel have over five years of experience conducting Level 2 vertebrate fauna surveys or invertebrate surveys. The survey was conducted under "Licence to Take Fauna for Scientific Purposes" Permit No. SF010530.

The phase 1 and 2 field surveys were conducted from 24 September to 3 October 2015 and 27 April to 9 May 2016, respectively. Data and trap sites previously set up in the survey area for the Robe Valley Mesas Fauna Survey (Biota Environmental Sciences 2011) was used to supplement the phase 1 data; this survey was completed by Biota from the 22 to 29 October 2010.

Daily weather observations recorded at the Mesa J Weather Station (Rio Tinto supplied data) directly adjacent to the survey area were used to identify local rainfall and temperatures preceding the survey as current data were not available from Pannawonica weather station (Figure 4).

Phase 1: Rainfall received in the 12 months preceding the phase 1 survey was 67.4 mm below the annual average. Rainfall for July, August and September 2015, the three months preceding the phase 1 survey, was almost 10 mm below the average monthly means with a total of only 14.6 mm. No rainfall was received during the phase 1 survey.

Phase 1 daily maximum temperatures averaged 38°C ± 3.0°C and daily minimum temperatures averaged 17°C ± 5.5°C. Mean maximum and minimum daily temperatures were higher during the phase 1 survey than the long-term means for September and October.

The weather conditions for the phase 1 survey conducted by Biota in 2010 included maximum temperatures from 33.4°C to 41.3°C and minimum temperatures from 18.7°C to 22°C. No rain was recorded during the survey. A total of 35.4 mm of rain fell at Mardie during the six months leading up to the survey. This is well below the average of 116.2 mm for this period (Biota Environmental Sciences 2011).

Phase 2: Rainfall received 12 months preceding the phase 2 survey was 145 mm above the annual average. However, rainfall for February, March and April 2016, the three months preceding the phase 2 survey, was almost 87 mm below the average monthly means with a total of 108.8 mm. A total of 35.4 mm was recorded across two days during the phase 2 survey.

Phase 2 daily maximum temperatures averaged 32°C ± 6.0°C and daily minimum temperatures averaged 26°C ± 5°C. Mean maximum daily temperatures were slightly lower during the phase 2 survey than the long-term means for April and May, this may be due to the high levels of cloud cover and subsequent rain. Minimum daily temperatures during the phase 2 survey were far warmer than the long term means for April and May, again attributed to the cloud cover experienced during the survey period.

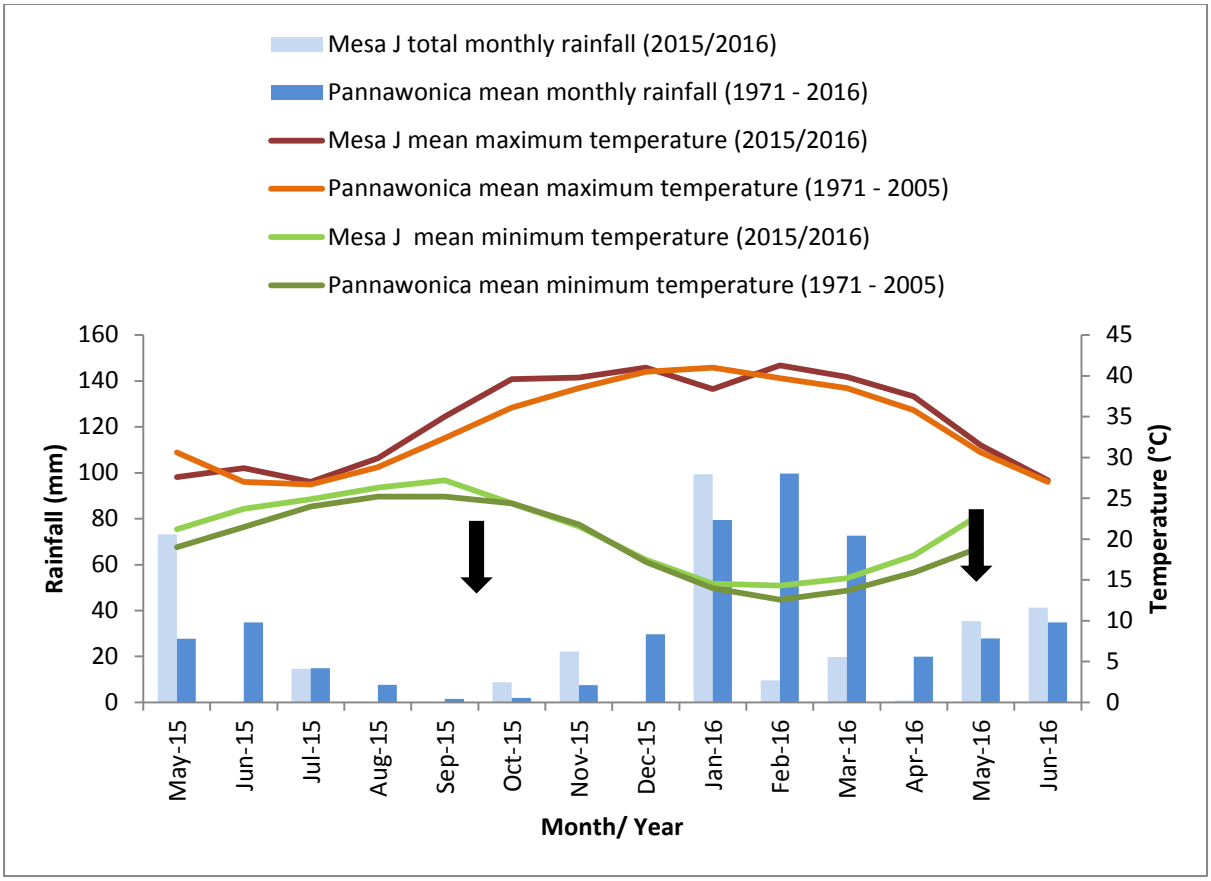

Figure 4: Pannawonica mean monthly rainfall (1971 – 2016) and Mesa J rainfall (2015 - 2016), and Pannawonica mean monthly maximum and minimum temperatures (1971 – 2005), and Mesa J mean monthly maximum and minimum temperatures, in the 12 months preceding the survey. Black arrow indicates field survey timing. Pannawonica data from Bureau of Meteorology (2016) and Mesa J data from Rio Tinto (2016f).

3.2.2 Vertebrate Fauna

3.2.2.1 Habitat Assessment

There were 24 fauna habitat assessments conducted within the seven fauna habitat types present in the survey area (Tables C.1-C.2, Appendix C). The locations are shown in Figure C.1 (Appendix C) and the following information was collected at each site:

- location – coordinates measured using a handheld GPS (GDA94)
- recorder and date – personnel involved in undertaking the fauna habitat assessment and the survey date
- habitat/landform – position in the landscape - major fauna habitat types were described based on the landform and vegetation
- vegetation type – a broad description of vegetation type and structure
- soils – a brief description of soil type
- microhabitat – presence of specific microhabitat features, e.g. leaf litter, logs, burrows, rocky outcrops, rock crevices, hollows, permanent or semi-permanent water

- condition – habitat condition was assessed based on the presence of anthropogenic (human-induced) disturbances, and using the condition ratings suggested by Thompson and Thompson (2010) (Table B.9, Appendix B)
- disturbance – any disturbance such as clearing, fire, weeds, flooding, vehicular, machinery, tracks or grazing
- photographs – a representative photograph was taken of each habitat assessment site.

The information derived from the fauna habitat assessments was used to delineate fauna habitats throughout the survey area, which were then mapped accordingly. The potential for the mapped habitats to provide suitable habitat for MNES species, Pilbara Olive Python (VU, S3), Northern Quoll (EN, S2), Ghost Bat (VU, S3) and Pilbara Leaf-nosed Bat (VU, S3) were ranked according to the criteria listed in Table B.10 (Appendix B) and then mapped for each species.

3.2.2.2 Trapping Grids

The phase 1 trapping program was a dry season survey encompassing five Biota trap sites undertaken in October 2010 (Biota Environmental Sciences 2011) and an additional three trapping sites undertaken in September/October 2015 by Astron. The phase 2 trapping program was a post wet season survey undertaken in April/May 2016 using all eight sites from phase 1 (Table 6). Sites were selected in areas of favourable micro-habitat to maximise the likelihood of fauna capture. The location of previous and current trap sites is shown in Figure C.1 (Appendix C).

Biota in phase 1 (October 2010) used the following trap design:

- three trap sites (RVM13-15) of 10 pitfall traps (20 L bucket and PVC pipes)
- one trap site (RVM12) of 12 funnel traps (fish-net style)
- one trap site (RVM16) of 50 Elliot (A) traps (aluminium box-trap).

Aston in phase 1 and phase 2 used the following trap design:

- six trap sites (MHT01-3 both phases and RVM13-15 phase 2 only) of 10 pitfall traps (20 L bucket and PVC pipes), six funnel traps, 20 Elliot traps and four cage traps (wire mesh cage trap)
- two trap sites in rocky habitats (RVM12 and RVM16 both phase 2) were established as Elliot sites, each with 20 Elliott traps and four cage traps arranged in a linear layout along the breakaway habitat. In phase 2, RVM12 was moved to a more suitable location further along the same breakaway habitat.

All pitfall and funnel traps were used in conjunction with a 100 m drift fence running over the centre of the pit, directing animal movement into the pitfall trap. The trap sites remained open for seven nights in phase 1 and phase 2. Traps were cleared each morning within three hours of sunrise to minimise the potential of trap death. The typical trap arrangement used by Astron in both the phase 1 and 2 surveys is depicted in Figure 5.

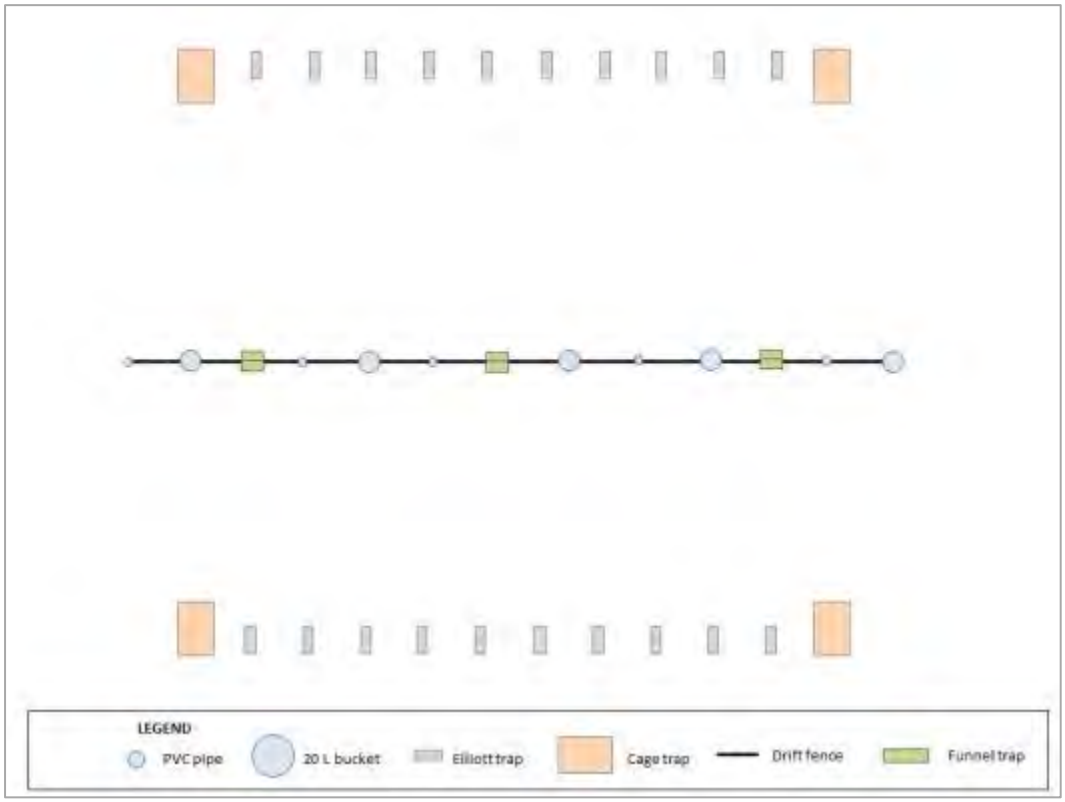

Figure 5: Diagrammatic layout of systematic trapping sites.

3.2.2.3 Avifauna Surveys

Systematic avifauna (bird) censuses were undertaken at each trapping grid for 20 minutes each day on five occasions over both survey phases, resulting in 100 minutes per person of survey effort at each site. This equates to a total of 2,200 minutes (36 hours and 40 minutes) over both phases of the survey. All species were recorded from sightings and/or from species-specific bird calls. Opportunistic records of species across the survey area were also recorded and habitats that may support species of conservation significance were targeted.

Biota (2011) undertook avifauna sampling in a similar manner at each of the trap sites. During the phase 1 survey avifauna survey, effort ranged between 40 minutes and 155 minutes at each of the sites with a total of 243 minutes avifauna sampling undertaken.

3.2.2.4 Motion Sensitive Cameras

Thirty motion sensitive cameras were used during both phases of the survey (Moultrie, Bushnell Trophy Cam infra-red, and Reconyx HC600 HyperFire). Cameras were set at 48 locations for between two and six nights with a combined trapping effort of 247 camera trap nights over both phases of the survey. The cameras were baited and placed in prospective/suitable habitat such as cave entrances and water holes aimed at targeting MNES species. Camera locations are shown in Figure C.1 and detailed in Table C.1-C.2 (Appendix C).

3.2.2.5 Acoustic Bat Surveys

Acoustic ultrahigh frequency equipment was used to record the presence of bats, in particular the Pilbara Leaf-nosed Bat and Ghost Bat. Four acoustic recording devices (Song Meter 2, SM2BAT+) were positioned in a total of 14 locations across both phases to achieve a broad coverage of the

survey area, but also distributed across the survey area to allow for an analysis of flying direction and the potential locations of any roosts. The detectors were set for one to four nights, resulting in a total of 27 recording nights. The locations are depicted in Figure C.1 and detailed in Table C.1-C.2 (Appendix C). The bat echolocation data collected on the SM2BAT+ detectors in the field was analysed by Robert Bullen (Bat Call WA 2016).

3.2.2.6 Active Foraging

Active searches were undertaken across both phases of the survey in microhabitats suitable for ground-dwelling reptiles and mammals. Active searches included the following:

- searching and recording scats, tracks and other traces
- turning over rock and logs and peeling off bark
- raking soil and leaf litter
- searching rocky habitats in cracks and caves, around water bodies and inside bore hole caps.

3.2.2.7 Targeted Searches

The aim of the targeted searches was to identify areas of potentially suitable habitat for conservation significant fauna, such as caves, and secondary signs including tracks, scats, diggings and burrows. Walked transects were undertaken throughout the survey area (Figure C.1, Appendix C). In addition, visual observation for conservation significant fauna habitat was ongoing whilst moving through the survey area. Track logs were recorded using a handheld GPS and are shown in Figure C.1 (Appendix C). Any opportunistic sightings of fauna species were recorded whilst traversing the survey area.

3.2.2.8 Nocturnal Spotlighting

Spotlighting at night was undertaken on foot and from vehicles to target fauna that are nocturnal or crepuscular, particularly conservation significant species. A total of 1,800 minutes (30 hours) of nocturnal spotlighting was undertaken in the survey area across both phases of the survey. Approximately, 1,080 minutes (18 hours) of nocturnal spotlighting was undertaken in phase 1 and 720 minutes (12 hours) of nocturnal spotlighting was undertaken in phase 2.

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Table 6: Trapping site locations and survey effort for the current survey.

Site	MGA Zone 50 K		Habitat	Vegetation description	Habitat Condition	Date opened	Date closed	Trap nights	No. of traps	Total trap nights	Photos
	Easting (mE)	Northing (mN)									
MHT01	414614	7597885	Riverine	*Melaleuca argentea, Eucalyptus camaldulensis* subsp. *refulgens* open forest over *Cyperus vaginatus* scattered sedges to very open sedgeland.	0.8 (Very Good)	26/09/2015	03/10/2015	7	40	280	
						28/04/2016	05/05/2016	7	40	280	
MHT02	416326	7599285	Loamy/Stony Plain	*Corymbia hamersleyana* scattered low trees over *Acacia inaequilatera* scattered tall shrubs over *Acacia bivenosa* scattered shrubs over *Triodia wiseana* hummock grassland.	1 (Excellent)	25/09/2015	02/10/2015	7	40	280	
						28/04/2016	05/05/2016	7	40	280	
MHT03	419181	7592799	Loamy/Stony Plain	*Corymbia hamersleyana* scattered low trees over *Acacia inaequilatera* scattered tall shrubs over *Acacia bivenosa* scattered shrubs over *Triodia wiseana* hummock grassland.	0.6 (Good)	25/09/2015	02/10/2015	7	40	280	
						28/04/2016	05/05/2016	7	40	280	
RVM12	418592	7598780	Breakaway	*Acacia bivenosa* open shrubland to open heath over *Triodia wiseana* hummock grassland.	1 (Excellent)	22/10/2010	29/10/2010	7	12	84	
	418592	7598780				29/04/2016	06/05/2016	7	24	168	
RVM13	418784	7597593	Riverine	*Corymbia hamersleyana* scattered low trees over *Acacia inaequilatera* scattered tall shrubs over *Acacia bivenosa* scattered shrubs over *Triodia wiseana* hummock grassland.	0.6 (Good)	22/10/2010	29/10/2010	7	10	70	
						29/04/2016	06/05/2016	7	40	280	

Site	MGA Zone 50 K		Habitat	Vegetation description	Habitat Condition	Date opened	Date closed	Trap nights	No. of traps	Total trap nights	Photos
	Easting (mE)	Northing (mN)									
RVM14	416472	7595267	Low Hills and Slopes	*Acacia inaequilatera* scattered tall shrubs over *Acacia bivenosa* scattered shrubs over *Triodia wiseana* hummock grassland.	0.6 (Good)	22/10/2010	29/10/2010	7	10	70	
						29/04/2016	06/05/2016	7	39	273	
RVM15	417439	7593941	Low Hills and Slopes	*Corymbia hamersleyana* and/or *Eucalyptus leucophloia* subsp. *leucophloia* scattered low trees over *Acacia tumida* var. *pilbarensis* tall open scrub over *Triodia wiseana* open hummock grassland.	0.8 (Very Good)	22/10/2010	29/10/2010	7	10	70	
						28/04/2016	05/05/2016	7	40	280	
RVM16	414925	7596459	Breakaway	*Acacia bivenosa* open shrubland to open heath over *Triodia wiseana* hummock grassland.	1 (Excellent)	22/10/2010	29/10/2010	7	50	350	
						29/04/2016	06/05/2016	7	24	168	
Total trap effort – Phase 1 Total trap effort – Phase 2 **Total trap effort – Both phases**										1,484 2,009 **3,493**	

3.2.3 Statistical Analyses

3.2.3.1 Sampling Effort

Sampling effort was assessed using species accumulation curves and modelled estimates of the total species pool. Species accumulation curves are created by randomly sampling an incremental number of sites while plotting the total number of species sampled. Species estimators are particular statistical models of species accumulation which estimate the total species pool available. Four species estimators were compared: Chao 2, Jackknife 1, Jackknife 2 and Bootstrap (Colwell and Coddington 1994). Species accumulation curves were created for each faunal group (mammals, birds and herpetofauna) and for the different monitoring programs (Astron phase 1, Astron phase 2, all Astron samples, and all samples including other consultant surveys). Species estimations were based on all Astron surveys. All analyses were performed in R 3.2.1 (R Development Core Team 2015) using the package "Vegan".

3.2.3.2 Site Classification

The similarity of species assemblages amongst sites was assessed using two dimensional ordinations based on Sorensen's index of similarity amongst sites. Significant groupings of sites by habitat type were identified using the ANOSIM function (Clarke, Somerfield, and Gorley 2008) within the package "Vegan". Ordinations and ANOSIM tests were performed for each faunal group.

3.2.4 SRE Invertebrates

3.2.4.1 Habitat Assessment

Fauna habitats within the survey area were mapped for their suitability to support SRE invertebrates as part of an initial desktop assessment (Section 3.1.3) and further refined following the field survey (Section 3.2.4.1).

3.2.4.2 Active Foraging

A total of 20 systematic sites (including the trapping sites) were sampled for SRE fauna across the survey area (Figure C.1, Appendix C). All sites were sampled by active foraging and litter-soil samples. The sites were selected so that they represented the landforms and vegetation associations inferred as prospective in the desktop assessment; however, some sites also targeted the less prospective habitats (e.g. Loamy/Stony Plains) to confirm the results of the initial desktop assessment. Detailed site descriptions, including associated landforms and vegetation features, are provided in Table C.1-C.2 (Appendix C). The descriptions provide qualitative information about factors influencing the macroclimate (e.g. landform, vegetation type, dominant substrate, and indicative plant species) and microclimate (e.g. amount of organic matter or existing damage).

Foraging was focused under boulders, crevices in rocky outcrops, at the base of tree logs, under loose tree bark, in moist and dry leaf litter accumulations and in *Triodia* clumps, but occurred in all habitats. The search for mygalomorph spider burrows was by visual inspections and using a leaf blower. Night-time searching for scorpions was undertaken in conjunction with the nocturnal spotlighting. Leaf litter was sifted *in situ* with a 16 mm soil sieve, and potential SRE invertebrates preserved directly in 98% ethanol. Approximately 800 minutes (13 hours and 20 minutes) were spent searching the 20 SRE sites. Any potential SRE invertebrates observed in the dry pitfall or funnel traps at each of the six relevant trapping grids were also collected.

3.3 SRE Specimen Identification

The samples were separated and sorted to morphospecies level under a dissecting microscope. Morphological identifications to species level were attempted for all collected specimens. These identifications were completed in-house and were based on the available taxonomic literature and keys, environmental reports and online databases. Compound microscopes were used to examine fine taxonomic characters not visible otherwise, e.g. trichobothria patterns in pseudoscorpions.

The identification of many invertebrates was straightforward; however, all slaters were identified by Dr Simon Judd (Edith Cowan University) and all arachnid groups were identified by Dr Erich Volschenk. Several pseudoscorpion species were compared with critical specimens from the WAM to assure species alignment whenever possible. WAM lodgement details for representative vouchers are provided in Appendix D.

DNA analyses were performed by Dr Gaynor Dolman from the WAM on representative arachnids specimens considered to represent potential SRE species. This was done because many of the specimens belong to complex family groups or were juvenile and could not be identified using morphology. In total, 10 specimens from two arachnid orders (Araneae, Scorpiones) were submitted to the WAM and the CO1 'barcoding' gene sequenced for nine specimens. Detailed results of the molecular analyses and lodgement details are available in Appendix E (Dolman 2016).

3.4 Taxonomy and Nomenclature

For species identified in the desktop assessment, every effort was made to determine the current scientific name for each taxon, including wherever there was doubt as to their true taxonomy (through subsequent name changes). In addition, some taxon names may be followed by 'sp.', meaning that the species name was not given in the original data source. Taxa that were identified as 'sp. indet.' usually belong to species complexes that are unresolved to a degree that accurate species identification is not possible. These complexes may include species that are newly recorded for a survey area or have been collected for the first time; however this cannot be determined from the data available. For named species in SRE groups, the taxonomy follows the published literature. WAM species codes were applied to unnamed species whenever possible (MYG codes for mygalomorph spiders) but alternative names applied by the taxonomic experts were used when WAM codes were unavailable (unpublished manuscript names for scorpions given as *Genus* 'name' by Dr Erich Volschenk).

The biology of many SRE species is not well known and the precise distribution and life history are poorly, if at all, documented (Harvey 2002; Harvey et al. 2011). Species identification is often very difficult because few specimens have been collected, reference collections are unavailable, the specimens are the wrong sex or life stage for identification, or they are morphologically cryptic and require DNA analyses. Taxonomic resolution can also be poor, either because there are no published taxonomic revisions for a group in question (terrestrial isopods in Western Australia), or because there is no expert actively working on one of the SRE groups.

3.5 Limitations

Following completion of the desktop assessment and field survey, a review of any limitations that may affect a complete assessment of the data collected was conducted. The limitations listed in Table 7 are based on those suggested as considerations in Technical Guidance - Terrestrial Fauna Surveys (Environmental Protection Authority 2016a).

Table 7: Statement of limitations for the vertebrate and SRE invertebrate fauna survey.

Potential limitation	Degree of limitation	Statement regarding potential limitations
(i) Competency/experience	No limitation	The ecologists responsible for conducting the survey have extensive experience in conducting Level 2 vertebrate and SRE fauna surveys in the Pilbara.
(ii) Scope What faunal groups were sampled and were some sampling methods not able to be employed because of constraints such as weather conditions.	No limitation	The survey scope employed was able to be completed and all sampling methods adequately employed. The fauna observed and identified is likely to represent a portion of the suite of species that utilise the survey area.
(iii) Proportion of fauna identified, recorded and/or collected	No limitation	The fauna observed and identified are likely to represent a portion of the suite of species that utilise the survey area. Fauna habitats were able to be adequately described and a list of species likely to be present was prepared based on this assessment. Species accumulation curves generally did not reach an asymptote, but when taking into account previous records as well as species recorded from methods other than trapping, then a large portion of the predicted assemblage was recorded. It is not possible to determine bat species abundance from echolocation records; bat activity levels provide a relative measure of the abundance of each species within the survey area.
(iv) Sources of information Previously available information (whether historic or recent) as distinct from new data.	No limitation	Adequate information was available from database searches and previous studies in the survey area and region.
(v) Proportion of task achieved. Further work which might be needed?	No limitation	The survey scope employed was able to be completed and all sampling methods adequately employed.
(vi) Timing/weather/season/ cycle	Minor limitation	Rainfall preceding the phase 1 survey was below average, however as this was the dry season survey it is not considered a limiting factor. The rainfall in the three months preceding the phase 2 survey was well below average. This was evident in the lack of surface water present specifically in the Riverine habitats. This is likely to have reduced the number of waterbirds recorded during the phase 2 survey. The temperatures during both phases 1 and 2 were above or close to the long term average. The higher than normal temperatures, especially at night may have resulted in an increased abundance of species being recorded, specifically reptiles and small mammals. The timing of the survey follows the EPA (2016b) guidelines for SRE sampling. Climatic conditions varied between the two survey periods with no climatic extremes that could affect the activity of SRE fauna.

Potential limitation	Degree of limitation	Statement regarding potential limitations
(vii) Disturbances e.g. fire, flood, accidental human intervention which affected results of survey	Minor limitation	Large portions of the Low Hills and Slopes and Loamy/Stony Plains habitat on top of Mesa H were affected by exploration drilling pads and their associated tracks. Fauna captures at trap sites RVM15 and MTH03, which were situated in the middle of disturbed areas, was comparable to other sites. No other disturbances were recorded in the survey area that would have affected the survey results.
(viii) Intensity In retrospect, was the intensity adequate?	No limitation	The intensity of the surveys was considered adequate for a Level 2 assessment.
(xi) Completeness Was the relevant area fully surveyed?	No limitation	All main habitats in the survey area were surveyed and coverage of habitat assessments and targeted surveys is considered adequate.
(x) Resources Degree of expertise available in animal identification to taxon level.	No limitation	Adequate resources were available to identify fauna species. All personnel involved in identification have extensive experience in conducting Level 2 vertebrate and SRE fauna surveys in the Pilbara. Taxonomic experts were consulted for all SRE fauna groups and DNA analyses were undertaken at the WAM to help identify the selected taxa.
(xi) Remoteness and/or access problems	Minor limitation	There were no access problems with all of the survey area able to be accessed by vehicle or on foot. Due to safety and heritage related constraints, internal inspections of caves are not permitted. The characteristics of Pilbara Leaf-nosed Bat and Ghost Bat roost caves are variable and therefore it is not possible to determine the potential for a cave to be a roost by external visual observation. The cave assessments provide an indication only as to whether Pilbara Leaf-nosed Bats or Ghost Bats may utilise the caves as habitat.
(xii) Availability of contextual information e.g. biogeographic information on the region.	No limitation	Database searches and previous fauna surveys in the survey area provided by Rio Tinto provided contextual information.

This assessment combines data collected from Biota's trapping program in 2010 with that recorded by Astron in 2015 and 2016. As such, differences in methodology of trap design (lack of Elliot traps at all Biota sites), survey effort for avian census (varying from 40 to 155 minutes per site), acoustic bat sampling (use of SM2 units versus AnaBat SD units) and their potential effect on the data are difficult to assess. Although different, the methods previously used are deemed adequate for a Level 2 survey.

EPA (2016b) recommends that assessments of SRE fauna in the Pilbara should be undertaken between November and April when there is increased activity of cryptic groups such as male mygalomorph spiders. Recent studies on millipedes and spiders suggest that adult specimens are frequently collected much later in the year (between May and October) and that SREs are not only active during the cyclone season (Car and Harvey 2013; Harvey et al. 2012; Miglio et al. 2014). The

current survey was conducted in two phases: October 2015 and late April/May 2016. The timing of survey therefore covers the period of greatest activity for SRE groups.

Most SRE species rely on moisture and are most active following periods of elevated rainfall and comparably low temperatures. Climatic conditions during the first phase of survey were relatively dry with no rainfall observed during this phase. However, there was permanent water in the Robe River and the vegetation was green and intact. Conditions were drier again in the second phase of survey and rainfall for the February-April period was almost 87 mm below the average monthly means. A total of 35 mm of rainfall was observed across two days during the second phase, potentially promoting SRE activity. Rainfall received 12 months preceding the survey was 145 mm above the annual average and climatic conditions are unlikely to have impacted on the SRE survey results. Previous surveys in the vicinity of the survey area (Astron Environmental Services 2016a, 2016b) collected a similar number of SRE species despite varying climatic conditions between these surveys.

It should be noted that some prospective SRE habitats identified in the desktop assessment were often degraded, or modified by infrastructure development. For example, site OPP38 was extensively disturbed and the vegetation had been cleared in a drainage culvert under a railway. Sites RVM14 and MTH03 were nested within drill pads and heavily disturbed through the construction of tracks and vegetation clearing. There were also signs of cattle grazing, such as site MTH02, although the level of disturbance was comparably minor.

4 Results

4.1 Desktop Assessment

4.1.1 Environmentally Sensitive Areas

There are no ESAs located within, or adjacent to the survey area (Department of the Environment and Energy 2008).

4.1.2 Vertebrate Fauna

The database searches and literature review results indicate that 322 vertebrate fauna have been previously recorded within 40 km of the survey area, including six amphibian species, 102 reptile species, 164 bird species (including one introduced bird species) and 50 mammal species (including 10 introduced mammal species) (Table F.1-F.4, Appendix F). Of these, 33 species are of conservation significance, including three reptile species, 21 bird species and nine mammal species (Table G.1, Appendix G). Of these, nine species were considered to have a 'high' likelihood (inclusive of those previously recorded within the survey area), 11 species were considered to have a 'moderate' likelihood and 13 were considered to have a 'low' likelihood of occurrence within the survey area (Table G.1, Appendix G). This is based on their respective ecology, habitats considered likely to be present and any previous records from historic survey and database records.

Previous surveys undertaken for Rio Tinto in the vicinity of the survey area recorded 12 conservation significant vertebrate fauna species: Northern Quoll (*Dasyurus hallucatus),* Pilbara Leaf-nosed Bat (*Rhinonicteris aurantia*), Ghost Bat (*Macroderma gigas*), Western Pebble-mound Mouse (*Pseudomys chapmani*), Eastern Great Egret (*Ardea modesta*) Rainbow Bee-eater (*Merops ornatus*), Wood Sandpiper (*Tringa glareola*), Common Sandpiper (*Actitis hypoleucos*), Sharp-tailed Sandpiper (*Calidris acuminata*), Pilbara Olive Python (*Liasis olivaceus barroni*), Blind Snake (*Anilios ganei*) and Lined Soil-crevice Skink (*Notoscincus butleri*) (Table 8).

Table 8: Summary of literature review results from surveys conducted within the vicinity of the survey area.

Author (year)	Survey area; size (ha)	Survey level	Survey timing	Survey effort	Conservation significant vertebrate fauna recorded
Astron (2011)	Mesa J Mine 78.63 ha	Level 1	June 2011	Desktop survey and site reconnaissance.	*Merops ornatus* (Rainbow Bee-eater)
Astron (2014)	Mesa H 2,582 ha	Level 1	October 2014	Targeted searches of suitable habitat, motion sensor cameras and SM2 acoustic bat call recorders were used to detect the presence of conservation significant fauna species.	*Dasyurus hallucatus* (Northern Quoll) *Rhinonicteris aurantia* (Pilbara Leaf-nosed Bat) *Macroderma gigas* (Ghost Bat) *Pseudomys chapmani* (Western Pebble-mound Mouse) *Ardea modesta* (Eastern Great Egret) *Merops ornatus* (Rainbow Bee-eater)
Astron (2016a)	Bungaroo 9,795 ha	Level 2 (dual phase)	May - June 2015 August 2015	Habitat assessments, eight trapping sites, avifauna censuses at each trapping site, foot traverses, targeted searches for both vertebrates and SRE invertebrates, and the use of motion sensitive cameras and SM2BAT ultrasonic bat detectors.	*Dasyurus hallucatus* (Northern Quoll) *Liasis olivaceus barroni* (Pilbara Olive Python) *Rhinonicteris aurantia* (Pilbara Leaf-nosed Bat) *Macroderma gigas* (Ghost Bat) *Pseudomys chapmani* (Western Pebble-mound Mouse) *Notoscincus butleri* (Lined Soil-crevice Skink) *Anilios ganei* (Blind Snake) *Merops ornatus* (Rainbow Bee-eater)
Astron (2016b)	Middle Robe/East Deepdale 11,816 ha	Level 2 (dual phase)	June 2015 August 2015	Habitat assessments, 15 trapping sites, avifauna censuses at each trapping site, foot traverses, targeted searches for both vertebrates and SRE invertebrates, and the use of motion sensitive cameras and SM2BAT ultrasonic bat detectors.	*Dasyurus hallucatus* (Northern Quoll) *Liasis olivaceus barroni* (Pilbara Olive Python) *Rhinonicteris aurantia* (Pilbara Leaf-nosed Bat) *Macroderma gigas* (Ghost Bat) *Pseudomys chapmani* (Western Pebble-mound Mouse) *Notoscincus butleri* (Lined Soil-crevice Skink) *Ardea modesta* (Eastern Great Egret) *Merops ornatus* (Rainbow Bee-eater)

Author (year)	Survey area; size (ha)	Survey level	Survey timing	Survey effort	Conservation significant vertebrate fauna recorded
Biologic (2014)	Yarraloola Size not stated	Level 1	December 2013	A Level 1 targeted survey for Northern Quolls, Pilbara Olive Pythons and Pilbara Leaf-nosed Bats.	*Dasyurus hallucatus* (Northern Quoll) *Liasis olivaceus barroni* (Pilbara Olive Python) *Pseudomys chapmani* (Western Pebble-mound Mouse) *Rhinonicteris aurantia* (Pilbara Leaf-nosed Bat) *Macroderma gigas* (Ghost Bat) *Merops ornatus* (Rainbow Bee-eater)
Biota (2005)	Mesa A and G 1,305 ha	Level 2 (single phase)	May 2004	Ten trapping sites utilising various combinations of pitfall traps (both PVC tubes and 20 L buckets), Elliott traps and/or funnel traps. Avifauna censuses at each trapping site and Anabat echolocation recordings.	*Dasyurus hallucatus* (Northern Quoll) *Macroderma gigas* (Ghost Bat)
Biota (2006)	Mesa A Transport Corridor and Warramboo 7,045 ha	Level 2 (dual phase)	April - May 2005 July - August 2005	Ten trapping sites, including pits (buckets and PVC tubes), medium sized Elliotts and funnels. Harp traps targeting bat species, avifauna census at each trapping site and targeted searches for both vertebrates and SRE invertebrates.	*Notoscincus butleri* (Lined Soil-crevice Skink) *Macroderma gigas* (Ghost Bat) *Pseudomys chapmani* (Western Pebble-mound Mouse)
Biota (2007)	Bungaroo Trial Pit and Transport Corridor to Mesa J Size not stated	Level 2 (dual phase)	March 2005 June 2006	Sixteen trapping sites, avifauna census, harp traps targeting bat species, and targeted searches for both vertebrates and SRE invertebrates.	*Dasyurus hallucatus* (Northern Quoll) *Notoscincus butleri* (Lined Soil-crevice Skink) *Pseudomys chapmani* (Western Pebble-mound Mouse) *Tringa glareola* (Wood Sandpiper)
Biota (2009)	Mesa G Size not stated	Level 2 (single phase)	August 2009	Six trapping sites, avifauna census, harp traps and echoloaction recordings targeting bat species, and targeted searches for both vertebrates and SRE invertebrates.	*Rhinonicteris aurantia* (Pilbara Leaf-nosed Bat) *Macroderma gigas* (Ghost Bat)

Author (year)	Survey area; size (ha)	Survey level	Survey timing	Survey effort	Conservation significant vertebrate fauna recorded
Biota (2010)	Greater Bungaroo 8,765 ha	Level 2 (dual phase)	August 2009 March 2010	Trapping at 14 locations, avifauna census, harp traps and echoloaction recordings targeting bat species, and targeted searches for both vertebrates and SRE invertebrates.	*Rhinonicteris aurantia* (Pilbara Leaf-nosed Bat) *Macroderma gigas* (Ghost Bat) *Notoscincus butleri* (Lined Soil-crevice Skink) *Merops ornatus* (Rainbow Bee-eater)
Biota (2011)	Robe Valley 9,354 ha	Level 2 (single phase)	October 2010	Trapping at 18 locations, avifauna census, harp traps and echoloaction recordings targeting bat species, and targeted searches for both vertebrates and SRE invertebrates.	*Dasyurus hallucatus* (Northern Quoll) *Macroderma gigas* (Ghost Bat) *Notoscincus butleri* (Lined Soil-crevice Skink) *Merops ornatus* (Rainbow Bee-eater)
ecologia Environment (2013)	Middle Robe/East Deepdale 6,092 ha	Level 2 (single phase)	September 2012	Eight fauna trapping sites, avifauna censuses, targeted searches for vertebrate fauna and SRE invertbrates and Anabat echolocation recordings.	*Dasyurus hallucatus* (Northern Quoll) *Rhinonicteris aurantia* (Pilbara Leaf-nosed Bat) *Ardea modesta* (Eastern Great Egret) *Actitis hypoleucos* (Common Sandpiper) *Calidris acuminata* (Sharp-tailed Sandpiper) *Tringa glareola* (Wood Sandpiper) *Merops ornatus* (Rainbow Bee-eater)

4.1.3 SRE Invertebrates

4.1.3.1 Habitat Characterisation

The focus of the SRE survey was on the geology and landforms likely to support a suitable microclimate for SRE fauna, such as deep creek lines, sheltered gorges, south-facing slopes, breakaways and areas with high vegetation cover.

There are seven broad habitat types in the survey area: Riverine, Drainage Line, Gorge, Breakaway, Rocky Hills, Low Hills and Slopes, and Loamy/Stony Plains. Some sections of the survey area have been cleared or are unsuitable for SRE fauna and are not assessed further.

The Loamy/Stony Plains habitat was inferred as unlikely to support significant SRE communities because it is exposed, generally has low moisture holding capacity, a lack of topographic relief, and has uniform vegetation (primarily introduced Buffel Grass and *Triodia* steppe). The riverbeds of the Drainage Line habitat are also not ideal habitat due to the lack of organic leaf litter from flooding and washouts. Low Hills/Slopes may support some SRE species but lack significant topographic relief and shelter. These habitats are not considered a prospective landform for SRE fauna.

The Gorge, Breakaway, Riverine and Rocky Hills landforms may provide suitable habitat for relictual SRE species owing to their capacity to provide sheltered microhabitats (such as between rock boulders, at the base of outcrops or south-facing gullies), the accumulation of organic matter such as leaf litter, and permanent moisture required for many SREs (Harvey 2002). The Gorge, Breakaway and Rocky Hills habitats are also likely to support specialist SRE species, such as *Synsphyronus* pseudoscorpions and selenopid spiders that live under rocks (Crews and Harvey 2011; Crews 2013; Harvey 2010).

4.1.3.2 Species

There are 16 arachnids, 19 crustaceans, four millipedes, three insects, one polychaete and one snail species from the Pilbara currently listed as Threatened or Priority fauna species. These species are mostly subterranean and not part of this assessment, or do not occur in the vicinity of the survey area. Only the two dragonfly species, *Antipodogomphus hodgkini* and *Nosoticta pilbara*, are surface species but no specimens have ever been recorded from the vicinity of the survey area and the species are unlikely to occur locally. There are no PECs or TECs in the vicinity of the survey area on the basis of terrestrial SRE taxa.

The study of available grey and published literature revealed diverse communities of SRE group species in the western Pilbara, including the vicinity of the survey area. However, there is considerable uncertainty about the ranges of most species, either because they are known from only a few specimens or because there is a lack of taxonomic resolution. The collation of data, including results from the WAM databases, revealed at least 137 potential or confirmed SRE species belonging to eight SRE groups that have been collected in the search area (Table F.5, Appendix F). These comprised terrestrial slaters (36), mygalomorph spiders (32), and non-marine snails (19), pseudoscorpions (15), araneomorph spiders (13), scorpions (10), millipedes (eight), centipedes (three) and harvestmen (one). The proportion of confirmed SRE species was low with 21 species comprising millipedes (eight species), spiders (seven), snails (five) and pseudoscorpions (one). Most species were potential SREs with deficient data, reflecting uncertainties caused by insufficient taxonomic resolution and/or the lack of reference collections.

The likelihood of SRE species groups occurring within the survey area is detailed in Table G.2 (Appendix G). Three SRE fauna surveys were conducted recently on behalf of Rio Tinto in the vicinity

of the survey area. The level 2 fauna survey at Bungaroo collected 30 species in SRE groups and seven potential SREs: the slaters *Spherillo* sp. indet., *Buddelundia* '61' and Buddelundiinae sp. indet., pseudoscorpions *Euryolpium* sp. 'Bungaroo', *Ideoblothrus* sp. 'Bungaroo' and *Tyrannochthonius* sp. 'Bungaroo 2', a scorpion species in the *Lychas* 'hairy tail'-group and the spider *Karaops* sp. 'Bungaroo' (Astron Environmental Services 2016a). The Level 2 survey at Middle Robe and East Deepdale collected 27 species in SRE groups and six potential SREs: slater *Philosciidae* sp. indet., scorpions in the *Lychas* 'hairy-tail' and *Lychas* 'multipunctatus'-groups, the spiders *Karaops* sp. 'Middle Robe 1' and *Karaops* sp. 'Middle Robe 2', and harvestman *Dampetrus* sp. nov. 'Middle Robe' (Astron Environmental Services 2016b). A third survey at the Mesa J Mine Extension collected only one species in SRE Groups: the widespread slater *Buddelundia* '15' (Astron Environmental Services 2016c)

Biota (2011) collected two terrestrial snails *Rhagagda convicta* and *Gastrocopta* sp. and two mygalomorph spiders *Aname* sp. A and *Aname* sp. C, from within the survey area. All species were recorded in the Breakaway habitats surrounding site RVM16. All species were classified as potential SRE and with the exception of *Aname* sp. A, had been previously recorded in multiple biological surveys in the vicinity (Astron Environmental Services 2016b).

Other surveys in the surrounding area recorded similar or lower numbers of SRE invertebrates. A seasonal fauna survey at Bungaroo in 2010 collected 10 locally widespread species in SRE groups: two mygalomorph spider species, a selenopid spider, three pseudoscorpion species, two terrestrial and two aquatic snail species (Biota Environmental Sciences 2010). A previous survey in the surrounding area collected four millipede species, one mygalomorph spider, one terrestrial and two aquatic snail species, which were also locally widespread (Biota Environmental Sciences 2007). The fauna survey for the Buckland Project identified seven potential SRE species: one terrestrial snail species in the family Camaenidae, four slater species, one selenopid spider species, and one species of centipede (Phoenix Environmental Sciences 2012). The fauna assessment for the Balla Balla Railway Project, located north-east of the Bungaroo survey area, collected 13 potential SRE invertebrates, comprising three arachnids, two centipedes, seven isopods and one terrestrial snail (Phoenix Environmental Sciences 2014b). Additional surveys across the Mesa A Transport Corridor (Biota Environmental Sciences 2006) and Middle Robe (ecologia Environment 2013) also collected millipedes, mygalomorph spiders and snail species, all more widespread in the area.

Overall, no confirmed SREs or listed invertebrate species have ever been recorded from the vicinity of the survey area or have been collected in previous surveys. None of the potential SRE species collected have ever been assessed as potentially threatened by economic development.

Based on the desktop assessment data, the SRE fauna in the vicinity of the survey area comprises primarily isopods, mygalomorph spiders, pseudoscorpions, scorpions, and terrestrial snails. Potential SRE millipedes, centipedes and harvestmen are less likely to occur. Although no confirmed SRE species have been recorded from the survey area, potential SRE species are most likely to belong to the slater, spider, snail and pseudoscorpion groups. However, such species are likely to be more widespread locally with total ranges of at least several square kilometres and ranges that mirror the wider distribution of landforms (Astron Environmental Services 2016a, 2016b; Biota Environmental Sciences 2007; ecologia Environment 2012).

4.2 Field Survey

4.2.1 Vertebrate Fauna Habitat

4.2.1.1 Fauna Habitats

Seven broad fauna habitat types were recorded in the survey area: Riverine, Drainage Line, Gorge, Breakaway, Rocky Hills, Low Hills and Slopes, and Loamy/Stony Plain. Areas of disturbed habitat were prevalent in the Low Slopes and Hills habitats on the top of Mesa H and the Loamy/Stony Plains habitat in the form of drill pads and the associated tracks. The habitats are described in Table 9 and mapping is presented in Figure H.1 (Appendix H). Habitat assessments undertaken during the survey are detailed in Table C.1-C.2 (Appendix C).

There was no record of recent or past fires in the survey area. The majority of Loamy/Stony Plain and Drainage Line habitats were generally in 'disturbed' to 'very good' condition. Some areas were heavily affected by cattle grazing and Buffel Grass. All other habitats were generally in 'good' to 'high quality' condition depending on the level of grazing, weeds and the presence of tracks. The Rocky Hills, Breakaway and Gorge habitats were generally in 'high quality' condition.

As stated in Section 3.5 a significant level of disturbance was recorded during the fauna survey, including drill tracks and pads, pastoralism and weed infestation. The majority of Drainage Line and Riverine habitats were generally in 'poor' to 'very good' condition due to weed infestation spread through pastoral activities; some areas were also heavily impacted from cattle grazing and therefore the introduction and spread of Buffel Grass (Thompson and Thompson 2010). All other habitats were generally in 'good' to 'high quality' condition depending on the level of grazing and weeds. The Rocky Hills, Gorges and Breakaway habitats generally had the highest quality fauna habitat condition due to isolation from threatening processes such as grazing.

Table 9: Vertebrate fauna habitat types recorded in the survey area.

Habitat type	Extent in survey area (proportion)	Broad habitat description	Vegetation description	Microhabitats	Sites	Habitat condition	Value (broad faunal assemblage and MNES species)	Representative photos	
Riverine	143 ha (2.9%)	Densely vegetated riparian zones of the Robe River often with permanent and semi-permanent water bodies on stony soils	*Eucalyptus camaldulensis* and *Melaleuca argentea* open forest over *Acacia* tall open shrubland over mixed open herbland and open hummock grassland.	Surface water (permanent and semi-permanent) Dense and varied leaf litter Hollow bearing trees and logs	BAT 11, BAT 12, CAM03, CAM06, CAM14, CAM15, CAM17, CAM18, CAM32, CAM33, CAM34, CAM37, HA01, HA02, HA04, HA13, HA15, MHT01, RVM13, SRE10, SRE11	Good to High Quality	High value to a wide spectrum of fauna species that are likely to reside in Riverine habitats. Moderate value to target MNES species as they are likely to traverse and forage within this habitat type.		
Drainage Line	589 ha (11.9%)	Broad open valley floor of the Robe River on stony soils	*Eucalyptus camaldulensis* or *Corymbia hamersleyana* low woodland over *Acacia* tall open shrubland over mixed open herbland and *Triodia wiseana* hummock grassland.	Sparse isolated vegetation Minimal leaf litter	BAT02, CAM05, CAM30, CAM43, CAM44, HA05, HA12 HA20, HA22, HA23, SRE08 SRE09	Disturbed to Good Quality	Moderate value to a wide spectrum of fauna species that are likely to reside in Drainage habitats. Low value to target MNES species as they do not provide significant refugia or shelter.		
Gorge	17 ha (0.3%)	Deep often rocky gorges, sometimes with ephemeral, semi-permanent or permanent pools	*Eucalyptus leucophloia* scattered low trees over *Triodia* hummock grassland.	Overhangs, crevices, caves, tree hollows, ephemeral, semi-permanent and permanent water	BAT08, BAT09, BAT10, CAM10, CAM11, CAM12, CAM13, CAM19, CAM20, CAM31, CAM35, CAM38, CAM39, HA14, HA21, SRE06, SRE07, SRE12, BAT14, HA06	High Quality	Primary high value habitat for target MNES species. Provides significant refugia/shelter sites and supports a diversity of fauna species.		
Breakaway	84 ha (1.7%)	Breakaway or ridge line, falling away to steep scree slope or drainage line	*Eucalyptus leucophloia* scattered low trees over *Acacia* open shrubland over *Triodia wiseana* open hummock grassland and *Eriachne mucronata* open tussock grassland.	Caves (roost/feed caves) Cracks and crevices Sheltered leaf litter	BAT13, CAM04, CAM07, CAM16, CAM21, CAM22, CAM23, CAM24, CAM26, CAM27, CAM28, CAM36, CAM40, CAM41, CAM42, HA10, HA17, RVM12, RVM16	High Quality	High value to a low diversity of fauna species that are likely to reside in Breakaway habitats. High value to target MNES species as they are likely to roost and den within this habitat type.		
Rocky Hills	66 ha (1.3%)	Stony hills on high ranges with dissected valleys and gorges	*Eucalyptus leucophloia* low open woodland over *Acacia inaequilatera* scattered tall shrubs over *Triodia* open hummock grassland.	Termite mounds, tree hollows, crevices	BAT07, HA03	High Quality	Moderate value for target MNES species as they are likely to traverse and forage within these habitats. Moderate value to a low diversity of fauna species that are rocky habitat specialists.		

Habitat type	Extent in survey area (proportion)	Broad habitat description	Vegetation description	Microhabitats	Sites	Habitat condition	Value (broad faunal assemblage and MNES species)	Representative photos	
Low Hills and Slopes	1,897 ha (38.5%)	Low stony hills and slopes with dissected valleys and drainage on stony soils	*Acacia inaequilatera* scattered tall shrubs over *A. bivenosa* scattered shrubs over *Triodia wiseana* open hummock grassland.	Termite mounds Large *Triodia* hummocks Minimal leaf litter	BAT01, BAT03, BAT04, CAM01, CAM02, CAM08, CAM09, CAM29, HA08, HA09, HA11, HA16, HA18, HA24, RVM14, RVM15, SRE01, SRE04, SRE05	Disturbed to High Quality	Low value to a wide spectrum of fauna species that are likely to reside in Stony Hills and Slopes habitats. Low value to target MNES species as this habitat type offers minimal ecological value to these species.		
Loamy/ Stony Plain	1,762 ha (35.8%)	Low-lying undulating loamy to stony plain within Robe valley floor	*Corymbia hamersleyana* scattered low trees over *Acacia* scattered shrubs over *Triodia wiseana* hummock grassland.	Termite mounds	CAM25, HA07, MHT02, MHT03, SRE02, SRE03	Disturbed to High Quality	Low value to a wide spectrum of fauna species. Low value to target MNES species as they do not provide significant refugia or shelter.		
Disturbed	372 ha (7.6%)	Cleared areas from mining and pastoralism activities	N/A	None	None	Highly Degraded	Little value as fauna habitat.		

Key: Cam - camera (active) site/location; HA - habitat assessment site/location; MTH/RVM- trapping grid site/location; BAT - SM2 acoustic bat recording site/location; SRE – Short Range Endemic sample site

Riverine habitat is considered to be of high importance to fauna species providing a range of ecological values to a wide suite of species. This habitat type in the survey area was often narrow linear isolated pockets of riparian vegetation which is usually denser, taller and more diverse than the adjacent Drainage Line habitat. The vegetation was complex and provided a range of micro niches for fauna species to exploit, such as for shelter and foraging. There were also a significant number of permanent and semi-permanent water bodies that provide drinking opportunities for a range of species and attract prey for predators. This habitat supports conservation listed fauna species such as the Rainbow Bee-eater and provides foraging sites for Ghost Bats and Pilbara Leaf-nosed Bats. In addition a female Northern Quoll was trapped within this habitat suggesting that this individual was using the habitat as a foraging site or an ecological corridor traversing different habitats across the landscape.

Drainage Line habitat is a commonly recorded habitat for the Pilbara region and considered to be of low to moderate value to a wide spectrum of fauna species. The Drainage Line habitat typically exhibits a moderate diversity of microhabitats, with some tree hollows and woody debris (logs and leaf litter). Within the survey area this habitat was generally devoid of vegetation when compared to Riverine habitat, with less dense and less complex vegetation. There were some locations with water bodies, albeit less significant and less permanent, which would likely be seasonally inundated during large rainfall events only. Conservation listed species including the Rainbow Bee-eater and Lined Soil-crevice Skink may occur in this habitat.

Gorge habitat is the most restricted habitat in the survey area. Gorges are a common feature of the Pilbara; however, as they tend to be narrow, linear features, gorges represent a small proportion of the total land area. In addition, they represent important shelter or roosting habitat for a number of MNES species, including the Pilbara Olive Python, Ghost Bat, Pilbara Leaf-nosed Bat and Northern Quoll. They may also support Priority listed species such as *Anilios ganei*. Deep caves and semi-permanent rock pools were recorded in this habitat type; these habitat features can provide refuge for fauna during harsher drier seasonal conditions. This habitat is considered of high value as it contains a complexity of microhabitats and supports conservation significant fauna species.

Breakaway habitat is a common feature of the Pilbara but because they tend to be narrow, linear features, they represent a small proportion of the total land area. The breakaways of the survey area were often associated with the Mesa habitat. Breakaway habitat contained microhabitats such as crevices, overhangs and caves that provide shelter opportunities for MNES species, including the Pilbara Olive Python and Northern Quoll. A number of caves were being used as diurnal roosts and nocturnal feeding roosts for the Ghost Bat, potential den sites for the Northern Quoll and for the Pilbara Olive Python. The Breakaway habitat provides critical habitat values to a number of conservation listed species including MNES, therefore it is considered of high importance for fauna.

Rocky Hills are common and widespread throughout the Pilbara. This habitat generally has low vegetation complexity and low diversity of microhabitats; however, MNES species (such as the Northern Quoll) are likely to traverse and forage within these habitats. Other conservation significant species such as the Western Pebble-mound Mouse and *Anilios ganei* may also utilise this habitat. Therefore this habitat is considered of moderate value for fauna.

Low Hills and Slopes habitat was the most common habitat within the survey area. The Low Hills and Slopes habitat is widespread and common throughout the Pilbara region and although there are a few conservation listed species that may utilise this habitat, they are unlikely to be restricted to it, with the possible exception of the Western Pebble-mound Mouse. This habitat generally has low vegetation complexity and low diversity of microhabitats available for fauna species to exploit. The soils are generally stony and compact, reducing the potential opportunities for burrowing species. This habitat is considered to be of low value to a broad spectrum of fauna species.

Loamy/Stony Plain habitat was the second most common habitat within the survey area. It is also widespread and common throughout the Pilbara region and although there are a few species of conservation significance that may utilise it, they are not restricted to this habitat type. Conservation significant fauna likely to occur in this habitat type include the Western Pebble-mound Mouse and Rainbow Bee-Eater. This habitat generally had low vegetation complexity and microhabitat diversity as well as areas that were heavily affected by grazing and Buffel Grass; therefore, it is considered to be of low value for fauna.

4.2.1.2 Significant Habitat Areas

Several significant habitat features were recorded throughout the survey area. This includes five permanent pools (8.5 ha) that were located within the Robe River (Figure H.1 and Table H.1, Appendix H).

No significant bat roosts or other significant areas were identified during the current survey. However, seven Ghost Bat caves were identified by Astron (2014) during a previous survey, two of which were deemed to be diurnal roosts (and possible maternal roosts), three (two that were part of one system) were deemed to be nocturnal feeding roosts and two caves were determined to not be used, following a targeted cave assessment by Bat Call WA Pty Ltd (2017) (Figure H.1 and Table H.1, Appendix H). An additional seven caves identified during the targeted cave assessment were deemed to be nocturnal feeding roosts (Bat Call WA 2017) (Figure H.1 and Table H.1, Appendix H).

None of the fauna habitats were considered to be synonymous with any TECs or PECs relating to terrestrial fauna listed in the Pilbara region (Department of Parks and Wildlife 2015c). It should be noted however, that two PECs relating to subterranean invertebrates overlap the survey area - '*Subterranean invertebrate communities of mesas in the Robe valley*' (P1) and '*Stygofaunal Community of the Bungaroo Aquifer'* (P1). These have not been addressed in this report as they relate to subterranean habitats.

4.2.1.3 Habitat Suitability for MNES Species

Northern Quoll

Approximately 101 ha (2%) of the survey area, comprising Gorge and Breakaway habitats, was considered potential shelter and foraging habitat for the Northern Quoll (Table B.10, Appendix B; Figure H.2, Appendix H). The Gorge and Breakaway habitats contain rocky environments of high relief that are particularly important for Northern Quolls in the Pilbara as they provide denning sites for breeding and shelter and diverse microhabitats for foraging.

Approximately 209 ha (4%) of the survey area was considered suitable foraging and dispersal habitat, which mostly consisted of Riverine and Rocky Hills habitats, particularly where these habitats were in close association with the Gorge and Breakaway habitats as they provided microhabitats such as crevices and cracks for foraging (Figure H.2, Appendix H). The remaining 4,620 ha (94%) of the survey area was considered to provide limited foraging and dispersal habitat, consisting of Drainage Line, Loamy/Stony Plain and Low Hills and Slopes habitats (Figure H.2, Appendix H).

Ghost Bat

Approximately 101 ha (2%) of the survey area, comprising the Gorge and Breakaway habitat, was considered potential shelter and foraging habitat (Table B.10, Appendix B; Figure H.3, Appendix H), due to the presence of two diurnal roosts and a number of nocturnal feeding roosts.. One of the diurnal roosts (possible maternal roost) was found in Gorge habitat and the other diurnal roost (possible occasional use as a maternal roost) was found within Breakaway habitat. Both Gorge and Breakaway habitats contained caves and deep shelters used as nocturnal feeding roosts. Both habitats contain complex vegetation structures and microhabitats that support prey species and foraging sites for the Ghost Bat.

Approximately 798 ha (16%) of the survey area, which consisted of Riverine, Drainage Line and Rocky Hills habitat, was considered suitable foraging and dispersal habitat (Figure H.3, Appendix H). The tall trees found in the Riverine and Drainage Line habitats provide ideal foraging/hunting perches particularly in areas that contain permanent surface water or thick vegetation. The Rocky Hills habitat contains microhabitats such as boulder piles, crack and crevices that support a wide range of prey species for the Ghost Bat.

The remaining 4,031 ha (82%) of the survey area, comprising the Loamy/Stony Plain and Low Hills and Slopes habitats, was considered to provide limited foraging and dispersal habitat (Figure H.3, Appendix H).

Pilbara Leaf-nosed Bat

Approximately 17 ha (0.3%) of the survey area, comprising the Gorge habitat, was considered potential shelter and foraging habitat for this species (Table B.10, Appendix B; Figure H.4, Appendix H), due to the presence of nocturnal refuge caves. The Pilbara Leaf-nosed Bat requires deep, humid, climatically stable caves for diurnal and maternal roost sites. The caves located in the Gorge habitat of the survey area do not fit these criteria; however, they can be classified as nocturnal refuge caves (Department of the Environment 2017) that are occupied or entered at night for resting or feeding.

Approximately 816 ha (16.7%) of the survey area, which consisted of Riverine, Drainage Line and Breakaway habitat, was considered suitable foraging and dispersal habitat (Figure H.4, Appendix H). The complex vegetation structure, in particular surrounding areas of permeant water, of the Riverine and Drainage Line habitats provide ideal foraging habitat for this species.

The remaining 4,097 ha (83%) of the survey area, comprising the Loamy/Stony Plain, Rocky Hills and Low Hills and Slopes habitats, was considered to provide limited foraging and dispersal habitat (Figure H.4, Appendix H).

Pilbara Olive Python

Approximately 244 ha (5%) of the survey area, comprising the Gorge, Breakaway and Riverine habitats, was considered as potential shelter and foraging habitat for the Pilbara Olive Python (Table B.10, Appendix B; Figure H.5, Appendix H). The caves and overhangs of the Gorge and Breakaway habitats provide denning sites and ambush locations frequented by this species. The thick vegetation and log piles/flood refuse provide shelter and ambush locations within the Riverine habitat, especially in areas containing permanent or semi-permanent water sources.

Approximately 655 ha (13%) of the survey area was considered suitable foraging and dispersal habitat, which consisted of Rocky Hills and Drainage Line habitats (Figure H.5, Appendix H). These

habitats are often adjacent to the more suitable Gorge and Riverine habitats and provide dispersal opportunities for the Pilbara Olive Python.

The remaining 4,031 ha (82%) of the survey area was considered to provide limited foraging and dispersal habitat, consisting of Loamy/Stony Plain and Low Hills and Slopes habitats (Figure H.5, Appendix H).

4.2.2 Vertebrate Fauna Species

There were 169 vertebrate fauna species recorded within the survey area during the survey (Table 10). A complete list of recorded species is provided in Tables F.6-F.10 (Appendix F). The following sections provide detailed results for each major taxonomic group sampled.

Table 10: Number of vertebrate fauna species recorded during the survey.

Fauna taxonomic group	No. of native species recorded	No. of conservation significant species recorded	No. of introduced species recorded
Amphibians	2	0	0
Reptiles	55	2	0
Birds	85	2	0
Mammals	27	4	4
Total	**169**	**8**	**4**

4.2.2.1 Herpetofauna

Two amphibian species were recorded during the survey: *Litoria rubella and Uperoleia saxatilis* (Table F.6, Appendix F). Frogs were either caught in pitfall traps, sighted, or heard calling during targeted searches. No conservation significant species were recorded.

Fifty-five reptile species were recorded during the survey (Table F.7, Appendix F). The most abundant groups encountered were the skinks (257 records, 63%), which was also the most speciose with 17 species, followed by the geckos (72 records, 18%) with 10 species. The most commonly recorded species were *Ctenotus grandis titan* (95 records) and *Eremiascincus isolopes* (50 records). The most speciose site was RVM15 (Low Hills and Slopes) with 20 species and MHT02, MHT03 and RVM14 (Loamy/Stony Plains and Low Hills and Slopes) each with 19 species. Six of the 55 reptile species (11%) were not captured at trapping grids, but were recorded from targeted and opportunistic records.

Two conservation significant species were recorded during the survey. The Lined Soil-crevice Skink (P4) was caught at MHT03, RVM14 and RVM15 (Loamy/Stony Plains and Low Hills and Slopes). An individual Pilbara Olive Python (S3; VU), was recorded opportunistically in the Riverine habitat during a nocturnal survey.

Species accumulation curves were beginning to asymptote during the current surveys (Figure 6), and based on estimates of total species richness, between 62% and 82% of the total species pool was recorded (Table 11). As an additional four species (7% of all species) were recorded using methods other than trapping, the survey effort recorded the majority of the herpetofauna present in the survey area.

Table 11: Total number of herpetofauna taxa sampled in comparison to estimates of the total species pool based on several models.

	Observed	Estimated			
		Chao2	Jackknife 1	Jackknife 2	Bootstrap
Number of species	51	70.9	72.6	82.1	61.6
Estimated % sampled		71.9	70.2	62.1	82.8

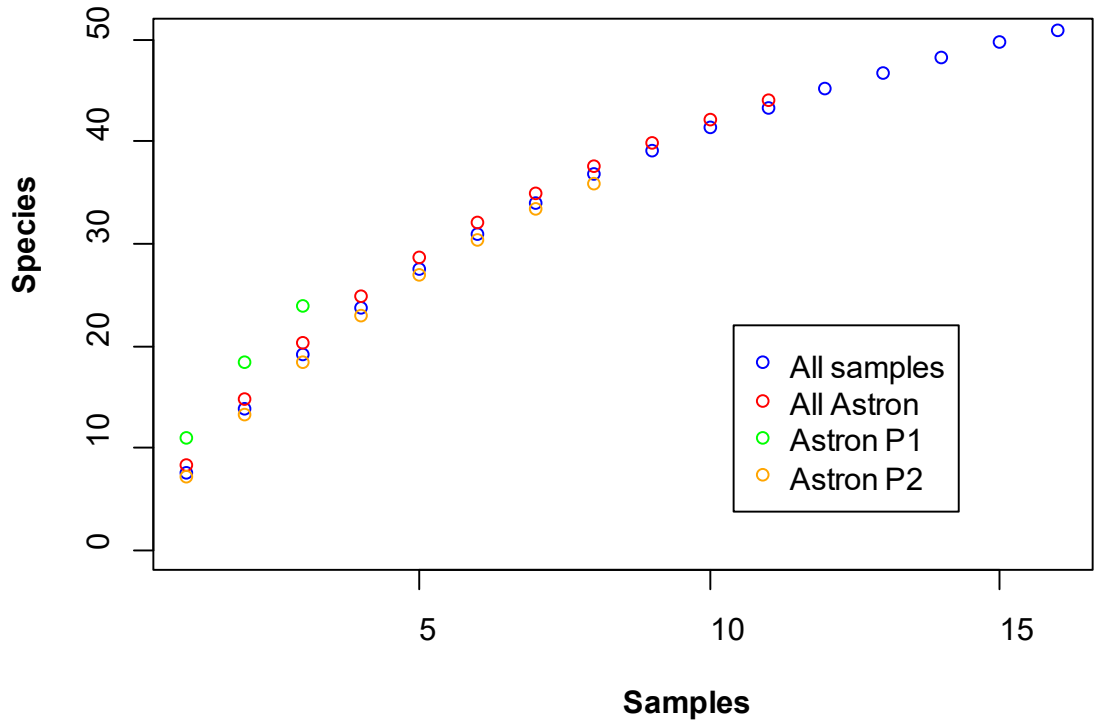

Figure 6: Species accumulation curves for herpetofauna surveys.

There was a significant difference in species composition between habitat types (ANOSIM R = 0.51, P=0.009), with each trapping site generally grouped with other trap sites in the same habitat type and showing similar species compositions. The trap sites in the Breakaway habitat were the most distinct in species composition for herpetofauna. This is likely due to the fact that the trap sites in this habitat type were comprised of Elliot traps rather than pitfall traps (owing to the lack of soil to dig pitfalls into). As such, herpetofauna captures were lower in the Breakaway habitat than the other habitats (Figure 7).

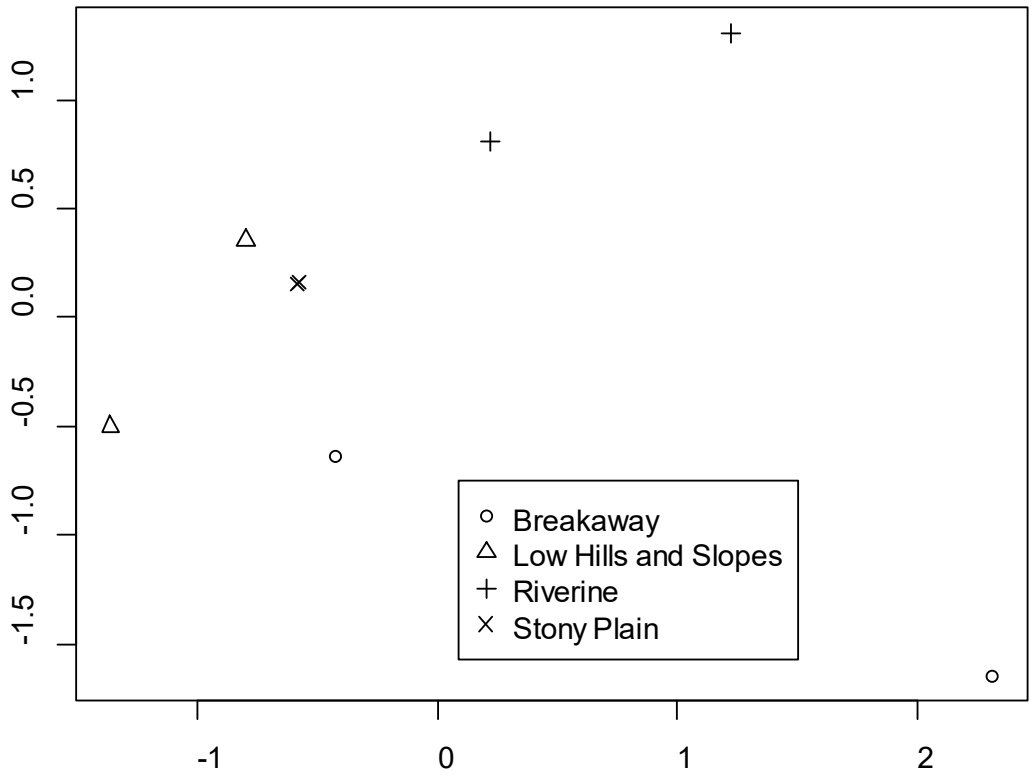

Figure 7: Two-dimensional ordination of herpetofauna species assemblages of each site.

4.2.2.2 Birds

Eighty-five bird species were recorded during the survey (Table F.8, Appendix F). The most commonly recorded species was the Painted Finch (*Emblema pictum),* with a total of 208 records and the Zebra Finch (*Taeniopygia guttata*) with 53 records. The most abundant group of birds was the Estrilidae (Finches), with 263 records accounting for 34% of all records. The most speciose families observed were the Accipitridae (Eagles, Kites and Hawks) and Meliphagidae (Honeyeaters), which comprised seven and six species, respectively. The most speciose sites were RVM13 (Riverine) with 36 species and MTH03 (Loamy/Stony Plain) with 29 species. Of the 85 bird species recorded 41 species were not recorded at trapping grids, but were recorded from targeted and opportunistic searches.

One species of conservation significance was recorded during the survey. The Rainbow Bee-eater (S5; Mi) was recorded on numerous occasions throughout the survey area in a variety of habitats including Loamy/Stony Plains, Drainage Lines and Breakaways.

Species accumulation curves appeared to asymptote during the current surveys (Figure 8), and based on estimates of total species richness, between 61% and 85% of the total species pool was recorded (Table 12). The data does not include an additional 25 bird species (29%) that were recorded opportunistically.

There was a significant difference in species composition between habitat types (ANOSIM R = 0.646, P=0.008; Figure 9) with each trapping site generally grouped with other trap sites in the same habitat type and showing similar species compositions.

Table 12: Total number of bird taxa sampled in comparison to estimates of the total species pool based on several models.

	Observed	Estimated			
		Chao2	Jackknife 1	Jackknife 2	Bootstrap
Number of species	60	94.8	83.5	98	70.9
Estimated % sampled		63.3	71.9	61.2	84.6

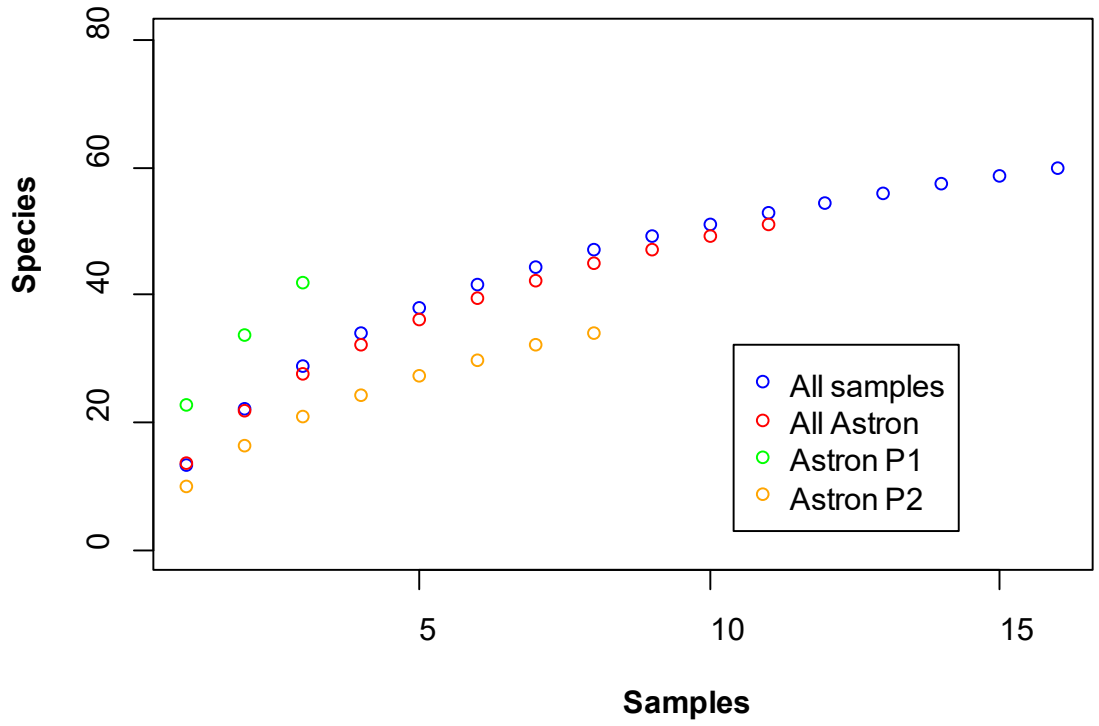

Figure 8: Species accumulation curves for bird surveys.

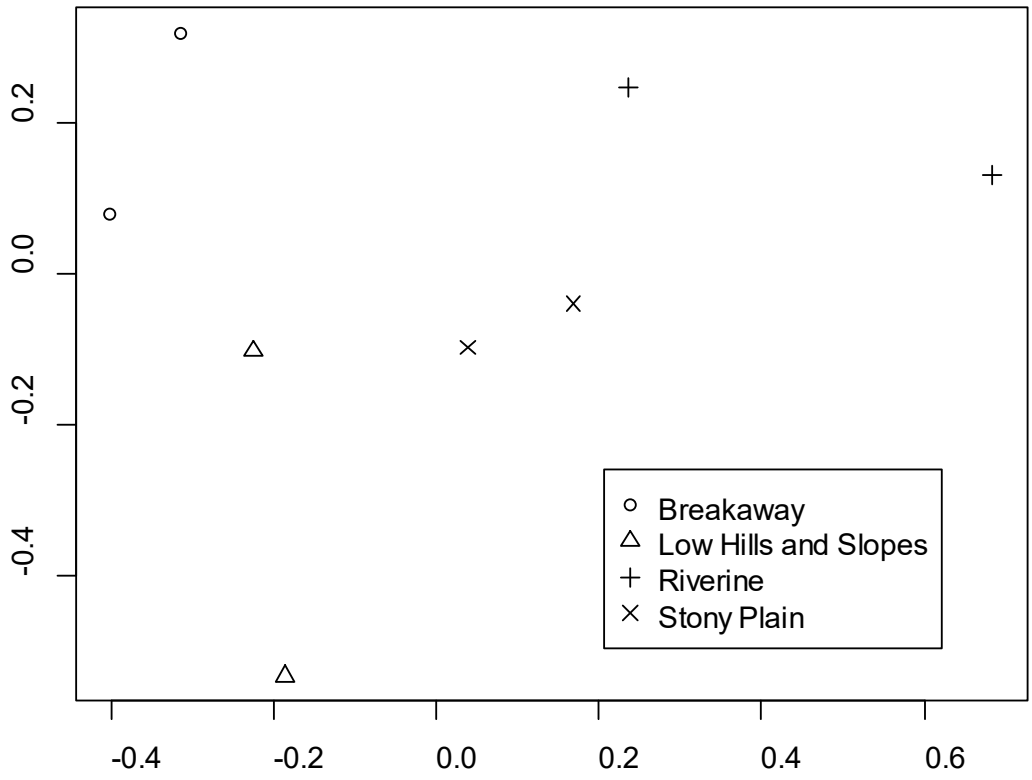

Figure 9: Two-dimensional ordination of bird species assemblages of each site.

4.2.2.3 Mammals

Twenty-seven species of mammal were recorded during the survey, including four introduced species: Cat (**Felis catus*), Dog/Dingo (**Canis familiaris*), European Cattle (**Bos taurus*) and House Mouse (**Mus musculus*) (Table F.9-F.10, Appendix F). The most commonly trapped species was the Pilbara Ningaui (*Ningaui timealeyi*) with 20 captures (23% of trap records). Also commonly encountered was Planigale (*Planigale* sp. 1) with 17 captures and the Common Rock Rat (*Zyzomys argurus*), with 14 captures. The most speciose trapping sites were MHT01 (Riverine) and MHT03 (Loamy/Stony Plain) with six species each. The most commonly recorded species including targeted and opportunistic records was Northern Quoll with four individuals captured and 22 image records at 14 different sites. Nine bat species were recorded from the acoustic recording sites (Table F.10, Appendix F).

Four species of conservation significance were recorded during the survey: Northern Quoll (S2; EN), Pilbara Leaf-nosed Bat (S3; VU), Ghost Bat (S3; VU) and Western Pebble-mound Mouse (P4).

Species accumulation curves reached an asymptote during the current surveys (Figure 10), and based on estimates of total species richness, between 81% and 90% of the total species pool were recorded (Table 13). The data does not include any bat species, which make up 33% of the mammal species, as well as an additional six species that were recorded opportunistically.

There was no significant difference in species composition between habitat types, although the two Loamy/Stony Plain sites were very similar in composition (ANOSIM R = 0.313, P=0.129, Figure 11).

Table 13: Total number of mammal taxa sampled in comparison to estimates of the total species pool based on several models.

	Observed	Estimated			
		Chao2	Jackknife 1	Jackknife 2	Bootstrap
Number of species	12	13.5	14.9	13.4	14.3
Estimated % sampled		88.9	80.5	89.6	83.9

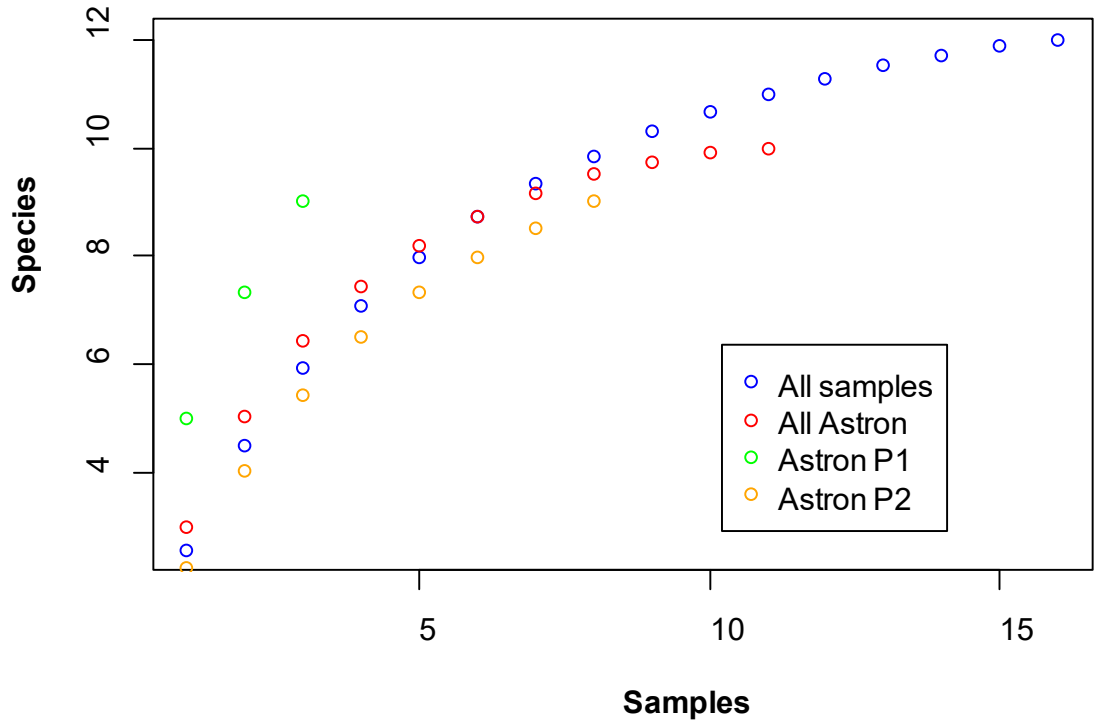

Figure 10: Species accumulation curves for mammal surveys.

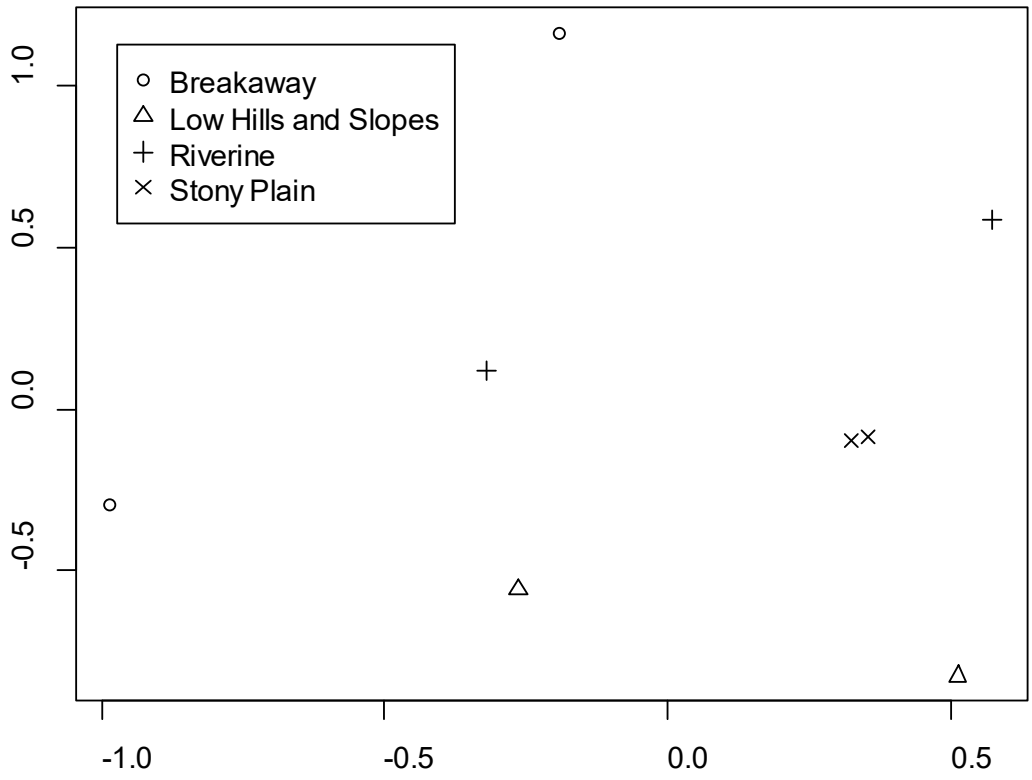

Figure 11: Two-dimensional ordination of mammal species assemblages of each site.

4.2.2.4 Conservation Listed Species Recorded

Eight vertebrate species of conservation significance have been recorded within the survey area. The locations of these species records from the current survey, as well as previously recorded species, are shown in Figure I.1 and detailed in Table I.1 (Appendix I).

Pilbara Olive Python (*Liasis olivaceus barroni*)

The Pilbara Olive Python (VU; S3) prefers escarpments, deep gorges, water holes and rock piles associated with permanent pools in rocky areas in the ranges of the Pilbara region (Pearson 1993; Wilson and Swan 2010). Microhabitat preferences of the Pilbara Olive Python are under rock piles, on top of rocks or under spinifex (Tutt et al. 2004). Individuals spend the cooler winter months within caves and rock crevices away from water sources. In the warmer summer months, the pythons are found to move around widely, usually in close proximity to water and rock outcrops (Wilson and Swan 2010). A population is known to exist along the Robe River near Pannawonica (Biota Environmental Sciences 2007).

A single juvenile Pilbara Olive Python was recorded within the Riverine habitat of the survey area (Figure I.1 and Table I.1, Appendix I). Additionally, the presence of this species was recorded on a further two occasions through the forms of scats within the Breakaway habitat type. This species is likely to be found within the Gorge, Breakaway and Riverine habitats particularly in the sites that contain semi-permanent and permanent water. This species has been previously recorded in the vicinity of the survey area (Astron Environmental Services 2016a, 2016b; Biologic Environmental Survey 2014).

Northern Quoll (*Dasyurus hallucatus*)

The Northern Quoll (EN; S2) occurs in a variety of habitats (Oakwood 2008) but is commonly found in open lowland savannah forest and rocky escarpments. Rocky areas are a particularly important zone for quolls in the Pilbara as these areas retain water and provide a diversity of microhabitats. These areas also tend to have greater floristic diversity and productivity resulting in greater prey density compared to non-rocky areas. These rocky areas also provide refuge from feral cats, fire and livestock (Hill and Ward 2010) and provide breeding potential (Department of the Environment 2013).

The Northern Quoll was recorded 32 times during the survey (Figure I.1 and Table I.1, Appendix I), with six capture records (four confirmed separate individuals), 22 remote camera records at 14 different locations and four scats, tracks and/or trace records. Generally the majority of these records were found in the Breakaway habitat; however some records occurred within Riverine and Gorge habitat types (Figure I.1, Appendix I).

A single Northern Quoll (sex unknown) was captured at site RVM16 (Breakaway) during phase 1 in 2010 (Biota Environmental Sciences 2011). During phase 2 a single female Northern Quoll was captured at MHT01 (Riverine) and a single male and two females were captured at RVM16 (Breakaway). As microchip PIT tags were used in the phase 2 survey these records are confirmed as separate individuals.

The Northern Quoll has previously been recorded for the survey area and within the general vicinity (Astron Environmental Services 2014, 2016a, 2016b; Biologic Environmental Survey 2014; Biota Environmental Sciences 2005, 2007, 2011; ecologia Environment 2013). Astron (2014) recorded the Northern Quoll at two locations in the survey area from scat records within the Rocky Hills habitat type. Within the survey area Biologic (2014) recorded the Northern Quoll at two locations, in the Riverine habitat type and Biota (2011) recorded this species once in the Breakaway habitat type. All previous records of this species in the survey area were from sites consistent with the preferred habitat for this species.

Pilbara Leaf-nosed Bat (*Rhinonicteris aurantia*)

Pilbara Leaf-nosed Bats (VU; S3) are known to require deep caves characterised by high levels of humidity and stable temperatures (Churchill 2008). This is a result of their limited ability to conserve heat and water (Armstrong 2001; Churchill 1991). Caves deep enough to create this environment are relatively uncommon in the Pilbara, with only 20 to 25 roost sites being known (R. Bullen 2014, pers. comm. 20 Oct 2014). Foraging habitat for the Pilbara Leaf-nosed Bat is diverse and includes riparian vegetation, hummock grassland, and sparse tree and shrub savannah (Duncan, Baker, and Montgomery 1999). Roost sites for the Pilbara Leaf-nosed Bat can be classified (Department of the Environment 2017) based on the following criteria:

- Permanent diurnal roosts—occupied year-round and likely the focus for some part of the 9-month breeding cycle; considered as critical habitat that is essential for daily.
- Non-permanent breeding (maternal) roosts—evidence of usage during some part of the 9-month breeding cycle (July–March), but not occupied year-round; considered as critical habitat that is essential for both the daily and long-term survival.
- Transitory diurnal roosts—occupied for part of the year only, outside the breeding season (i.e. April–June), and which could facilitate long distance dispersal in the region; considered as critical habitat that is essential for both the daily and long-term survival.

- Nocturnal refuge—occupied or entered at night for resting, feeding or other purposes, with perching not a requirement. Excludes overhangs. Not considered critical habitat, but are important for persistence in a local area.

Pilbara Leaf-nosed Bats have also been recorded flying over small watercourses amongst granite boulder terrain, over pools and low shrubs in ironstone gorges, and above low shrubs and around pools in gravelly watercourses with *Melaleuca leucadendron*, such as in Barlee Range Nature Reserve (Armstrong 2001). In the Pilbara, the species has been observed in *Triodia* hummock grasslands covering low rolling hills and shallow gullies, with scattered *Eucalyptus camaldulensis* along the creeks (Armstrong 2001; Churchill 1991).

The Pilbara Leaf-nosed Bat was recorded at eight of the 14 SM2 bat detector locations that were all deemed to be at low activity levels, apart from BAT 14 which recorded 257 calls, which is classified as being a site with high activity levels (Bat Call WA 2016) (Appendix J). BAT 14 was situated at the enterance to a large gorge system, of which most occurs to the south of the survey area. To identify where the Pilbara Leaf-nosed Bats were roosting, four SM2 units were placed strategically along the gorge system during 3 to 8 June 2016 (after the main survey was completed). Progressively increasing time differentials between the SM2 units in the south to the north of this gorge suggest the Pilbara Leaf-nosed Bats likely originated from a known roost site approximately 10 km south of the survey area (Bat Call WA 2016) (Appendix J).

The Pilbara Leaf-nosed Bat has previously been recorded for the survey area and within the general vicinity (Astron Environmental Services 2014, 2016a, 2016b; Biologic Environmental Survey 2014; Biota Environmental Sciences 2009, 2010; ecologia Environment 2013). This species was previously recorded within the survey area by Astron (2014). Acoustic detections were made of this species at eight separate sites within Gorge, Riverine and Low Hills and Slopes habitat types.

The caves of the survey area do not match the criteria to be classsified as roost sites for the Pilbara Leaf-nosed Bat, which is supported by the low activity levels from the SM2 units across most of the survey area. The deeper caves located in the Gorge habitat of the survey area have the dimentions to be classified as potential nocturnal refuges.

Ghost Bat (*Macroderma gigas*)

The preferred habitat of Ghost Bats (VU; S3) is considered to be rocky gorges and breakaways that support caves and crevices used as maternity roosts. The Ghost Bat uses different natural formations for various purposes and for groups to persist they generally require habitats that provide:

- a selection of roosting opportunities with night roosts or feeding sites, day roosts and at least one deep cave with characteristics of a maternity roost
- nearby gullies and gorges with vegetation of vertical complexity (diverse vegetation heights and density) and presence of water that would attract prey species
- a productive foraging area within a 5 km to 10 km radius, usually including a good quality riparian drainage line.

Transient roosts and feeding sites are used by small numbers of Ghost Bats, whereas maternity roosts are used by larger colonies (Armstrong and Anstee 2000). Night feeding roosts (feed caves) are typically shallow caves and shelters/overhangs high in the strata and poorly insulated from the elements (Armstrong and Anstee 2000). Transient day roosts are deeper and more complex, have more insulation providing a more stable temperature and typically have one or more large chambers high enough to avoid predators. Maternity roosts provide additional features to support a

reproducing population including high temperature (27°C to 33°C) and humidity (>85%) (Armstrong and Anstee 2000). The Ghost Bat can have a relatively small nightly foraging range (up to 2 km from the roost where it has been studied in Queensland) (Tidemann et al. 1985; Pettigrew et al. 1986), but has the flight capability to range widely (Bullen and McKenzie 2002), perhaps tens of kilometres in a night. This is evident from genetic markers, which suggest that males are particularly likely to disperse long distances throughout the landscape (Worthington Wilmer et al. 1994; 1999).

Ghost Bats require caves of varying shapes and sizes to fulfil each of its ecological requirements. Caves usage can be classified into three categories: feed caves, day roosts and maternal roosts.

- Feed caves are typically shallow caves or overhangs high in the strata that are poorly insulated from the elements (Armstrong and Anstee 2000). Ghost Bats hunt at night and use feed caves to consume prey they have captured in the surrounding area. Feed caves often contain Ghost Bat scats and/or feeding remnants (typically feathers and small animal bones).
- Day roosts are generally deep, complex caves or disused mines that contain domed ceilings, fissures or passages which create a stable microclimate. These caves are usually lower in the strata making them well insulated. The stable temperature and elevated humidity of these caves relative to the ambient conditions create physiologically benign conditions (McKenzie and Bullen 2009; Armstrong and Anstee 2000; Hall et al. 1997; Leitner and Nelson 1967).
- Maternal roosts like day roosts are generally deep, complex caves or disused mines that contain domed ceilings, fissures or passages which create a stable microclimate and often contain multiple entrances (McKenzie and Hall 2008). Maternal roosts have a stable temperature of 23°C to 28°C and moderate to high relative humidity of 50% to 100% (Armstrong and Anstee 2000; Churchill 1991; Churchill and Helman 1990; Pettigrew et al. 1986).

The Ghost Bat was recorded twice during the current survey through scat collections and acoustic recordings from SM2 bat detectors (Figure I.1 and Table I.1, Appendix I). This includes acoustic recordings on four separate occasions (Figure G.1, Appendix G; Bat Call WA 2016) and from scat piles within temporary feed caves. Seven caves have been previously identified in the 2014 survey of Mesa H (Astron Environmental Services 2014), two of which were deemed to be diurnal roosts (and possible maternal roosts), three (two that were part of one system) were deemed to be nocturnal feeding roosts and two caves were determined to not be used, following a targeted cave assessment (Bat Call WA 2017). An additional seven caves identified during the targeted cave assessment were deemed to be nocturnal feeding roosts (Bat Call WA 2017) (Figure H.1 and Table H.1, Appendix H).

The Ghost Bat has been previously recorded within the vicinity of the survey area (Figure I.1, Appendix I) from past fauna surveys (Astron Environmental Services 2014, 2016a, 2016b; Biologic Environmental Survey 2014; Biota Environmental Sciences 2005, 2006, 2009, 2010, 2011). Within the survey area Astron (2014) has previously recorded the presence of Ghost Bats at 12 locations (six scat locations and six acoustic records).

Rainbow Bee-eater (*Merops ornatus*)

The Rainbow Bee-eater (Mi; S5) is one of the most common and widespread birds in Australia and was a commonly recorded species during bioregional surveys in the Pilbara (Burbidge, Johnstone, and Pearson 2010). The species winters from the Gascoyne north to Indonesia, moving south mainly in late September and early October and north from February to April (Johnstone and Storr 1998). Rainbow Bee-eaters tend to prefer lightly wooded, preferably sandy country near water (Johnstone and Storr 1998).

The Rainbow Bee-eater was recorded on numerous occasions throughout the survey area during both phases of the fauna survey in all habitats including Riverine, Drainage Line, Loamy/Stony Plains, Low Hills and Slopes, Gorge and Breakaway (Figure I.1 and Table I.1, Appendix I). Nine previous records of this species were made within the survey area (Astron Environmental Services 2014; Biota Environmental Sciences 2011; ecologia Environment 2013) and numerous records exist in the vicinity of the survey area (Astron Environmental Services 2011, 2016a, 2016b; Biologic Environmental Survey 2014; Biota Environmental Sciences 2010; ecologia Environment 2013).

Eastern Great Egret (*Ardea modesta*)

The Eastern Great Egret (Mi; S5) is an inland wetland specialist often seen wading in a range of wetlands from lakes, rivers and swamps to estuaries (Johnstone and Storr 1998). Eastern Great Egrets can be seen alone or in small flocks, often with other egret species, and roost at night in small groups. This species has been recorded within the survey area in the Riverine habitat (Astron Environmental Services 2014) and in the vicinity of the survey area (Astron Environmental Services 2014, 2016b; ecologia Environment 2013). The Eastern Great Egret is likely to be present at permanent pools within the Riverine and Drainage Line habitats of the survey area.

Lined Soil-crevice Skink (*Notoscincus butleri*)

The Lined Soil-crevice Skink (P4) is endemic to Western Australia and restricted to the arid north-west of the Pilbara bioregion (Storr, Smith, and Johnstone 1999). This species has been associated with spinifex-dominated areas near creek and river margins (Wilson and Swan 2010).

The Lined Soil-crevice Skink was captured on five occasions during the survey at three trapping grids (MHT03, RVM14 and RVM15); all within the Loamy/Stony Plains and the Low Hills and Slopes habitat types (Figure I.1 and Table I.1, Appendix I). Four previous records of this species were made within the survey area (Biota Environmental Sciences 2006, 2011; ecologia Environment 2013) and the vicinity of the survey area (Astron Environmental Services 2016a, 2016b; Biota Environmental Sciences 2006, 2007, 2010, 2011).

Western Pebble-mound Mouse (*Pseudomys chapmani*)

Although suitable habitat is patchy, extant Western Pebble-mound Mouse (P4) populations are widespread in the extensive ranges of the central and southern Pilbara region (Start 2008). The persistence of abandoned mounds in the Gascoyne and Murchison regions and small, isolated, coastal ranges in the Pilbara indicates considerable recent decline (Start 2008). Colonies occur on the gentler slopes of rocky ranges where the ground is covered by stony mulch and vegetated by hard spinifex, often with a sparse overstorey of eucalypts and scattered shrubs, typically *Senna, Acacia* and *Ptilotus* (Start 2008). Mounds are also sited close to narrow ribbons of *Acacia* dominated scrub along incised drainage lines (Start 2008).

Five inactive mounds were recorded within the Low Hills and Slopes habitat type during the survey (Figure I.1 and Table I.1, Appendix I). This species has been previously recorded in the survey area; Astron (2014) recorded one inactive pebble-mound and Biota (2006) captured one individual from the Low Hills and Slopes habitat type. Numerous records of this species exist from the vicinity of the survey area (Astron Environmental Services 2014, 2016a, 2016b; Biologic Environmental Survey 2014; Biota Environmental Sciences 2006, 2007).

4.2.2.5 Conservation Listed Species Potentially Occurring in the Survey Area

One species, the Blind Snake, *Anilios ganei* (P1), was not recorded in the survey area but was considered to have a high likelihood of occurring (Table G.1, Appendix G).

The Blind Snake *Anilios ganei*, is often poorly collected in vertebrate fauna surveys, but is known from the Pannawonica local area. This species has been associated with moist gorges and gullies (Wilson and Swan 2010) but potentially occurs over a wide range of other stony habitats. Given its cryptic fossorial habit this species is rarely encountered. Little is known of this species' ecology but like most other blind snakes, it is insectivorous, feeding on termites and their eggs, and larvae and pupae of ants (Wilson and Swan 2010). This species has been recorded within the vicinity of the survey area (Astron Environmental Services 2016a) and is likely to be present within suitable habitats, including the Gorge, Breakaway and Rocky Hills habitat types of the survey area.

Eleven species were not found in the survey area but were all considered to have a moderate likelihood of occurrence: Fork-tailed Swift (Mi; S5), Cattle Egret (Mi; S5), Letter-winged Kite (P4), Australian Painted Snipe (EN; S2), Common Sandpiper (Mi; S5), Sharp-tailed Sandpiper (Mi; S5), Wood Sandpiper (Mi; S5), Common Greenshank (Mi; S5), Oriental Pratincole (Mi; S5), Long-tailed Dunnart (P4) and Short-tailed Mouse (P4) (Table G.1, Appendix G). Although suitable habitat is present within the survey area, these species are either seasonal migrants only present at certain times of the year or they are cryptic species such as Australian Painted Snipe and Oriental Pratincole, making individuals difficult to record during fauna surveys.

An additional 13 species not found in the survey area were considered to have a low likelihood of occurrence due to lack of suitable habitats (Table G.1, Appendix G).

4.2.3 Invertebrate Fauna Species

4.2.3.1 Invertebrate Habitats

Seven potential SRE habitat types were identified differing in their prospectivity for SRE fauna. The most prospective habitats were Breakaway and Gorge habitats, followed by Rocky Hills, Riverine habitats and Drainage Line habitats. Breakaway and Gorge habitats were also the least common landforms, which together comprised only 2% of the survey area. The most common habitat types, that together account for more than 74.3% of the survey area, were assessed as not suitable or having low suitability for supporting SREs in the desktop assessment. The fauna habitats' suitability to support SRE species are detailed in Table 14 and mapping is presented in Figure H.1.

Table 14: Suitability of habitat types for SRE fauna within the survey area.

Landform/habitat	Total area (ha)	Total area (%)	Suitability for SRE fauna
Riverine	143 ha	2.9%	Moderate
Drainage Lines	589 ha	11.9%	Moderate
Gorge	17 ha	0.3%	High
Breakaway	84 ha	1.7%	High
Rocky Hills	66 ha	1.3%	Moderate
Low Hills and Slopes	1,897 ha	38.5%	Low-Moderate
Loamy/Stony Plains	1,762 ha	35.8%	Low
Disturbed	372 ha	7.6%	N/A
TOTAL	**4,930 ha**		

Riverine habitats of the Robe River valley in the survey area comprised linear isolated pockets of riparian vegetation and associated woodlands which are denser, taller and more diverse than the adjacent Drainage Line habitat. The vegetation was complex and provided a range of micro-niches for SRE fauna. Permanent pools of water were present during the survey and the area generally had more moisture than adjacent habitat types. This habitat was sampled as sites MTH01, SRE10, SRE11 and RVM13 and the potential SRE scorpion *Lychas* 'sp. nov. 1' (MHT01, RVM13) was collected. This species was identified using molecular methods and its actual range is currently not clear. Overall, the survey data confirmed the desktop assessment that this is moderately suitable habitat for SRE fauna.

Drainage Line habitats are open riverbeds of the Robe River that runs through the survey area from east to west. Although some portions of this habitat are well-vegetated, the majority of the Drainage Line habitat in the survey area is open, exposed riverbeds with little leaf litter. The Drainage Line habitat associated with the Low Hills and Slopes or Breakaway habitats have an elevated capacity to hold moisture and complex vegetation associations providing a more suitable environment for SRE species. Site SRE09 represented this habitat type. The collected *Indolpium* pseudoscorpions, are widespread species that have been collected during previous fauna surveys in the surrounding area (Astron Environmental Services 2016a, 2016b). This habitat is considered to have moderate suitability for SRE fauna but it appears that the species in SRE groups are locally widespread.

Gorge habitat is associated with the Rocky Hills or Breakaway habitats, where deeply carved rock incisions and minor drainage lines provide shade and diverse microhabitats. Minor creek lines and water run-offs lead to higher moisture availability compared to the surrounding areas. Most of the Gorge habitat in the survey area was open and exposed, therefore limiting the amount of moist microhabitats available for SRE species. This is a relatively rare habitat type in the survey area and was represented by sites SRE06, SRE07 and SRE12. The potential SRE slater *Buddelundia* '61' was collected in the Gorge habitat but is also known from the Bungaroo area (Astron Environmental Services 2016a). No other potential SREs were collected in this habitat type. The Gorge habitat is generally considered as having high suitability for SRE habitat but was surprisingly poor in the survey area for unknown reasons. Site-specific characteristics such as sun exposition and hydrogeology may account for this.

Breakaway habitat contains exposed rock faces with accumulations of rock boulders and scree. It differs from the geologically similar Low Hills and Slopes habitat in that the rock strata are not compacted and without a weathered zone near the surface. It provides shelter for SRE fauna and diverse microhabitats for both habitat specialists and moisture-dependent SRE fauna. This habitat type was sampled as sites SRE08, RVM12, RVM16 and OPP37. The collected fauna comprised both widespread (*Buddelundia* '14hr') and potential SRE (*Buddelundia* '61') species. Similar results were acquired for the arachnid fauna, with two of the collected species (*Indolpium* sp. indet. and *Beierolpium* 8/4) widespread and the third (spider *Karaops* sp. indet.) representing a potential SRE. All sampled SRE groups are typical representatives of Breakaway habitats and specialist species that live under rocks and gravel. The distribution of the species present will mirror the degree of connectivity for these habitats.

Rocky Hills habitat denotes the high-elevation rock features isolated to the south-west of the survey area. This habitat type is deeply incised by creek lines and valleys. No SRE sampling was undertaken within this habitat type. Based on its rocky microhabitats it is expected to provide habitat for specialist species that live under rocks and gravel, similar to those found in the Breakaway habitats. This habitat type represents a small portion of the survey area and is the dominant habitat/landform to the south of the survey area.

Low Hills and Slopes habitat is widespread in the survey area and was sampled by sites SRE01, SRE04, SRE05, RVM14 and RVM15. Both sites RVM14 and RVM15 were generally well-vegetated with *Triodia* and some emergent *Eucalyptus leucopholia* over a stony surface. The collected invertebrates comprised widespread species (scorpions *Lychas* 'pilbara1' and *Lychas* 'harveyi' and spider *Aname mellosa*) and no potential SRE species were collected. Although there is some potential for SRE fauna to be present in this habitat, most species are clearly widespread in the western Pilbara and have also been recorded in previous fauna surveys from other habitat types (Astron Environmental Services 2016a, 2016b). Overall, this confirms the general assessment that this habitat has low to moderate suitability for SRE fauna.

Loamy/Stony Plains habitat is the most widespread habitat type in the survey area and was sampled by sites MHT02, MHT03, SRE02 and SRE03. Although soil types differ, this habitat type is generally exposed and has low microhabitat diversity compared to other landforms. It is therefore surprising that a moderately diverse SRE community was recorded in this habitat, including the potential SRE scorpion *Lychas* 'sp. nov. 2' and the more widespread *Lychas* 'multipunctatus'. However, both species were identified from genetic data and range estimates are conservative because no comparative genetic data is available for morphologically similar specimens from other areas in the Pilbara. Both species may actually have been sampled during previous surveys in this region (Astron Environmental Services 2016a, 2016b) but more sequencing work would be required to test this. Certainly, it appears that there is a high degree of connectivity in this habitat type over wide areas.

Overall, none of the habitat types sampled in the survey area were inferred as having a very high prospect for SRE fauna. The Loamy/Stony Plains habitat had a higher suitability than suggested by the desktop review, which may reflect site-specific characteristics or survey design. Other habitat types that are usually considered highly prospective (Gorge habitat) did not have a very diverse SRE fauna. No individual sites were overly rich and there were no local 'hotspots' of SRE biodiversity. The two habitat types that are highly localised and have the potential to restrict dispersal in SRE fauna (Gorge and Breakaway habitats) were not overly rich in SRE fauna.

4.2.3.2 Invertebrate Species

A total of 36 specimens belonging to at least 14 invertebrate morphospecies were collected from the survey area. Scorpions were the most diverse group with seven species and 12 specimens, followed by slaters (three species; 16 specimens), pseudoscorpions (two species; four specimens) and spiders (two species; four specimens). No centipedes, harvestmen, millipedes and snail specimens (aquatic or terrestrial) were collected. No listed invertebrate species were collected during the survey.

Based on these results, eight species (64%) were not considered to be, or unlikely to be, SREs. No confirmed SRE species were collected; however, five species (36%) were classified as potential SRE species, principally in the scorpion (two species), spider (two species) and slater (one species) faunas (Table 15 and Figure I.2, Table I.2, Appendix I). These species are:

- slaters – *Buddelundia* '61'
- scorpions – *Lychas* 'sp. nov. 1' and *Lychas* 'sp. nov. 2'
- spiders – *Karaops feedtime* and *Karaops* sp. indet.

Of these potential species, the slater *Buddelundia* '61' was collected from multiple habitats that extend far beyond the survey area. The scorpions *Lychas* 'sp. nov. 1' and *Lychas* 'sp. nov. 2' were identified using DNA sequence data and are treated here as potential SREs primarily because there were no matching sequences in the databases of the WAM and the distribution ranges cannot be inferred at present. It is likely that both species are more widespread and future genetic work is

likely to show a wider distribution. Morphologically similar specimens have been collected from other areas of the western Pilbara but genetic work still has to be undertaken on these samples. The two spider-species were collected from juveniles and also identified using DNA sequence data. *Karaops feedtime* is a potential SRE but has been collected from a disturbed site and is certainly more widespread, as has been suggested by the genetic data. *Karaops* sp. indet. is also a potential SRE and has been collected from the Breakaway habitat. However, genetically similar specimens have been collected from localities outside the Mesa H survey area and the species is clearly more widespread. *Karaops* specimens have also been collected previously during fauna surveys at Bungaroo and Middle Robe/East Deepdale (Astron Environmental Services 2016a, 2016b) and they may belong to this species.

Overall, only a relatively small number of potential SRE species were collected in the survey area. The status of the potential SREs is also often unclear and the data available is not sufficient to establish SRE status with certainty (WAM sub-categories 'Data Deficient' or 'Molecular Evidence' for SRE species). Four of the potential SREs were collected from Loamy/Stony Plains, Low Hills and Slopes or Riverine habitats that are widespread habitat types extending far beyond the survey area, with no obvious barriers for the dispersal of fauna within these habitats. Only one spider species (*Karaops* sp. indet.) occurs in a habitat type that may be more restricted but additional specimens of this species are known from outside the survey area. It should also be noted that no species of *Karaops* have ever been shown to have ranges smaller than the survey area.

Many species known from the desktop assessment to potentially occur within the survey area were not collected. For example, no mygalomorph spider species of the genera *Missulena* (Actinopodidae) and *Synothele* (Barychelidae) were collected, although they occur in similar habitats nearby (Biota Environmental Sciences 2007, 2010, 2011), indicating they are likely to be absent from the survey area. Most species identified in the desktop assessment occur in the wider search area and outside the survey area. They may be absent locally, were not collected, or have ranges that do not coincide with the survey area.

Disturbance factors, such as the presence of weeds, were unlikely to have affected the survey results. The potential impact of these factors is discussed in more detail in Section 3.5. Importantly, sampling for SRE invertebrates is principally opportunistic because most SREs have patchy distributions and can be very difficult to sample, especially when habitat preferences of particular species are unknown, they occur at low abundance, or sampling is outside their narrow activity period.

Table 15: Summary of the potential SRE species within the survey area.

Species / SRE category	WAM SRE category	No. of specimens	Site(s)	Landform	Linear range	Status	Habitat surrogates
Slaters							
Buddelundia '61'	Potential SRE – Research and Expertise	5	OPP37 SRE12	Breakaway Gorge	6.0 km	Also known from Bungaroo	Available
Scorpiones							
Lychas 'sp. nov. 1'	Potential SRE – Molecular Evidence	2	MHT01 RVM13	Loamy/Stony Plains	7.0 km	Probably more widespread	Available
Lychas 'sp. nov. 2'	Potential SRE – Molecular Evidence	3	MHT02 MHT03	Loamy/Stony Plains	Unknown	Sequenced for the first time. Possibly conspecific with the more widespread *Lychas* 'gracilimanus'	Available
Spiders							
Karaops feedtime	Potential SRE – Data Deficient	1	OPP38	Disturbed Areas	Unknown	Unresolved taxonomy, additional records from outside the survey area	Available
Karaops sp. indet.	Potential SRE – Molecular Evidence	1	SRE08	Breakaway	5.7 km	Unresolved taxonomy, additional records from outside the survey area	Available

A summary of the SRE groups recorded and the six potential SRE species identified is provided below.

4.2.3.3 Slaters

Three slater species (and 16 specimens) were collected in this survey. They all belong to *Buddelundia*, a genus that is highly diverse and comprises more than 100 species of which almost all are currently undescribed. All species collected in this survey are widespread.

***Buddelundia* '10bf'**

Thirteen specimens of this morphospecies were collected from site MHT02 in the Loamy/Stony Plains habitat. This species is widespread in the northern Pilbara (Simon Judd, pers. comm. 2016) and was collected from a habitat type that extends well beyond the survey area. This species is not of conservation significance.

***Buddelundia* '14hr'**

This species was collected from the Breakaway habitat at site SRE08 and Riverine habitat at site MHT01. This morphospecies is widespread in the northern Hamersley Range and is commonly collected during fauna surveys (Simon Judd, pers. comm. 2016). This species is not of conservation significance.

***Buddelundia* '61'**

This species was collected from sites SRE12 and OPP37 in the Breakaway habitat and Gorge Habitat. It was collected by Astron during a previous fauna survey at Bungaroo (Astron Environmental Services 2016a) adjacent to the survey area and is a **potential SRE** in the WAM category 'Research and Expertise'. As in the Bungaroo fauna survey, it has been collected from multiple habitat types and seems to be a habitat generalist. The areas located north and west of the Mesa H survey area have not yet been surveyed for slaters and it is possible that the species also occurs in the wider area surrounding Mesa H (Simon Judd, pers. comm. 2016). The notion that the species was collected in habitat types extending beyond the survey area makes a wider distribution likely.

4.2.3.4 Pseudoscorpions

Four specimens of pseudoscorpions were collected in the current survey. They all belong to the arid-adapted family Olpiidae that is diverse in north-western Australia.

***Beierolpium* sp. 8/4**

A single male of this morphotype was collected from Breakaway habitat at site SRE08. There is no taxonomic framework for species in this group of *Beierolpium* but these pseudoscorpions are commonly collected in fauna surveys, often very abundant, and currently considered widespread fauna.

***Indolpium* sp. indet.**

Three specimens of *Indolpium* were collected from Drainage Line habitat (site SRE09) and Breakaway habitat (site SRE08). *Indolpium* is the most commonly collected pseudoscorpion genus in the Pilbara and are currently understood to comprise widespread species. This species of pseudoscorpion is not considered SRE fauna.

4.2.3.5 Scorpions

Six scorpion species were collected in the current survey. Five species belong to the genus *Lychas* and one species belongs to the genus *Urodacus*. Two species of *Lychas* are potential SRE species in the WAM category 'Molecular Evidence' (Dolman 2016) whereas the remaining four species are widespread.

***Lychas* 'sp. nov. 1'**

Two specimens of this species were collected from sites MHT01 and RVM13 and tentatively assigned to *Lychas* 'multipunctatus' by Erich Volschenk based on morphology. Both specimens were sequenced by WAM staff and do in fact represent a currently undescribed species that differs from *Lychas* 'multipunctatus' and other commonly collected species of *Lychas* in the Pilbara, such as *Lychas* 'hairy-tail'. It is currently not possible to estimate the distribution range of *Lychas* 'sp. nov. 1' and the species is classified a **potential SRE** in the sub-category 'Molecular Evidence'. The specimens

were collected from Riverine habitat that extends beyond the survey area. This may indicate a wider distribution of the species and future field work may establish a wider distribution.

***Lychas* 'sp. nov. 2'**

Three specimens of this species were collected from the Loamy/Stony Plains habitat at sites MHT02 and MHT03 (Plate 1c). One specimen (WAM T141172) was sequenced but there are no genetic matches in the databases of the WAM. As such, it is not possible to estimate the distribution range of this species based on molecular data. Using a precautionary approach, the species is classified as a **potential SRE** in the sub-category 'Molecular Evidence'. Based on morphology, the specimens could possibly be conspecific with *Lychas* 'gracilimanus' which is an informally described species by Erich Volschenk but no DNA sequences are available in the WAM database for this species. *Lychas* 'gracilimanus' is also considered a potential SRE by Erich Volschenk but has been previously collected during fauna surveys in the Pilbara, including a location north-east of Mile Camp and Bonney Downs Homestead (290 km east of the survey area) (Phoenix Environmental Sciences 2014a).

***Lychas* 'harveyi'**

This is a widespread and commonly collected species with a distribution that encompasses most of arid Western Australia. A single specimen was collected from the Low Hills and Slopes habitat at site RVM15. This species is not of conservation concern.

***Lychas* 'multipunctatus'-group**

Lychas 'multipunctatus' was long considered a widespread morphological species but recent molecular work at the WAM has shown that it comprises several genetically distinct lineages that may represent separate species (Plate 1d). Two specimens of *Lychas* 'multipunctatus' were sequenced by WAM for this project (T141176 and TT141177) and they indeed belong to *Lychas* 'multipunctatus' as recognised by Erich Volschenk, with genetic divergences from other sequenced specimens < 3.6% (Dolman 2016). *Lychas* 'multipuncatus' is an undescribed species and there is some uncertainty about its distribution range because the taxonomy has yet to be formalised. However, a corroborated approach of both morphology and molecular data suggests that the distribution of this species may be wider than 10,000 km^2. The two specimens collected here are from the Loamy/Stony Plains habitat (site MHT02); a habitat type that extends beyond the survey area. Morphologically similar specimens have also been collected during the Middle Robe/East Deepdale survey (Astron Environmental Services 2016b), supporting the idea of a widespread distribution.

***Lychas* 'pilbara 1'**

This undescribed species is widespread in the Pilbara bioregion and not of conservation significance (Erich Volschenk, pers. comm. 2016). Two specimens were collected from the Low Hills and Slopes habitat at site RVM15.

Urodacus megamastigus

Two specimens of this rather large species were collected from Loamy/Stony Plains habitat at site MHT02. This species is widespread in arid Western Australia (Atlas of Living Australia 2015) and not of conservation significance.

4.2.3.6 Spiders

Three spider species belonging to SRE groups were collected in the current survey: the mygalomorph spider *Aname mellosa*, and the selenopid spider species *Karaops feedtime* (Crews 2013) *and Karaops* sp. indet.

Aname mellosa

Two specimens of wishbone spiders (genus *Aname*) were collected from sites MHT02 and RVM14 in the Loamy Stony Plains and Low Hills and Slopes habitats respectively. These specimens were juvenile and DNA sequencing was undertaken by WAM staff to clarify their status. One of these specimens was identified as *Aname mellosa* whereas the DNA amplification for the second specimen failed. However, given that both specimens share an almost identical morphology we also consider this to belong to *Aname mellosa*. A recent review of the genus *Aname* in the Pilbara (Harvey et al. 2012) suggests that *Aname mellosa* is a widespread species despite high genetic divergences between populations that may indicate some degree of population isolation (Dolman 2016). This species is not of conservation concern and widespread in the Pilbara. It is possible that the specimens collected by Biota Environmental Sciences (Biota Environmental Sciences 2011) during the Rove Valley Mesas fauna survey in this area also belong to *Aname mellosa* but additional genetic analyses would be required to test this.

***Karaops feedtime* and *Karaopos* sp. indet.**

Two juvenile specimens of selenopid spiders (genus *Karaops*) were collected from Breakaway habitat and a drainage culvert (Plate 1a). DNA analyses indicate these specimens belong to two distinct species. Specimen T141164 from site Opp38 most likely belongs to the more widespread *Karaops feedtime* (Crews 2013) but the genetic data are somewhat inconclusive and the specimen may also represent a new species that is genetically and morphologically similar to *Karaops feedtime* (Dolman 2016). Considering this uncertainty, this sample is conservatively classified as a **potential SRE** species in the WAM sub-category 'Data Deficient' but referred to as *Karaops feedtime* throughout this report to avoid confusion. We note that this specimen was collected from a disturbed site and may be more generalist in habitat choice. The second sequenced specimen T141165 from Site SRE8 belongs to currently undescribed species of *Karaops* with an unknown distribution (Dolman 2016). All other sequenced specimens of this species are from an area < 10,000 km^2 from Mesa H and *Karaop*s sp. indet. is therefore classified as a **potential SRE** in the 'Data Deficient' sub-category. This species was collected from Breakaway habitat, which is the preferred habitat of selenopid spiders.

Plate 1: Examples of species in SRE groups collected within the survey area. A, *Karaops feedtime* (T141164); B, *Kwonkan* sp. (T141166); C, *Lychas* 'sp. nov 2' (T141172); D, *Lychas* 'multipunctatus' (T141176); E, *Lychas* 'sp. nov. 1' (T141171); F, *Lychas* 'pilbara1'. Scale Bars = 2mm.

5 Discussion

5.1 Vertebrate Fauna

5.1.1 Habitats

Habitats within the survey area are not restricted at the local, sub-regional or regional scale and no restricted or uncommon geological units or land systems occur within the survey area. The Gorge and Breakaway habitats in the survey area are considered significant for fauna. Deeply incised gorges, characteristic of the Hamersley subregion, generally have high levels of species endemism and diversity, and are considered important as refugia in a local context (Kendrick 2001). This is due to the microhabitats they provide such as caves and semi-permanent water pools, which were recorded during the current survey. Gorge and Breakaway habitats are considered suitable for several MNES species including the Pilbara Olive Python, Northern Quoll, Ghost Bat and Pilbara Leaf-nosed Bat (for foraging) that were all recorded during this survey. Two caves classified as diurnal roosts for Ghost Bats were recorded in the survey area, one of which was considered a possible maternal roost and the other considered possible occasional use as a maternal roost although no current evidence of use was observed (Bat Call WA 2017). In a regional context, the Gorge and Breakaway habitats in the Pilbara are restricted to the Chichester and Hamersley Ranges but they are well represented in these areas.

The Riverine habitat in the survey area is considered significant for fauna. The deep pools and shallow spring fed pools provide an important permanent water source for drinking and a refuge for amphibians and waterfowl that occur in a wide area up and downstream of the survey area. This habitat contains microhabitats not common in other habitat types such as large tree hollows, hollow logs and moist leaf litter which provide a productive ecosystem attracting and supporting a range of predators and prey. This habitat supports conservation listed fauna species such as the Rainbow Bee-eater and Pilbara Olive Python and acts as foraging sites for Northern Quolls, Ghost Bats and Pilbara Leaf-nosed Bats. The survey area contains some of the most significant pools in the area (such as Yerra Bluff) that are significant ecological features to the local fauna both up and downstream. The springs and pools of the Robe River that occur in the survey area are considered wetlands of sub-regional significance (Kendrick 2001).

The gullies and valleys of the Rocky Hills habitat type also contain caves and rock crevices and are likely to be utilised by a range of species, including those of conservation significance. This habitat type has a distinct herpetofauna assemblage due to the presence of a number of rocky habitat specialists, including *Varanus pilbarensis, Egernia cygnitos, Ctenotus rubicundus* and *Anilios ganei*. The Rocky Hills habitat is widespread and common throughout the Pilbara bioregion and is not restricted to the Chichester and Hamersley Ranges.

The Drainage Line habitats within the survey area are mainly the broad valley of the Robe River or minor ephemeral drainage lines that are not likely to provide significant refugia for species. Drainage Line habitats, although not necessarily large in terms of area, are common habitats within the Pilbara region and immediate surrounds, e.g. the Robe River.

The Low Hills and Slopes and Loamy/Stony Plains in the survey area provide fewer microhabitat opportunities for terrestrial fauna and are also more widespread in the immediate vicinity as well as the Hamersley subregion and wider Pilbara bioregion.

5.1.2 Species

5.1.2.1 General Assemblage

There were 169 vertebrate fauna species, comprising two amphibians, 55 reptiles, 85 birds and 27 mammals (including four introduced species) recorded within the survey area during the current surveys. This compares to 151, 204, 181, 148 and 147 species recorded from the wider Pannawonica area (Astron Environmental Services 2016a, 2016b; Biota Environmental Sciences 2006, 2007, 2010), respectively. The fauna species assemblage recorded during the current survey is considered typical of the Hamersley Range subregion extending from near Pannawonica to Mt Brockman as well as a subset of typical fauna assemblages across the Pilbara bioregion.

The number of reptile and amphibian species recorded (57 species) is consistent with that recorded during other dual phase surveys in the vicinity (47 to 64 species in comparable surveys) (Astron Environmental Services 2016a, 2016b; Biota Environmental Sciences 2006, 2007, 2010). Again the number of bird species recorded during the survey (85 species) is consistent with other dual season surveys conducted in the area (70 to 107 species) (Astron Environmental Services 2016a, 2016b; Biota Environmental Sciences 2007, 2010). However, this number is slightly lower than expected given the large water pools recorded within the survey area. Many species of waterfowl recorded elsewhere were not recorded during the current survey (phase 1 and 2). This may be because the survey area received poor rainfall preceding the phase 2 survey and the amount of surface water during the post wet season survey was relatively lower than normal. The current surveys (phase 1 and 2) recorded a comparatively high number of mammal species (27 species) compared to other dual season surveys in the vicinity (16 to 31 species). This was mainly due to the high number of bat species recorded; nine species were recorded in the current survey using acoustic recordings, whereas only two bat species were previously recorded by Biota Environmental Sciences (2007) using harp nets.

5.1.2.2 Conservation Significant Species

Of the 33 conservation significant species identified in the literature review, eight species have been previously recorded or were recorded during the current survey. An additional species *Anilios ganei* was considered to have a 'high' likelihood of occurrence, 11 species to have a 'moderate' likelihood and 13 species to have a 'low' likelihood.

Target MNES Species

The Gorge and Breakaway habitats within the survey area were considered suitable for the target MNES species: Pilbara Olive Python, Ghost Bat, Pilbara Leaf-nosed Bat and Northern Quoll. The current survey included a targeted search for these species. The majority of the survey area was mapped as low habitat suitability for the target MNES species; Northern Quoll, Ghost Bat, Pilbara Leaf-nosed Bat and Pilbara Olive Python (94%, 82%, 83% and 82% of the survey area classified as low habitat suitability, respectively). Low potential habitat for all four species generally comprised areas of disturbed habitat, Loamy/Stony Plain and Low Hills and Slopes habitats. These habitats contained no significant refugia or shelter, or semi-permanent or permanent water.

A single juvenile Pilbara Olive Python was recorded within the Riverine habitat and two scats were recorded within the Breakaway habitat type during the survey. This species is likely to be found within the Gorge, Breakaway and Riverine habitats particularly in the locations that contain semi-permanent and permanent water, which has been defined as their preferred habitat (Pearson 1993). The Rocky Hills and Drainage Line habitats (particularly those that contain permanent or semi-permanent pools) are considered suitable foraging and dispersal habitat for the Pilbara Olive Python.

All other habitats were considered to provide limited foraging and dispersal habitat for the Pilbara Olive Python.

The Northern Quoll was one of the more commonly recorded mammals within the survey area and was recorded 32 separate times during the survey. The majority of these records occurred in Breakaway habitats, but some records occurred within Riverine and Gorge habitat types. The Gorge and Breakaway habitats are considered potential shelter and foraging habitat for the Northern Quoll. The Riverine and Rocky Hills are also considered suitable foraging and dispersal habitats for the Northern Quoll.

In the Pilbara, Northern Quolls are generally associated with rocky habitats, although records of this species in the Riverine habitats and the presence of permanent water close to rocky habitats, suggest that it is an important foraging site for this species. All other habitats were considered to provide limited foraging and dispersal habitat for the Northern Quoll. Based on the high number of camera triggers and captures (Department of the Environment and Energy 2016) the survey area (specifically the Gorge and Breakaway habitats) supports a permanent, high density population of Northern Quolls.

The Ghost Bat was recorded twice during the current survey through scat collections and acoustic recordings from SM2 bat detectors. This includes acoustic recordings on four separate occasions and from scat piles (Figure I.1 and Table I.1, Appendix I). Seven caves have been previously identified in the 2014 survey of Mesa H (Astron Environmental Services 2014); two of which were deemed to be diurnal roosts (possible maternal roosts) (Bat Call WA 2017). Another three of the caves (two caves part of one system) were determined to be nocturnal feeding roosts and the other two caves were considered to not be used (Bat Call WA 2017). An additional seven sites identified during a targeted cave assessment were deemed to be nocturnal feeding roosts (Bat Call WA 2017).. The Gorge and Breakaway habitat was categorised as providing foraging and shelter habitat due to the presence of diurnal roost caves and nocturnal feeding roost caves.

The Pilbara Leaf-nosed Bat was recorded at eight of the 14 SM2 bat detector locations that were all deemed to be at low activity levels, apart from BAT 14 which recorded 257 calls (which is classified as having high call activity levels) (Bat Call WA 2016). Further data and analysis of the BAT 14 site suggests that the Pilbara Leaf-nosed Bats likely originated from a known roost site approximately 10 km south of the survey area (Bat Call WA 2016).

Pilbara Leaf-nosed Bat calls were recorded infrequently from a variety of habitats throughout the survey area, including Low Hills and Slopes, Gorge and Riverine habitats. The timing of calls from acoustic recordings suggests that the Pilbara Leaf-nosed Bats within the survey area originate from a known roost outside the survey (Bat Call WA 2016). The occurrence of Pilbara Leaf-nosed Bats within the survey area is likely to be influenced by the presence of water pools (typically persisting within deeply incised, shaded gorges) and major drainage lines with dense vegetation (Specialised Zoological 2010). The Pilbara Leaf-nosed Bat requires deep, humid, climatically stable caves for diurnal and maternal roost sites. The caves located in the Gorge habitat of the survey area do not fit these criteria however they can be classified as nocturnal refuge caves (Department of the Environment 2017) that are occupied or entered at night for resting or feeding.

Other Conservation Significant Species

Other conservation significant species recorded from within the survey area include the Western Pebble-mound Mouse, Eastern Great Egret, Rainbow Bee-eater and Lined Soil-crevice Skink.

Five inactive mounds from the Western Pebble-mound Mouse (P4) were recorded all within the Low Hills and Slopes habitat type during the fauna survey (Figure I.1 and Table I.1, Appendix I). Generally this species prefer gentle rocky slopes, hills and spurs. As such, the Low Hills and Slopes and Rocky Hills habitats of the survey area are likely to support this species. These habitats that are suitable for the Western Pebble-mound Mouse are also widespread and common adjacent to the survey area.

The Rainbow Bee-eater was recorded on numerous occasions throughout the survey area during both phases of the fauna survey in almost all habitats including Riverine, Drainage Line, Loamy/Stony Plains, Low Hills and Slopes, Gorge and Breakaway habitats. This species is highly mobile and generally less reliant on specific habitats.

This species has been recorded within the survey area in the Riverine habitat and in the vicinity of the survey area and is likely to be present at permanent pools within the Riverine and Drainage Line habitats of the survey area.

The Lined Soil-crevice Skink was captured on five occasions during the survey at three trapping grids (MHT03, RVM14 and RVM15); both within the Loamy/Stony Plains and the Low Hills and Slopes habitat types (Figure I.1 and Table I.1, Appendix I). Suitable habitats also exist adjacent to the survey area and are common within the wider region.

5.2 SRE Invertebrates

5.2.1 Habitats

Prospective SRE habitats within the survey area are not restricted at the local, sub-regional or regional scale. Gorge habitats are islands of high moisture retention and usually refugia for moisture-dependent SRE fauna, with some potential for dispersal-restriction in species present. Breakaway habitats are also expected to be rich in microrefugia and offer potential for specialist SRE fauna. Together, these habitats comprise only 2% of the survey area. Neither Breakaway nor Gorge habitats were found to support rich SRE communities with only two potential SREs collected in these habitats. Riverine habitat was also not overly rich in SRE fauna with only one potential SRE species recorded.

Although there is a variety of a potential SRE habitat types, the diversity of SRE fauna is comparatively low. The survey area has as many habitat types as Bungaroo (Astron Environmental Services 2016a) and Middle Robe/East Deepdale (Astron Environmental Services 2016b) but it appears to support less diverse SRE communities and fewer potential SRE species.

Overall, the habitat assessment indicates that potential SRE species in the survey area should be widespread due to the wider occurrence of similar habitats within the Hamersley subregion and Pilbara bioregion. The Bungaroo and Middle Robe/East Deepdale surveys (Astron Environmental Services 2016a, 2016b) contained similar habitats to the survey area and many species in SRE groups, including some potential SRE species, have ranges that encompass all these different survey areas. There are no habitat types unique to the survey area and the habitat types and landforms are common in the vicinity of the Mesa H survey area.

5.2.2 Species

A total of 36 specimens belonging to at least 14 invertebrate morphospecies were collected from the survey area, with six potential SRE species identified. Scorpions were the most diverse group with seven species and 12 specimens, followed by slaters (three species; 16 specimens), spiders (three species; four specimens) and pseudoscorpions (two species; four specimens). This is comparable to the six potential SRE species collected at Middle Robe/East Deepdale and the eight species collected at Bungaroo in 2015. This number is much lower than the 19 potential SRE species collected during earlier fauna surveys at Bungaroo South (Phoenix Environmental Sciences 2014b) and the 10 potential SRE species collected in the wider Bungaroo area (Biota Environmental Sciences 2010). The deviation between the 2015/16 surveys and the earlier surveys may reflect differences in sampling design, survey timing and also an increased knowledge of species taxonomy and distributions of Pilbara invertebrate fauna. Certainly, the diversity of landforms in the survey area is lower than in some of the previously surveyed areas and may account for some of the differences.

None of the species recorded within the survey area are listed as Threatened or Priority species under State or Federal legislation. The two listed dragonfly species were not seen or collected and are unlikely to occur in the survey area. Based on the survey results, the majority of the species were not considered to be, or are unlikely to be, SREs. No confirmed SRE species were collected but five species were considered potential SRE species:

- slaters: *Buddelundia* '61'
- scorpions: *Lychas* 'sp. nov. 1' and *Lychas* 'sp. nov. 2'
- spiders: *Karaops feedtime* and *Karaops* sp. indet.

The potential SRE slater *Buddelundia* '61' was collected from multiple habitat types that extend far beyond the survey area. This species has been collected during previous fauna surveys in the surrounding area (Astron Environmental Services 2016a) and clearly has a range that is much wider than the survey area.

The scorpions *Lychas* 'sp. nov. 1' and *Lychas* 'sp. nov. 2' were identified using DNA sequence data and are treated here as potential SREs primarily because there were no matching sequences in the databases of the WAM. As such, the distribution ranges cannot be inferred from the data available. It is likely that both species are more widespread and future genetic work is likely to show a wider distribution, following the more widespread nature of the habitat types in which the species were collected. Morphologically similar specimens have been collected from other areas of the western Pilbara (Astron Environmental Services 2016a, 2016b) but genetic work still needs to be undertaken on these samples.

The two spider-species were collected from juveniles and identified using DNA sequence data. *Karaops feedtime* is classified as a potential SRE. As this species was collected from a disturbed site it is certainly more widespread, as has been suggested by the genetic data. *Karaops* sp. indet. is also classified as a potential SRE and was collected from the Breakaway habitat. However, genetically similar specimens have been collected from localities outside the Mesa H survey area and the species is clearly more widespread. Specimens of *Karaops* have also been collected previously during fauna surveys at Bungaroo and Middle Robe/East Deepdale (Astron Environmental Services 2016a, 2016b) that may also belong to these species.

Overall, the survey data indicated that species richness for SREs was lower in the survey area than in other areas of the western Pilbara. All but one potential SRE species were collected from habitat types that extend far beyond the survey area. Three of the five potential SREs have also been

collected during previous fauna surveys (Astron Environmental Services 2016a, 2016b) and have established ranges that are much wider than the survey area. The habitat types that are usually considered prospective for SRE fauna (Gorges and Breakaways) did not support rich SRE communities and no habitat type was unique to the survey area.

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Appendix A: Background Information Figures

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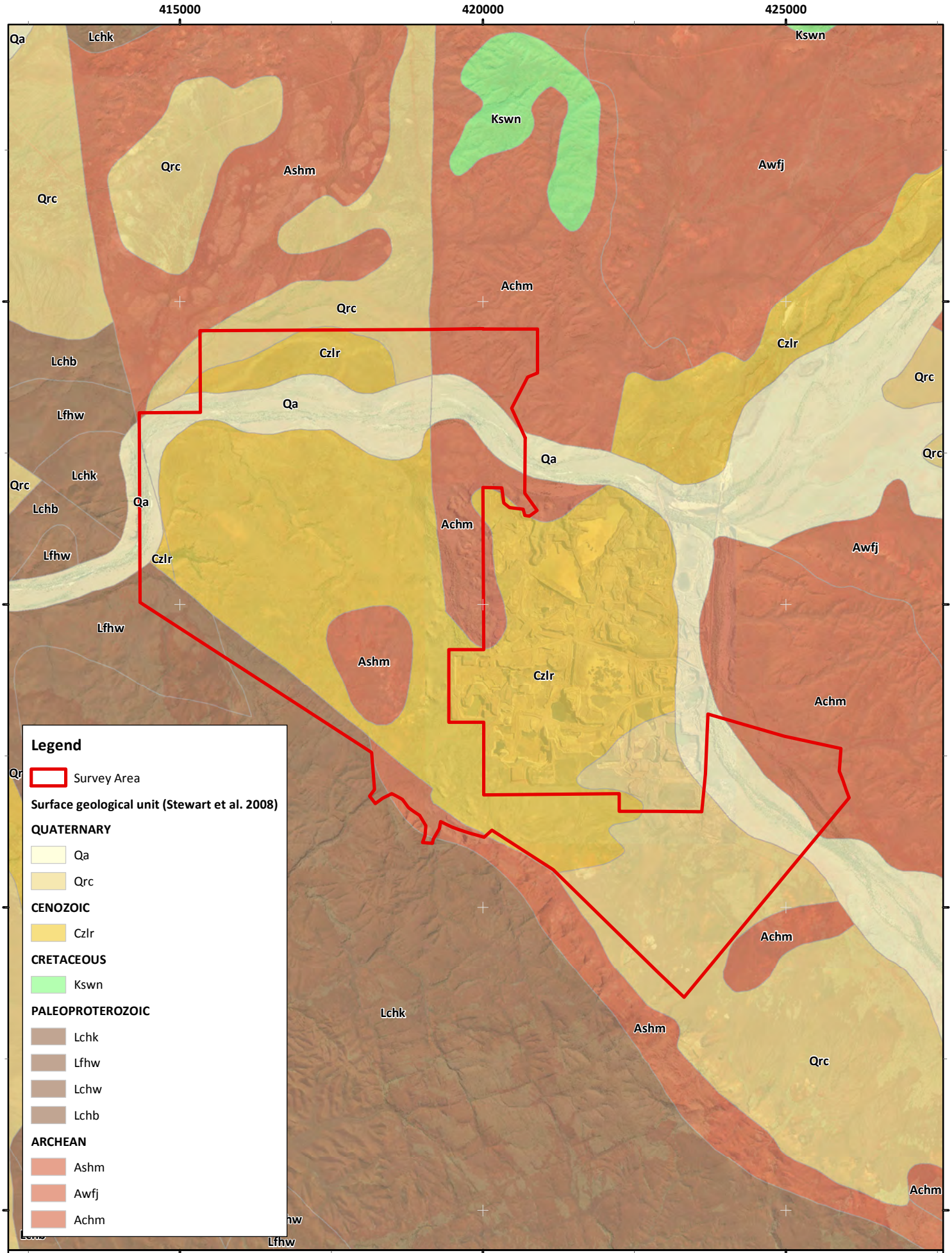

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Mesa H – Level 2 Fauna Assessment, May 2016

Figure A.1: Geological units of the Mesa H survey area

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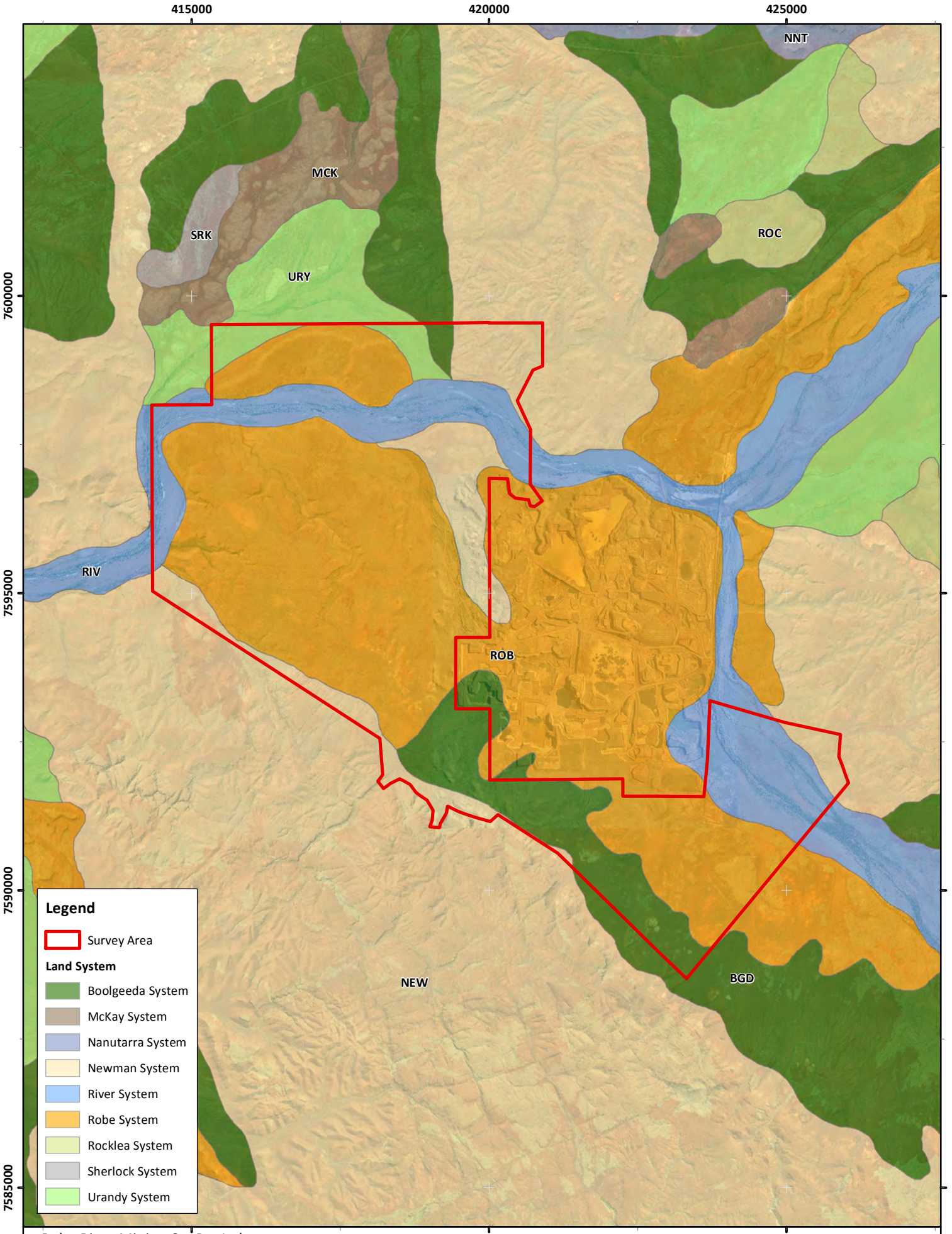
Author: J. Trainer	Date: 15-08-2017
Drawn: C. Dyde	Figure Ref: 14269-16-BIDR-3Rev1_170815_FigA1_Geo

Datum: GDA 1994 - Projection: MGA Zone 50

0 1 2 3 Km

N



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Mesa H – Level 2 Fauna Assessment, May 2016

Figure A.2: Land systems of the Mesa H survey area

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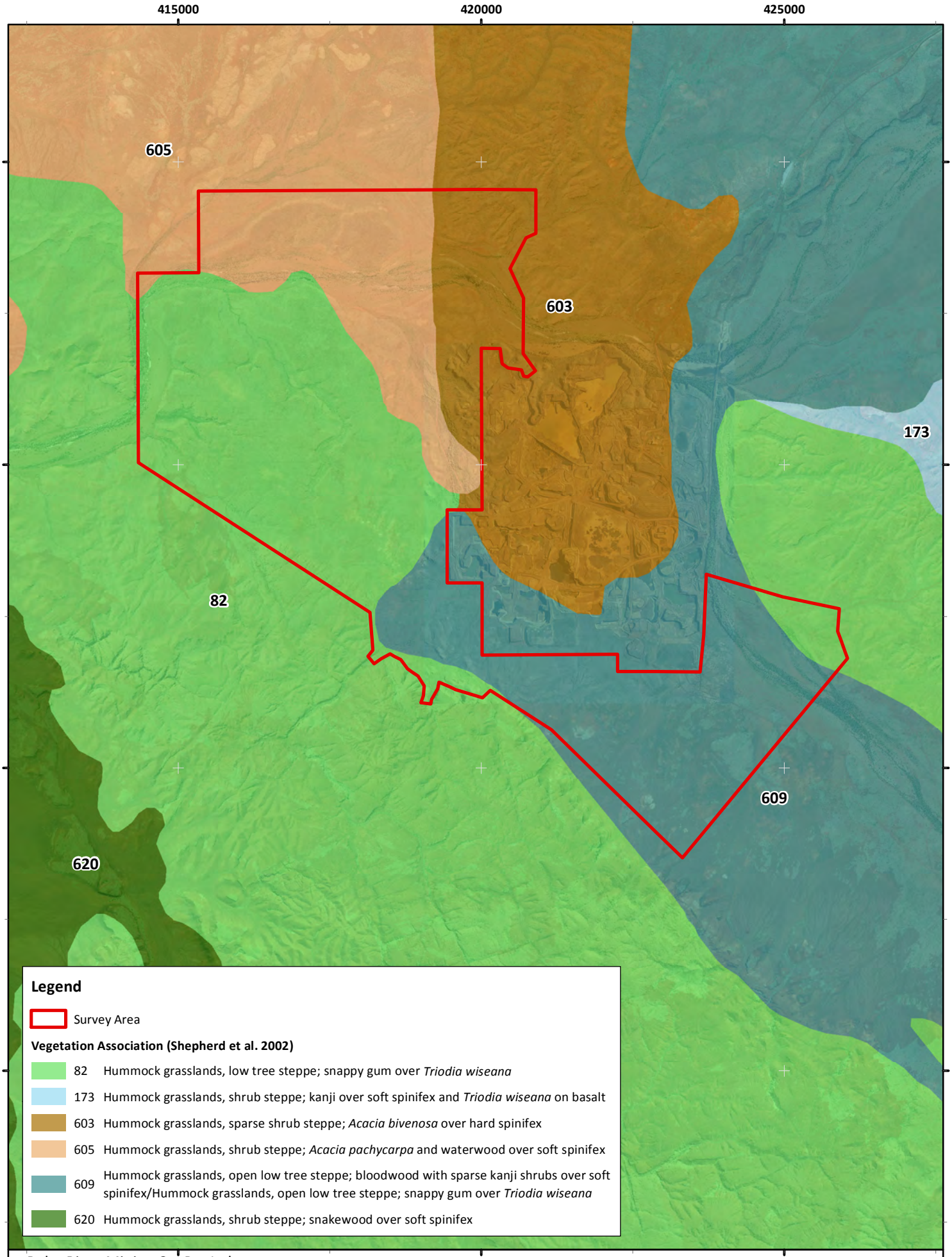
Author: J. Trainer	Date: 15-08-2017
Drawn: C. Dyde	Figure Ref: 14269-16-BIDR-3Rev1_170815_FigA2_LandSys

Datum: GDA 1994 - Projection: MGA Zone 50

0 1 2 3 Km

N



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Mesa H – Level 2 Fauna Assessment, May 2016

Figure A.3: Pre-European vegetation of the Mesa H survey area

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Author: J. Trainer	Date: 15-08-2017	Datum: GDA 1994 - Projection: MGA Zone 50
Drawn: C. Dyde	Figure Ref: 14269-16-BIDR-3Rev1_170815_FigA3_PreEuroVeg	0 1 2 3 Km; N

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Appendix B: Conservation Fauna Categories, Habitat Condition Scales and Likelihood Criteria

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Table B.1: Categories of Threatened Ecological Communities (Department of Environment and Conservation 2013).

PD: Presumed Destroyed
An ecological community that has been adequately searched for but for which no representative occurrences have been located. The community has been found to be totally destroyed or so extensively modified throughout its range that no occurrence of it is likely to recover its species composition and/or structure in the foreseeable future. An ecological community will be listed as presumed totally destroyed if there are no recent records of the community being extant **and either** of the following applies (A or B): A) Records within the last 50 years have not been confirmed despite thorough searches of known or likely habitats **or** B) All occurrences recorded within the last 50 years have since been destroyed.
CR : Critically Endangered
An ecological community that has been adequately surveyed and found to have been subject to a major contraction in area and/or that was originally of limited distribution and is facing severe modification or destruction throughout its range in the immediate future, or is already severely degraded throughout its range but capable of being substantially restored or rehabilitated. An ecological community will be listed as **Critically Endangered** when it has been adequately surveyed and is found to be facing an extremely high risk of total destruction in the immediate future. This will be determined on the basis of the best available information, by it meeting **any one or more of** the following criteria (A, B or C): A) The estimated geographic range, and/or total area occupied, and/or number of discrete occurrences since European settlement have been reduced by at least 90% **and either or both** of the following apply (i or ii): i) geographic range, and/or total area occupied and/or number of discrete occurrences are continuing to decline such that total destruction of the community is imminent (within approximately 10 years); ii) modification throughout its range is continuing such that in the immediate future (within approximately 10 years) the community is unlikely to be capable of being substantially rehabilitated. B) Current distribution is limited, **and one or more** of the following apply (i, ii or iii): i) geographic range and/or number of discrete occurrences, and/or area occupied is highly restricted and the community is currently subject to known threatening processes which are likely to result in total destruction throughout its range in the immediate future (within approximately 10 years); ii) there are very few occurrences, each of which is small and/or isolated and extremely vulnerable to known threatening processes; iii) there may be many occurrences but total area is very small and each occurrence is small and/or isolated and extremely vulnerable to known threatening processes. C) The ecological community exists only as highly modified occurrences that may be capable of being rehabilitated if such work begins in the immediate future (within approximately 10 years).

En: Endangered

An ecological community that has been adequately surveyed and found to have been subject to a major contraction in area and/or was originally of limited distribution and is in danger of significant modification throughout its range or severe modification or destruction over most of its range in the near future.

An ecological community will be listed as **Endangered** when it has been adequately surveyed and is not Critically Endangered but is facing a very high risk of total destruction in the near future. This will be determined on the basis of the best available information by it meeting **any one or more** of the following criteria (A, B, or C):

A) The geographic range, and/or total area occupied, and/or number of discrete occurrences have been reduced by at least 70% since European settlement **and either or both** of the following apply (i or ii):

i) the estimated geographic range, and/or total area occupied and/or number of discrete occurrences are continuing to decline such that total destruction of the community is likely in the short term future (within approximately 20 years);

ii) modification throughout its range is continuing such that in the short term future (within approximately 20 years) the community is unlikely to be capable of being substantially restored or rehabilitated.

B) Current distribution is limited, **and one or more** of the following apply (i, ii or iii):

i) geographic range and/or number of discrete occurrences, and/or area occupied is highly restricted and the community is currently subject to known threatening processes which are likely to result in total destruction throughout its range in the short term future (within approximately 20 years);

ii) there are few occurrences, each of which is small and/or isolated and all or most occurrences are very vulnerable to known threatening processes;

iii) there may be many occurrences but total area is small and all or most occurrences are small and/or isolated and very vulnerable to known threatening processes.

C) The ecological community exists only as very modified occurrences that may be capable of being substantially restored or rehabilitated if such work begins in the short-term future (within approximately 20 years).

VU: Vulnerable

An ecological community that has been adequately surveyed and is found to be declining and/or has declined in distribution and/or condition and whose ultimate security has not yet been assured and/or a community that is still widespread but is believed likely to move into a category of higher threat in the near future if threatening processes continue or begin operating throughout its range.

An ecological community will be listed as **Vulnerable** when it has been adequately surveyed and is not Critically Endangered or Endangered but is facing a high risk of total destruction or significant modification in the medium to long-term future. This will be determined on the basis of the best available information by it meeting **any one or more of** the following criteria (A, B or C):

A) The ecological community exists largely as modified occurrences that are likely to be capable of being substantially restored or rehabilitated.

B) The ecological community may already be modified and would be vulnerable to threatening processes, is restricted in area and/or range and/or is only found at a few locations.

C) The ecological community may be still widespread but is believed likely to move into a category of higher threat in the medium to long term future because of existing or impending threatening processes.

Reference: Department of Environment and Conservation 2013, Definitions, Categories and Criteria for Threatened and Priority Ecological Communities DEC (Parks and Wildlife), <https://www.dpaw.wa.gov.au/images/plants-animals/threatened-species/definitions_categories_and_criteria_for_threatened_and_priority_ecological_communities.pdf.>

Table B.2: Definitions and criteria for Threatened Ecological Communities (Department of Environment and Conservation 2013).

Three categories exist for listing Threatened Ecological Communities under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). An ecological community may be categorised as:

Categories of ecological communities	
Critically endangered	If, at that time, it is facing an extremely high risk of extinction in the wild in the immediate future.
Endangered	If, at that time, it is not critically endangered and is facing a very high risk of extinction in the wild in the near future.
Vulnerable	If, at that time, it is not critically endangered or endangered, and is facing a high risk of extinction in the wild in the medium-term future.

Reference: Department of Environment and Conservation 2013, Definitions, Categories and Criteria for Threatened and Priority Ecological Communities DEC (Parks and Wildlife), <https://www.dpaw.wa.gov.au/images/plants-animals/threatened-species/definitions_categories_and_criteria_for_threatened_and_priority_ecological_communities.pdf.>

Table B.3: Definitions and criteria for Priority Ecological Communities (Department of Environment and Conservation 2013).

Possible Threatened Ecological Communities that do not meet survey criteria or that are not adequately defined are added to the Priority Ecological Community Lists under Priorities 1, 2 and 3. Ecological communities that are adequately known, and are rare but not threatened or meet criteria for Near Threatened, or that have been recently removed from the threatened list, are placed in Priority 4. These ecological communities require regular monitoring. Conservation Dependent ecological communities are placed in Priority 5.

P1: Priority One – Poorly-known ecological communities
Ecological communities that are known from very few occurrences with a very restricted distribution (generally ≤5 occurrences or a total area of ≤ 100ha). Occurrences are believed to be under threat either due to limited extent, or being on lands under immediate threat (e.g. within agricultural or pastoral lands, urban areas, active mineral leases) or for which current threats exist. May include communities with occurrences on protected lands. Communities may be included if they are comparatively well-known from one or more localities but do not meet adequacy of survey requirements, and/or are not well defined, and appear to be under immediate threat from known threatening processes across their range.
P2: Priority Two – Poorly-known ecological communities
Communities that are known from few occurrences with a restricted distribution (generally ≤10 occurrences or a total area of ≤200ha). At least some occurrences are not believed to be under immediate threat of destruction or degradation. Communities may be included if they are comparatively well known from one or more localities but do not meet adequacy of survey requirements, and/or are not well defined, and appear to be under threat from known threatening processes.
P3: Priority Three – Poorly-known ecological communities
(i) Communities that are known from several to many occurrences, a significant number or area of which are not under threat of habitat destruction or degradation or: (ii) communities known from a few widespread occurrences, which are either large or with significant remaining areas of habitat in which other occurrences may occur, much of it not under imminent threat, or; (iii) communities made up of large, and/or widespread occurrences, that may or may not be represented in the reserve system, but are under threat of modification across much of their range from processes such as grazing by domestic and/or feral stock, and inappropriate fire regimes. Communities may be included if they are comparatively well known from several localities but do not meet adequacy of survey requirements and/or are not well defined, and known threatening processes exist that could affect them.
P4: Priority Four
Ecological communities that are adequately known, rare but not threatened or meet criteria for Near Threatened, or that have been recently removed from the threatened list. These communities require regular monitoring. (i) Rare. Ecological communities known from few occurrences that are considered to have been adequately surveyed, or for which sufficient knowledge is available, and that are considered not currently threatened or in need of special protection, but could be if present circumstances change. These communities are usually represented on conservation lands. (ii) Near Threatened. Ecological communities that are considered to have been adequately surveyed and that do not qualify for Conservation Dependent, but that are close to qualifying for Vulnerable. (iii) Ecological communities that have been removed from the list of threatened communities during the past five years.
P5: Priority Five – Conservation dependent ecological communities
Ecological communities that are not threatened but are subject to a specific conservation program, the cessation of which would result in the community becoming threatened within five years.

Reference: Department of Environment and Conservation 2013, Definitions, Categories and Criteria for Threatened and Priority Ecological Communities DEC (Parks and Wildlife), <https://www.dpaw.wa.gov.au/images/plants-animals/threatened-species/definitions_categories_and_criteria_for_threatened_and_priority_ecological_communities.pdf.>

Table B.4: Conservation codes for Western Australian fauna (Department of Parks and Wildlife 2015).

Code	Conservation category	Definition
S1	Schedule 1 of the Wildlife Conservation (Specially Protected Fauna) Notice under the Wildlife Conservation Act 1950.	Fauna that is rare or likely to become extinct, as critically endangered fauna.
S2	Schedule 2 of the Wildlife Conservation (Specially Protected Fauna) Notice under the Wildlife Conservation Act 1950.	Fauna that is rare or likely to become extinct, as endangered fauna.
S3	Schedule 3 of the Wildlife Conservation (Specially Protected Fauna) Notice under the Wildlife Conservation Act 1950.	Fauna that is rare or likely to become extinct, as vulnerable fauna.
S4	Schedule 4 of the Wildlife Conservation (Specially Protected Fauna) Notice under the Wildlife Conservation Act 1950.	Fauna that is presumed to be extinct.
S5	Schedule 5 of the Wildlife Conservation (Specially Protected Fauna) Notice under the Wildlife Conservation Act 1950.	Birds that are subject to international agreements relating to the protection of migratory birds.
S6	Schedule 6 of the Wildlife Conservation (Specially Protected Fauna) Notice under the Wildlife Conservation Act 1950.	Fauna that are of special conservation need being species dependent on ongoing conservation intervention.
S7	Schedule 7 of the Wildlife Conservation (Specially Protected Fauna) Notice under the Wildlife Conservation Act 1950.	Declared to be fauna that is in need of special protection, otherwise than for the reasons mentioned.

Reference: Department of Parks and Wildlife 2015, *Conservation Codes For Western Australian flora and fauna*, The Government of Western Australia.

Table B.5: Priority species under Western Australian Wildlife Conservation Act 1950 (Department of Parks and Wildlife 2015).

Taxa that have not yet been adequately surveyed to be listed under Schedule 1 or 2 are added to the Priority Flora and Priority Fauna Lists under Priorities 1, 2 or 3. These three categories are ranked in order of priority for survey and evaluation of conservation status so that consideration can be given to their declaration as threatened flora or fauna. Taxa that are adequately known, are rare but not threatened, or meet criteria for Near Threatened, or that have been recently removed from the threatened list for other than taxonomic reasons, are placed in Priority 4. These taxa require regular monitoring. Conservation Dependent species are placed in Priority 5.

P1: Priority One – Poorly known taxa
Taxa that are known from one or a few collections or sight records (generally less than five), all on lands not managed for conservation, e.g. agricultural or pastoral lands, urban areas, Shire, Westrail and Main Roads WA road, gravel and soil reserves, and active mineral leases and under threat of habitat destruction or degradation. Taxa may be included if they are comparatively well known from one or more localities but do not meet adequacy of survey requirements and appear to be under immediate threat from known threatening processes.
P2: Priority Two – Poorly known taxa
Taxa that are known from one or a few collections or sight records, some of which are on lands not under imminent threat of habitat destruction or degradation, e.g. national parks, conservation parks, nature reserves, State forest, vacant Crown land, water reserves, etc. Taxa may be included if they are comparatively well known from one or more localities but do not meet adequacy of survey requirements and appear to be under threat from known threatening processes.
P3: Priority Three – Poorly known taxa
Taxa that are known from collections or sight records from several localities not under imminent threat, or from few but widespread localities with either large population size or significant remaining areas of apparently suitable habitat, much of it not under imminent threat. Taxa may be included if they are comparatively well known from several localities but do not meet adequacy of survey requirements and known threatening processes exist that could affect them.
P4: Priority Four: Rare, near threatened and other taxa in need of monitoring
(a) Rare. Taxa that are considered to have been adequately surveyed, or for which sufficient knowledge is available, and that are considered not currently threatened or in need of special protection, but could be if present circumstances change. These taxa are usually represented on conservation lands. (b) Near Threatened. Taxa that are considered to have been adequately surveyed and that do not qualify for Conservation Dependent, but that are close to qualifying for Vulnerable. (c) Taxa that have been removed from the list of threatened species during the past five years for reasons other than taxonomy.
P5: Priority Five: Conservation dependent taxa
Taxa that are not threatened but are subject to a specific conservation program, the cessation of which would result in the taxa becoming threatened within five years.

Reference: Department of Parks and Wildlife 2015, *Conservation Codes For Western Australian flora and fauna*, The Government of Western Australia.

Table B.6: Categories and definitions for EPBC Act listed fauna species.

Conservation category	Definition
Extinct	Taxa with no reasonable doubt that the last member of the species has died.
Extinct in the wild	Taxa known to survive only in cultivation, in captivity or as a naturalized population well outside its past range; or it has not been recorded in its known and/or expected habitat, at appropriated seasons, anywhere in its past range, despite exhaustive surveys over a time frame appropriate to its life cycle and form.
Critically endangered (CR)	Taxa facing an extremely high risk of extinction in the wild in the immediate future, as determined in accordance with the prescribed criteria.
Endangered (E)	Taxa are not critically endangered; and are facing a very high risk of extinction in the wild in the near future, as determined in accordance with the prescribed criteria.
Vulnerable (V)	Taxa are not critically endangered or endangered; and are facing a high risk of extinction in the wild in the medium-term future, as determined in accordance with the prescribed criteria.
Conservation dependent (CD)	Taxa are the focus of a specific conservation program the cessation of which would result in the species becoming vulnerable, endangered or critically endangered; or the following subparagraphs are satisfied: i) the taxa is a species of fish; ii) the taxa is the focus of a management plan that provides management actions necessary to stop the decline of, and support the recovery of, the taxa so that its chances of long term survival in nature are maximized; iii) the management plan is in force under a law of the Commonwealth or of a State or Territory; iv) Cessation of the management plan would adversely affect the conservation status of the taxa Fish includes all taxa of bony fish, sharks, rays, crustaceans, molluscs and other marine organisms, but does not include marine mammals/reptiles.

Table B.7: Criteria used to define likelihood occurrence of conservation significant fauna species.

Likelihood of occurrence	Pre-survey	Post-survey
Recorded	N/A	Species or evidence of species recorded during survey.
High	Species has been recorded within the survey area or within 20 km of the survey area and preferred habitat appears to be present.	Core or preferred habitats present in the survey area which are abundant and/or high quality condition. OR Species is known to be cryptic and may not have been detected despite adequate survey effort and suitable habitat present within the survey area. OR Species or evidence of species recorded within the survey area however doubt remains over the taxonomic identification, validity of record.
Moderate	Species has not been recorded from within the survey area, however species has been recorded within 20 km of the survey area and suitable habitat appears to be present.	Core or highly suitable habitats present in the survey area, however, non-cryptic species that was not detected despite adequate survey effort. OR Core or preferred habitats present in the survey area are mainly in poor or modified condition.
Low	Species recorded within 20 km of the survey area but suitable habitat does not appear to be present.	Species has not been recorded in the survey area despite adequate survey effort. OR Species dependent on specific habitats that do not occur in the survey area. OR Species considered locally extinct.

Table B.8: Criteria used to determine SRE status of invertebrates.

Status	Criteria
Confirmed	This species has a high probability of being an SRE based on expert opinion, reference databases or the scientific literature. Usually, this species belongs to a group that is well known taxonomically and contains a high proportion of SRE species. Example: Millipedes belonging to the genus *Boreohesperus* (Car and Harvey 2013).
Potential	This species has a moderate probability of being an SRE because it belongs to a group with a high proportion of SRE species, has specific biological and/or ecological attributes that may indicate range restriction, or has been collected from a single microhabitat type. Usually, this species will belong to a group with a poorly or moderately resolved taxonomy. Example: Many trapdoor spiders in the infraorder Mygalomorphae (Castalanelli *et al.* 2014). The WAM recognises the uncertainty involved with this category and lists five sub-categories that may help elucidating this status: i) data deficient because there is insufficient information; ii) habitat indicators that are associated with potential SRE status; iii) morphological indicators; iv) molecular evidence; and v) research and expert knowledge held within the WAM (WAMTS staff 2013). These sub-categories are implicitly addressed as part of the species assessments.

Reference: Car, CA & Harvey, MS 2013, 'A review of the Western Australian keeled millipede genus *Boreohesperus* (Diplopoda, Polydesmida, Paradoxosomatidae)', *ZooKeys*, vol. 290, pp. 1-19.

Castalanelli, MA, Teale, RJ, Rix, MG, Kennington, WJ & Harvey, MS 2013, 'Barcoding of mygalomorph spiders (Araneae: Mygalomorphae) in the Pilbara bioregion of Western Australia reveals a highly diverse biota', *Invertebrate Systematics*, vol. 28, pp. 375-85.

Table B.9: Fauna habitat condition scale (Thompson and Thompson 2010).

Habitat condition	Condition description
High Quality Fauna Habitat (1.0)	These areas closely approximate the vegetation mix and quality that would have been in the area prior to any human induced disturbance. The habitat has connectivity with other habitats and is likely to support the most natural vertebrate fauna assemblage.
Very Good Fauna Habitat (0.8)	These areas show minimal signs of human induced disturbance (e.g. grazing, clearing, fragmentation, weeds) and retain almost all of the characteristics of the habitat had it not been disturbed. The habitat has connectivity with other habitats, and fauna assemblages in these areas are likely to be minimally effected by disturbance.
Good Fauna Habitat (0.6)	These areas show signs of human induced disturbance (e.g. grazing, clearing, fragmentation, weeds) but generally retain many of the characteristics of the habitat had it not been disturbed. The habitat still retains some connectivity with other habitats but fauna assemblages in these areas are likely to be affected by disturbance. Fauna assemblages in these areas are likely to be similar to what might be expected in this habitat.
Disturbed Fauna Habitat (0.4)	These areas show signs of human induced significant disturbance (e.g. mining, clearing, tracks and roads). Many of the trees, shrubs and undergrowth have died or have been cleared. These areas may be in the early succession and regeneration stages. Areas may show signs of significant grazing, contain an abundance of weeds or have been damaged by vehicles or machinery. Habitats are fragmented or have limited connectivity with other fauna habitats. Fauna assemblages in these areas are likely to differ significantly from what might be expected in the area had the disturbance not occurred.
Highly Degraded Fauna Habitat (<0.2)	These areas often have a significant human induced loss of vegetation, and / or a large number of vehicle tracks and / or have been completely cleared, and / or areas have been heavily grazed or farmed. There is limited or no fauna habitat connectivity. Fauna assemblages in these areas are likely to differ significantly from what existed prior to the disturbance, and are often depleted compared to what existed prior to the disturbance.

Reference: Thompson, SA & Thompson, GG 2010, *Terrestrial Vertebrate Fauna Assessments for Ecological Impact Assessment*, Terrestrial Ecosystems, Mt Claremont.

Table B.10: Suitability/significance of habitat ranking criteria for the three target Matters of National Environmental Significance (MNES) species.

Species	Potential shelter and foraging habitat (a)	Suitable foraging and dispersal habitat (b)	Limited foraging and dispersal habitat (c)
Pilbara Olive Python (*Liasis olivaceus barroni*)	Rocky habitat such as gorges, escarpments and Breakaways along with Drainage lines including or in close proximity to permanent or semi-permanent water holes.	Drainage lines with dense vegetation enabling transitory behaviours and/or providing foraging potential. Rocky habitats that are not in close proximity to water.	Habitat that has limited sheltering and foraging capacity with no permanent or semi-permanent water.
Northern Quoll *(Dasyurus hallucatus)*	Rocky habitats such as ranges, escarpments, mesas, ranges, gorges, Breakaways and boulder fields. Also major Drainage lines or tree-lined drainage systems that are structurally diverse and contain large diameter trees, termite mounds or hollow logs.	Habitat important for foraging, dispersal and buffering of the species including moderate to small sized Drainage lines and native vegetation in close proximity (within 2 km) denning or shelter habitat.	Habitat that has limited sheltering and foraging capacity and not connected to potential denning/shelter and foraging habitat.
Pilbara Leaf-nosed Bat (*Rhinonicteris aurantia*) and Ghost Bat (*Macroderma gigas*)	Rocky habitat that contains caves suitable as diurnal or maternity roosts sites, or potentially contains these caves and has not adequately surveyed; OR Areas highly suitable for foraging that are likely to be used on a regular basis.	Habitat important for foraging including diverse rocky terrain, moderately sized Drainage lines and dense complex vegetation stands.	Habitat that has limited ecological value but may provide capacity for transitory movement across the landscape and/or limited foraging potential.

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Appendix C: Survey Sampling Locations

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414000 416000 418000 420000

7600000 7598000 7596000

Legend

- GPS Tracklogs
- Survey Area

Fauna Sample Locations

- Bat acoustic recording
- Motion camera
- Habitat assessment
- SRE foraging site
- Trapping grid

C.1A C.1B C.1C

HA05 MHT02 CAM09 BAT03 CAM08 HA03 CAM13 BAT01 CAM02 CAM01 SRE09 RVM12 CAM15 HA15 CAM14 HA04 CAM03 CAM06 HA13 CAM04 HA02 CAM07 ROBE RIVER MHT01 CAM16 CAM34 CAM37 BAT12 BAT11 RVM13 CAM22 CAM28 HA14 HA06 CAM19 HA17 CAM18 CAM17 HA01 CAM20 SRE06 CAM36 CAM40 RVM16 CAM41 CAM42 BAT13 CAM26 CAM27 CAM21 CAM23 HA10 HA16

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Mesa H – Level 2 Fauna Assessment, May 2016

Figure C.1A: Current and previous survey sampling locations

Coordinate System: GDA 1994 MGA Zone 50

0 200 400 600 800 1,000 Metres

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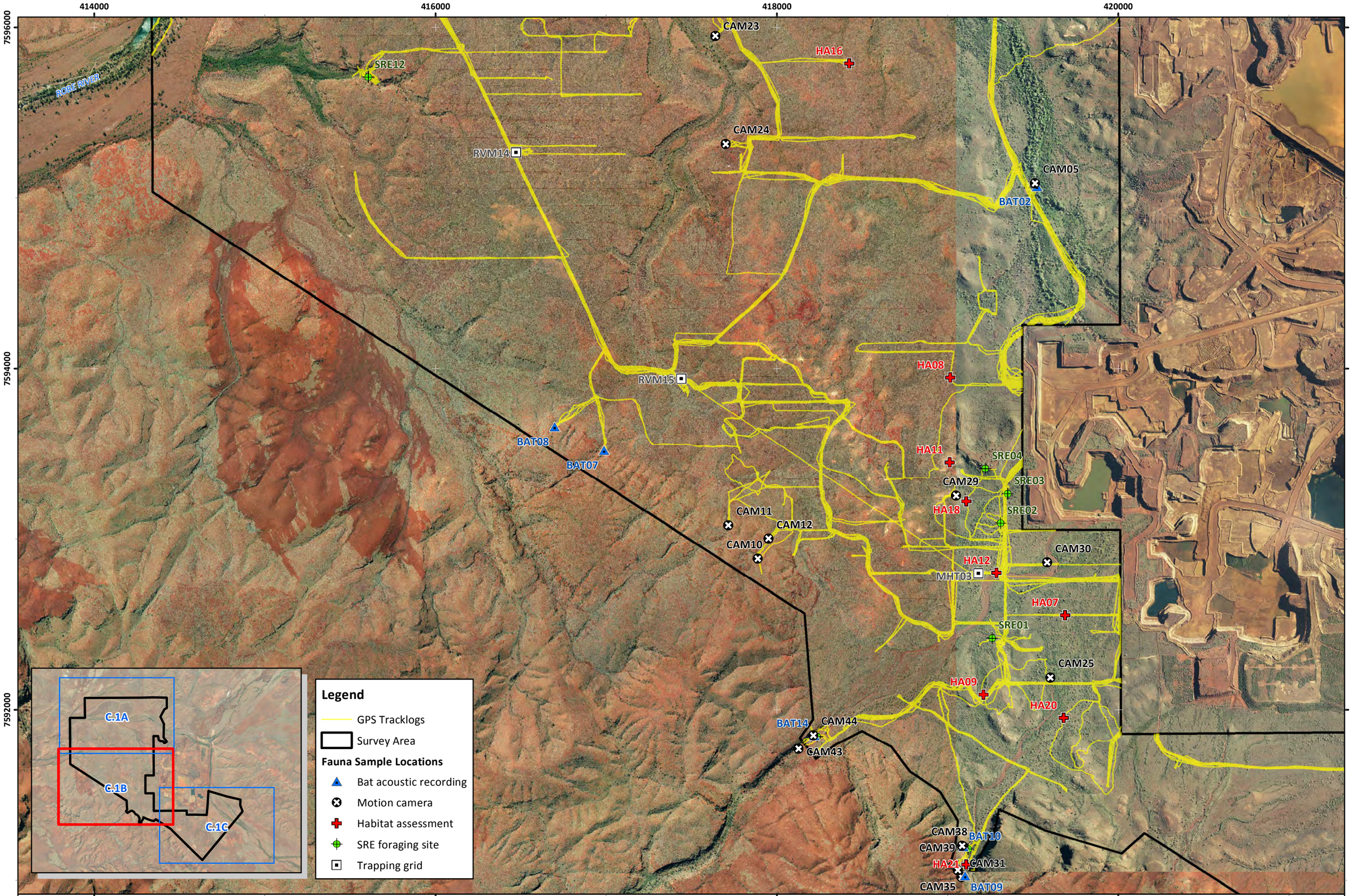
Author: J. Trainer | Drawn: C. Dyde | Date: 15-08-2017 | Figure Ref: 14269-16-BIDR-3Rev1_170815_FigC1



Robe River Mining Co. Pty Ltd

Mesa H – Level 2 Fauna Assessment, May 2016

Figure C.1B: Current and previous survey sampling locations

Coordinate System: GDA 1994 MGA Zone 50

0 200 400 600 800 1,000 Metres

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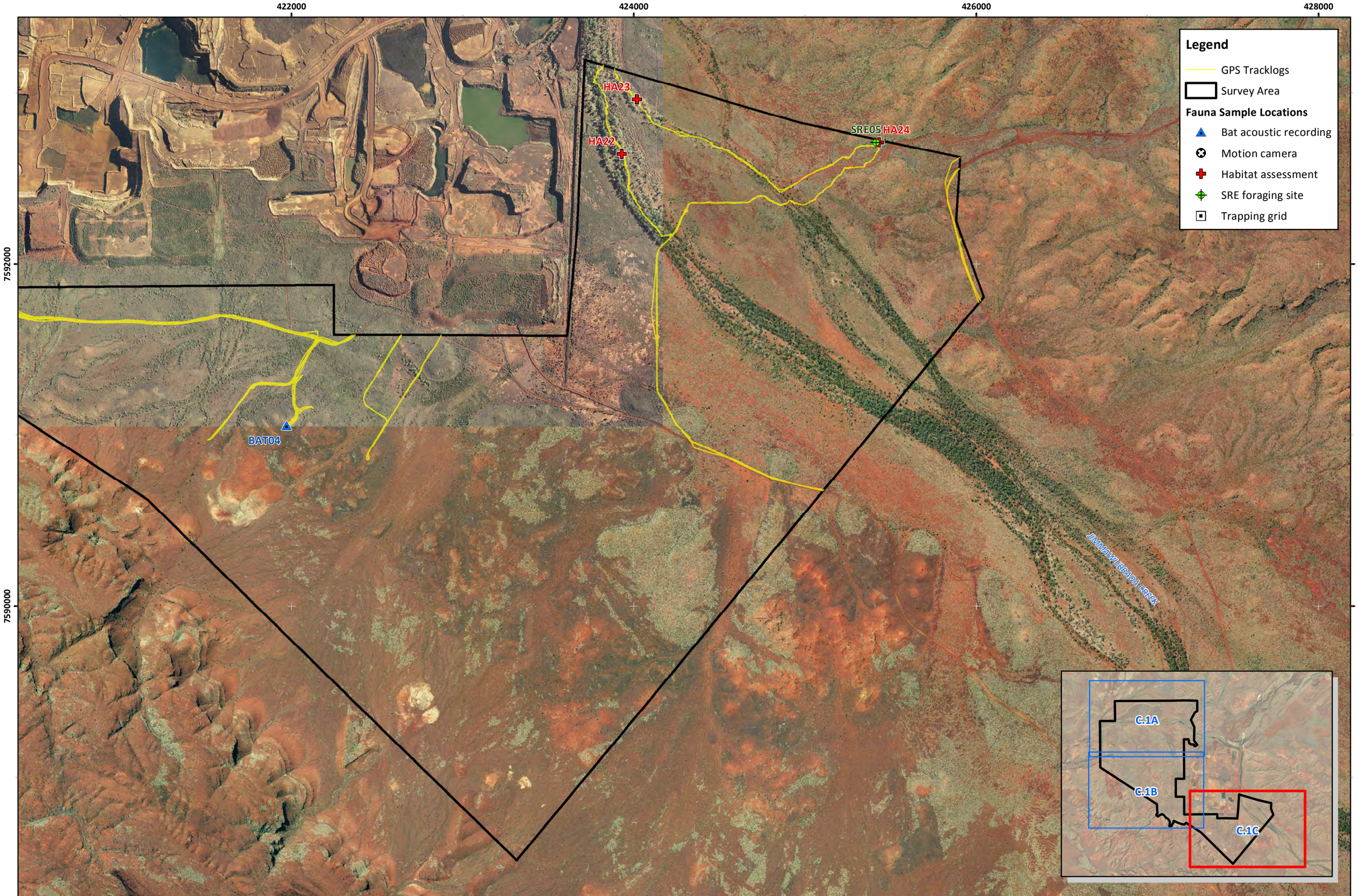

Robe River Mining Co. Pty Ltd

Mesa H – Level 2 Fauna Assessment, May 2016

Figure C.1C: Current and previous survey sampling locations

Coordinate System: GDA 1994 MGA Zone 50

0 200 400 600 800 1,000 Metres

N

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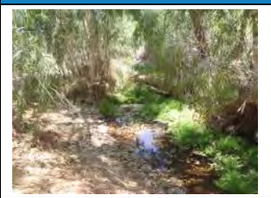
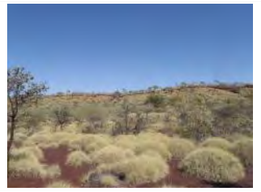
Table C.1: Astron Phase 1 fauna sampling locations.

Site ID	MGA Zone 50 K		Sampling method	Date	Habitat	Condition	Disturbance	Microhabitats	Photo
	Easting (mE)	Northing (mN)							
MHT01	414614	7597885	Trapping grid	26/09/2015 – 03/10/2015	Riverine	0.8	Grazing, tracks, weeds	Standing water	
MHT02	416326	7599285	Trapping grid	25/09/2015 – 02/10/2015	Loamy/Stony Plain	1.0	Nil	Dense leaf litter, termite mounds and spinifex clumps	
MHT03	419181	7592799	Trapping grid	25/09/2015 - 02/10/2015	Loamy/Stony Plain	0.6	Drill lines, tracks	Dense leaf litter, termite mounds and spinifex clumps	
HA01	414405	7596614	Habitat assessment	26/09/2015	Riverine	0.8	Weeds	Standing water	No photo
HA02	419980	7597945	Habitat assessment	26/09/2015	Riverine	0.8	Weeds, grazing, vehicular tracks	Standing water	No photo
HA03	418221	7599166	Habitat assessment	27/09/2015	Rocky Hills	1.0	Nil	Spinifex	
HA04	418205	7598125	Habitat assessment	27/09/2015	Riverine	0.8	Grazing	Standing water, rushes	
HA05	415598	7599460	Habitat assessment	28/09/2015	Drainage Line	0.6	Weeds	Woodland	

Site ID	MGA Zone 50 K		Sampling method	Date	Habitat	Condition	Disturbance	Microhabitats	Photo
	Easting (mE)	Northing (mN)							
HA06	414884	7597109	Habitat assessment	28/09/2015	Gorge	1.0	Nil	Caves, crevices	
HA07	419688	7592554	Habitat assessment	28/09/2015	Loamy/Stony Plain	0.6	Drill lines, tracks	Spinifex	
HA08	419017	7593947	Habitat assessment	28/09/2015	Low Hills and Slopes	0.4	Drill lines, tracks	Spinifex	
HA09	419211	7592088	Habitat assessment	28/09/2015	Low Hills and Slopes	0.8	Drill lines, tracks	Spinifex	No photo
HA10	420000	7596093	Habitat assessment	30/09/2015	Breakaway	1.0	Nil	Crevices, overhangs	No photo
HA11	419013	7593450	Habitat assessment	30/09/2015	Low Hills and Slopes	0.4	Drill lines, tracks	Spinifex	No photo
HA12	419288	7592802	Habitat assessment	30/09/2015	Drainage Line	0.4	Drill lines, tracks		No photo
HA13	419528	7598021	Habitat assessment	30/09/2015	Riverine	0.8	Grazing, weeds	Standing water	No photo
HA14	416892	7597275	Habitat assessment	30/09/2015	Gorge	1.0	Nil	Crevices, overhangs	
HA15	417192	7598072	Habitat assessment	30/09/2015	Riverine	0.8	Grazing, weeds	Standing water	

Site ID	MGA Zone 50 K		Sampling method	Date	Habitat	Condition	Disturbance	Microhabitats	Photo
	Easting (mE)	Northing (mN)							
HA16	418423	7595787	Habitat assessment	30/09/2015	Low Hills and Slopes	0.8	Drill lines, tracks	Spinifex	
HA17	416744	7596954	Habitat assessment	30/09/2015	Breakaway	1.0	Nil	Crevices, overhangs	
HA18	419110	7593221	Habitat assessment	30/09/2015	Low Hills and Slopes	0.4	Drill lines, tracks	Spinifex	
HA20	419680	7591952	Habitat assessment	30/09/2015	Drainage line	0.6	Drill lines, tracks		
CAM01	419547	7599030	Camera (active)	26/09/2015 – 30/09/2015	Low Hills and Slopes	1.0	Nil	Crevices	No photo
CAM02	419593	7599047	Camera (active)	26/09/2015 – 30/09/2015	Low Hills and Slopes	1.0	Nil	Crevices	No photo
CAM03	419654	7598155	Camera (active)	26/09/2015 – 30/09/2015	Riverine	0.6	Grazing, weeds	Standing water	No photo
CAM04	419600	7597975	Camera (active)	26/09/2015 – 30/09/2015	Breakaway	1.0	Nil	Crevices, overhangs	No photo
CAM05	419513	7595085	Camera (active)	26/09/2015 – 29/09/2015	Drainage line	0.6	Grazing, weeds	Hollows	No photo
CAM06	419823	7598058	Camera (active)	26/09/2015 – 30/09/2015	Riverine	0.6	Grazing, weeds	Standing water	No photo
CAM07	419961	7597823	Camera (active)	26/09/2015 – 30/09/2015	Breakaway	1.0	Nil	Crevices, overhangs	No photo
CAM08	417566	7599144	Camera (active)	27/09/2015 – 30/09/2015	Low Hills and Slopes	1.0	Nil	Crevices	No photo

Site ID	MGA Zone 50 K		Sampling method	Date	Habitat	Condition	Disturbance	Microhabitats	Photo
	Easting (mE)	Northing (mN)							
CAM09	416743	7599257	Camera (active)	27/09/2015 – 02/09/2015	Low Hills and Slopes	1.0	Nil	Crevices	No photo
CAM10	417888	7592885	Camera (active)	27/09/2015 – 02/09/2015	Gorge	1.0	Nil	Crevices, overhangs, caves	No photo
CAM11	417716	7593081	Camera (active)	27/09/2015 – 02/09/2015	Gorge	1.0	Nil	Crevices, overhangs, caves	No photo
CAM12	417951	7593003	Camera (active)	27/09/2015 – 02/09/2015	Gorge	1.0	Nil	Crevices, overhangs, caves	No photo
CAM13	418099	7599090	Camera (active)	27/09/2015 – 02/09/2015	Gorge	1.0	Nil	Crevices, overhangs, caves	No photo
CAM14	418136	7598043	Camera (active)	27/09/2015 – 29/09/2015	Riverine	0.6	Grazing, weeds	Standing water	No photo
CAM15	418314	7598215	Camera (active)	27/09/2015 – 29/09/2015	Riverine	0.6	Grazing, weeds	Standing water	No photo
CAM16	415050	7597802	Camera (active)	28/09/2015 – 02/09/2015	Breakaway	1.0	Nil	Crevices, overhangs	No photo
CAM17	414384	7596548	Camera (active)	28/09/2015 – 02/09/2015	Riverine	0.8	Grazing, weeds	Standing water, boulders	No photo
CAM18	414384	7596626	Camera (active)	28/09/2015 – 02/09/2015	Riverine	0.8	Grazing, weeds	Standing water, boulders	No photo
CAM19	415013	7596948	Camera (active)	28/09/2015 – 02/09/2015	Gorge	1.0	Nil	Crevices, overhangs, caves	No photo
CAM20	415163	7596516	Camera (active)	28/09/2015 – 02/09/2015	Gorge	1.0	Nil	Crevices, overhangs, caves	No photo
CAM21	417651	7596094	Camera (active)	30/09/2015 – 02/09/2015	Breakaway	1.0	Nil	Crevices, overhangs	No photo
CAM22	416896	7597282	Camera (active)	30/09/2015– 02/09/2015	Breakaway	1.0	Nil	Crevices, overhangs	No photo
CAM23	417640	7595949	Camera (active)	30/09/2015 – 02/09/2015	Breakaway	1.0	Nil	Crevices, overhangs	No photo
CAM24	417700	7595316	Camera (active)	30/09/2015 – 02/09/2015	Breakaway	1.0	Nil	Crevices, overhangs	No photo
CAM25	419602	7592188	Camera (active)	29/09/2015 – 02/09/2015	Loamy/Stony plain	0.6	Drill lines, tracks	Spinifex	No photo
CAM26	419437	7596593	Camera (active)	30/09/2015 – 02/09/2015	Breakaway	1.0	Nil	Crevices, overhangs	No photo

Site ID	MGA Zone 50 K		Sampling method	Date	Habitat	Condition	Disturbance	Microhabitats	Photo
	Easting (mE)	Northing (mN)							
CAM27	419441	7596644	Camera (active)	30/09/2015 – 02/09/2015	Breakaway	1.0	Nil	Crevices, overhangs	No photo
CAM28	416880	7597284	Camera (active)	30/09/2015 – 02/09/2015	Breakaway	1.0	Nil	Crevices, overhangs	No photo
CAM29	419050	7593255	Camera (active)	29/09/2015 – 02/09/2015	Low Hills and Slopes	0.6	Drill lines, tracks	Spinifex	No photo
CAM30	419584	7592863	Camera (active)	29/09/2015 – 02/09/2015	Drainage Line	0.6	Drill lines, tracks		No photo
BAT01	419610	7599052	Acoustic recording	26/09/2015 – 28/09/2015	Low hills and slopes	1.0	Nil	Crevices	No photo
BAT02	419524	7595067	Acoustic recording	26/09/2015 – 28/09/2015	Drainage line	0.6	Grazing, weeds	Hollows	No photo
BAT03	417682	7599195	Acoustic recording	28/09/2015 – 30/09/2015	Low Hills and Slopes	1.0	Nil	Crevices	No photo
BAT04	421971	7591055	Acoustic recording	28/09/2015 – 30/09/2015	Low Hills and Slopes	0.8	Drill lines, tracks		No photo
BAT07	416988	7593520	Acoustic recording	01/10/2015 – 02/10/2015	Rocky Hills	1.0	Nil	Crevices, overhangs	No photo
BAT08	416698	7593658	Acoustic recording	01/10/2015 – 02/10/2015	Gorge	1.0	Nil	Crevices, overhangs	No photo
SRE01	419261	7592420	SRE foraging site	29/09/2015	Low Hills and Slopes	0.4	Drill lines, tracks	Spinifex	No photo
SRE02	419311	7593093	SRE foraging site	29/09/2015	Loamy/Stony Plain	0.4	Drill lines, tracks	Spinifex	No photo
SRE03	419352	7593267	SRE foraging site	02/10/2015	Loamy/Stony Plain	0.4	Drill lines, tracks	Spinifex	No photo
SRE04	419222	7593413	SRE foraging site	02/10/2015	Low Hills and Slopes	0.6	Drill lines, tracks	Spinifex	No photo

1.0 (Excellent)
0.8 (Very Good)
0.6 (Good)
0.4 (Poor)
0.2 (Very Poor)
0.1 (Completely Degraded)

Table C.2: Astron Phase 2 fauna sampling locations.

Site ID	MGA Zone 50 K		MGA Zone 50 K	Date	Habitat	Condition	Disturbance	Microhabitats	Photo
	Easting (mE)	Northing (mE)							
MHT01	414614	7597592	Trapping grid	28/04/2016 – 05/05/2016	Riverine	0.8	Grazing, tracks, weeds	Standing water	No photo
MHT02	416326	7599285	Trapping grid	28/04/2016 – 05/05/2016	Loamy/Stony plain	1.0	Nil	Dense leaf litter, termite mounds and spinifex clumps	No photo
MHT03	419181	7592799	Trapping grid	28/04/2016 – 05/05/2016	Loamy/Stony plain	0.6	Drill lines, tracks	Dense leaf litter, termite mounds and spinifex clumps	No photo
RVM12	418592	7598780	Trapping grid	29/04/2016 – 06/05/2016	Breakaway	1.0	Nil	Rocky overhangs, crevices and small caves; low levels of leaf litter, sparse open vegetation.	
RVM13	418784	7597593	Trapping grid	29/04/2016 – 06/05/2016	Riverine	0.6	Weeds, grazing		
RVM14	416472	7595267	Trapping grid	29/04/2016 – 06/05/2016	Low Hills and Slopes	0.6	Weeds, grazing		
RVM15	417439	7593941	Trapping grid	28/04/2016 – 05/05/2016	Low Hills and Slopes	0.8	Weeds, grazing		
RVM16	414925	7596459	Trapping grid	29/04/2016 – 06/05/2016	Breakaway	1.0	Nil	Rocky overhangs, crevices and small caves; low levels of leaf litter, sparse open vegetation.	
HA21	419109	7591092	Habitat assessment	01/05/2016	Gorge	1.0	Nil	Steep sided gorge with numerous overhangs and caves	

Site ID	MGA Zone 50 K		MGA Zone 50 K	Date	Habitat	Condition	Disturbance	Microhabitats	Photo
	Easting (mE)	Northing (mE)							
HA22	423930	7592643	Habitat assessment	02/05/2016	Drainage Line	0.4	Weeds	Standing water	
HA23	424018	7592961	Habitat assessment	02/05/2016	Drainage Line	0.4	Weeds		
HA24	425433	7592710	Habitat assessment	02/05/2016	Low Hills and Slopes	1.0	Nil		
CAM31	419083	7591017	Camera (active)	01/05/2016 – 05/05/2016	Gorge	1.0	Nil		No photo
CAM32	414360	7597586	Camera (active)	03/05/2016 – 06/05/2016	Riverine	1.0	Nil		No photo
CAM33	414412	7597587	Camera (active)	02/05/2016 – 06/05/2016	Riverine	1.0	Nil		No photo
CAM34	414390	7597588	Camera (active)	02/05/2016 – 06/05/2016	Riverine	1.0	Nil	Steep sided gorge with numerous overhangs and caves	No photo
CAM35	419060	7591059	Camera (active)	01/05/2016 – 05/05/2016	Gorge	1.0	Nil	Rocky overhangs, crevices and small caves; low levels of leaf litter, sparse open vegetation.	No photo
CAM36	415342	7596472	Camera (active)	03/05/2016 – 06/05/2016	Breakaway	1.0	Nil		No photo
CAM37	414395	7597589	Camera (active)	03/05/2016 – 06/05/2016	Riverine	1.0	Nil	Steep sided gorge with numerous overhangs and caves	No photo
CAM38	419085	7591202	Camera (active)	01/05/2016 – 05/05/2016	Gorge	1.0	Nil	Steep sided gorge with numerous overhangs and caves	No photo
CAM39	419092	7591197	Camera (active)	01/05/2016 – 05/05/2016	Gorge	1.0	Nil	Rocky overhangs, crevices and small caves; low levels of leaf litter, sparse open vegetation.	No photo
CAM40	415252	7596465	Camera (active)	03/05/2016 – 06/05/2016	Breakaway	1.0	Nil	Rocky overhangs, crevices and small caves; low levels of leaf litter, sparse open vegetation.	No photo

Site ID	MGA Zone 50 K		MGA Zone 50 K	Date	Habitat	Condition	Disturbance	Microhabitats	Photo
	Easting (mE)	Northing (mE)							
CAM41	416117	7596650	Camera (active)	05/05/2016 – 06/05/2016	Breakaway	1.0	Nil	Rocky overhangs, crevices and small caves; low levels of leaf litter, sparse open vegetation.	No photo
CAM42	416205	7596566	Camera (active)	05/05/2016 – 06/05/2016	Breakaway	1.0	Nil		No photo
CAM43	418128	7591772	Camera (active)	05/05/2016 – 06/05/2016	Drainage / Breakaway	1.0	Nil		No photo
CAM44	418214	7591850	Camera (active)	05/05/2016 – 06/05/2016	Drainage / Breakaway	1.0	Nil		No photo
BAT09	419102	7591026	Acoustic recording	01/05/2016 – 05/05/2016	Gorge	1.0	Nil	Steep sided gorge with numerous overhangs and caves	No photo
BAT10	419092	7591197	Acoustic recording	01/05/2016 – 05/05/2016	Gorge	1.0	Nil	Steep sided gorge with numerous overhangs and caves	No photo
BAT11	414380	7597584	Acoustic recording	03/05/2016 – 06/05/2016	Riverine	0.8	Weeds, grazing		No photo
BAT12	414397	7597585	Acoustic recording	02/05/2016 – 06/05/2016	Riverine	0.8	Weeds, grazing		No photo
BAT13	416235	7596587	Acoustic recording	05/05/2016 – 06/05/2016	Breakaway	1.0	Nil	Rocky overhangs, crevices and small caves; low levels of leaf litter, sparse open vegetation.	No photo
BAT14	418220	7591848	Acoustic recording	05/05/2016 – 06/05/2016	Gorge / Drainage Line	1.0	Nil	Steep sided gorge with numerous overhangs and caves	No photo
NOC01	419407	7595169	Spotlighting	30/04/2016		0.8	Tracks		No photo
NOC02	420350	7591713	Spotlighting	03/05/2016		0.8	Tracks		No photo
SRE05	425416	7592710	SRE foraging site	02/05/2016	Low Hills and Slopes	1.0	Nil		
SRE06	415332	7596472	SRE foraging site	03/05/2016	Gorge	1.0	Nil	Steep sided gorge with numerous overhangs and caves	

Site ID	MGA Zone 50 K		MGA Zone 50 K	Date	Habitat	Condition	Disturbance	Microhabitats	Photo
	Easting (mE)	Northing (mE)							
SRE07	419120	7591183	SRE foraging site	05/05/2016	Gorge	1.0	Nil	Steep sided gorge with numerous overhangs and caves	
SRE08	418236	7591842	SRE foraging site	05/05/2016	Breakaway	1.0	Nil		
SRE09	420602	7598929	SRE foraging site	07/05/2016	Drainage Line	0.6	Weeds		
SRE10	414408	7597590	SRE foraging site	08/05/2016	Riverine	0.6	Weeds, grazing		
SRE11	414384	7597591	SRE foraging site	08/05/2016	Riverine	0.8	Weeds, grazing		
SRE12	415606	7595708	SRE foraging site	08/05/2016	Gorge	1.0	Nil	Steep sided gorge with numerous overhangs and caves	

1.0 (Excellent)
0.8 (Very Good)
0.6 (Good)
0.4 (Poor)
0.2 (Very Poor)
0.1 (Completely Degraded)

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Appendix D: List of Specimens Lodged with the Western Australian Museum

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Table D.1: List of specimens submitted to the Western Australian Museum.

Species	Site	Latitude	Longitude	No of specimens	Collecting Date	WAM Rego
Buddelundia '14hr'	MHT01	21°43`13.69"S	116°10`27.88"E	2	28/09/2015	67228
Buddelundia '14 hr'	SRE08	21°46`30.84"S	116°12`32.88"E	2	5/05/2016	67231
Buddelundia '61'	OPP37	21°42`37.35"S	116°13`56.12"E	1	7/05/2016	67230
Buddelundia '61'	SRE12	21°44`24.66"S	116°11`2.01"E	4	8/05/2016	67232
Buddelundia '10bf'	MHT02	21°42`28.45"S	116°11`27.73"E	7	26/09/2015	67229
Karaops feedtime	OPP38	21°42`47.59"S	116°13`53.31"E	1	7/05/2016	141164
Karaops `sp. indet. `	SRE08	21°46`30.84"S	116°12`32.87"E	1	5/05/2016	141165
Aname mellosa	MHT02	21°42`28.45"S	116°11`27.73"E	1	26/09/2015	141166
Aname mellosa	RVM14	21°44`39.15"S	116°11`32.08"E	1	02/05/2016	141167
Beierolpium 8/4	SRE08	21°46`30.84"S	116°12`32.87"E	1	5/05/2016	141168
Indolpium 'sp. indet. `	SRE09	21°46`30.84"S	116°12`32.87"E	1	5/05/2016	141169
Indolpium `sp. indet. `	SRE08	21°42`40.74"S	116°13`56.48"E	2	7/05/2016	141170
Lychas `sp. nov 1`	MHT01	21°43`23.22"S	116°10`27.83"E	1	26/09/2015	141171
Lychas ` sp. nov 2`	MHT03	21°45`59.87"S	116°13`05.95"E	1	30/04/2016	141172
Lychas ` sp. nov 2`	MHT02	21°42`28.45"S	116°11`27.73"E	2	30/04/2016	141173
Lychas `sp. nov 1`	RVM13	21°43`23.89"S	116°12`52.97"E	1	30/04/2016	141174
Lychas `harveyi`	RVM15	21°45`22.44"S	116°12`05.5"E	1	30/04/2016	141175
Lychus 'multipunctatus'	MTH02	21°42`28.45"S	116°11`27.73"E	1	29/04/2016	141176
Lychus 'multipunctatus'	MTH02	21°42`28.45"S	116°11`27.73"E	1	28/04/2016	141177
Lychas `pilbara1`	RVM15	21°45`22.44"S	116°12`05.5"E	1	30/04/2016	141178
Lychas `pilbara1`	RVM15	21°45`22.44"S	116°12`05.5"E	1	03/05/2016	141179
Urodacus 'megamastigus `long`	MHT02	21°42`28.45"S	116°11`27.73"E	1	29/04/2016	141182
Urodacus 'megamastigus `long`	MHT02	21°42`28.45"S	116°11`27.73"E	1	30/04/2016	141183

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Appendix E: Western Australian Museum Molecular Identification of Arachnids Report

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Molecular Identification of Arachnids (Selenopidae, Nemesiidae, Buthidae) from Mesa H, WSW, SW and SSW of Pannawonica (12.5-19 km), Western Australia

Report to *Astron* 19 August 2016

Amended 30 January 2016

Gaynor Dolman

Department of Terrestrial Zoology, Western Australian Museum,
Locked Bag 49, Welshpool DC, Western Australia 6986, Australia

Although identifications in this report were consistent with the best available information and current scientific thinking at the time of identification the use of this report is at the risk of the user. Any liability to users of this report for loss of any kind arising out of the use of this report or the information and identifications it contains is expressly disclaimed.

Summary

Ten specimens from two Orders (Araneae, Scorpiones) and three Families (Selenopidae, Nemisiidae and Buthidae) were among those collected from Mesa H, WSW, SW and SSW of Pannawonica (12.5-19 km), Western Australia, and were lodged into the Western Australian Museum collection by E.S. Volschenk from *Alacran Environmental Science* (see Appendix 1 for specimen details). DNA-based identifications were sought. The main objectives of the WA Museum's Molecular Systematics Unit (MSU) were to use COI DNA barcoding to compare DNA sequences to the WAM and published DNA databases to: 1) determine the taxonomic identity of the arachnid specimens where possible; and 2) determine the distribution and thus SRE status of the queried specimens.

A summary of specimen identifications together with their SRE status may be found in Table 1. A full explanation of the SRE categories used by the Western Australian Museum may be found in Appendix 2.

Table 1. Summary of WAMTS440 specimen identifications and SRE status

FAMILY	GENUS	SPECIES	# OF SPECIMENS	SRE SUB-CATEGORY
Selenopidae	*Karaops*	*feedtime*	1	Potential SRE- (A) Data Deficient
Selenopidae	*Karaops*	'sp. Indet'	1	Potential SRE- (D) Molecular Evidence
Nemesiidae	*Aname*	*mellosa*	1	Widespread (not an SRE)
Buthidae	*Lychus*	*'multipunctatus'*	2	Widespread (not an SRE) (morph* and DNA)/ Potential SRE- (D) Molecular Evidence
Buthidae	*Lychus*	*'sp. nov 1'*	2	Potential SRE- (D) Molecular Evidence
Buthidae	*Lychus*	*'sp. nov 2'*	1	Potential SRE- (D) Molecular Evidence

*Rigour of the morphology cannot be assured (identified by consultant- not confirmed by WAM arachnologists)

Methods and Results

DNA was extracted from a leg or half leg of each of the ten arachnid specimens using a Qiagen DNA extraction kit. The Folmer's primers, LCO1490 and HCO2198 were used to amplify COI DNA barcodes. COI DNA barcodes were successfully amplified and sequenced from nine of the ten specimens. PCR conditions were altered for the remaining specimen, but amplification remained unsuccessful. Barcodes from eight of the nine specimens represented the mitochondrial COI sequences being targeted. However one sequence contained two copies of the COI and the copies that could be clearly identified from chromatograms contained numerous stop codons signifying dysfunctional copies of the gene (pseudogene). Pseudogenes cannot be used to accurately identify species. A summary of the comparison (BLAST/phylogenetic results) for the nine successful specimens is provided in Table 2. Details of museum specimens that were identified in BLAST searches and contextualise the status of the queried species are provided in Table 3. Simple Neighbour-Joining (distance based) tree is provided in Appendix 3 for visualisation of genetic relationships. DNA sequences of queried specimens are provided in Appendix 4.

Options for Future Resolution of Pseudogene Problem for this study

The barcoding gene, Cytochrome Oxidase I, is a protein-coding mitochondrial gene. Mitochondrial genes can sometimes be copied to the nucleus and become dysfunctional. These genes are called pseudogenes. The protein coding DNA sequence in pseudogenes often contain stop-codons, making them readily detectable in DNA analyses, but this is not always the case. For the one specimen where a pseudogene was amplified in this study it is possible to perform a technique that will improve chances of obtaining the correct target COI gene. I can perform limiting dilution on these samples. This method is based on the fact that there is only one nucleus in each cell but many more mitochondria. The idea is to dilute the sample to the extent where the nuclear copies are removed and there are only mitochondrial copies left. Success is not guaranteed, but the likelihood of getting only the mitochondrial copy of the gene is improved. I am happy to negotiate cost of this method if required.

Table 2. Summary of BLAST analysis

REGNO	SPECIES	SUMMARY OF BLAST RESULTS
T141164	*Karaops feedtime*	This specimen was 6.42% divergent from a lineage that contains the holotype of *Karaops feedtime* (T111456; Crews 2013) and a juvenile presumed to be *K. feedtime* (T123838). According to currently available data it is unclear whether the queried specimen (T141164) and another specimen related to *K. feedtime* (T122639) represent a single widespread species or multiple species.
T141165	*Karaops sp. indet*	T141165 was 0.86% divergent from a lineage containing five specimens of juveniles (species indetermined). According to the COI barcoding data, these specimens represent a distinct and undescribed species.
T141166	*Aname mellosa*	T141166 is 7.29% divergent from its nearest two specimens which are in the *Aname mellosa* lineage. *Aname mellosa* is recognised as an unusually genetically diverse and widespread lineage of Nemesiidae. For this reason and phylogenetic placement, the current evidence suggests T141166 is *A. mellosa*.
T141167	(Nemesidae)	No PCR amplification
T141171 T141174	*Lychus 'sp. nov 1'*	T141171 and T141174 are 99.54% genetically similar. T141171, T141174 are 8.32% divergent from *Lychus 'hairytail'* and 7.75% divergent from *L. 'sp. indet*'.
T171172	*Lychus 'sp. nov 2'*	T141172 is 11.04% divergent from *Lychus 'pilbara 1'* and 9.26% divergent from *Lychus 'multipunctatus'*.
T171176 T171177	*Lychus 'multipunctatus'*	T141176 and T141177 are 99.85% genetically similar. T141176 and T141177 are 3.59% divergent to *Lychus 'multipunctatus'* and according to current evidence are most likely are members of this species.

Table 3. Details of registered WAM specimens in related lineages to the queried specimens according to DNA barcoding (see Table 2, Conclusion and Neighbour-joining trees in Appendix 3 for details of relatedness).

Reg. No.	Field No.	Order	Family	Genus	Species	Locality	Sex	Latitude	Longitude
T122639	Target 1-4	Araneae	Selenopidae	*Karaops*	*`sp. indet.'*	ca. 60 km SW. of Marble Bar	juvenile	-21.6111	119.032
T123838		Araneae	Selenopidae	*Karaops*	*`sp. indet.'*	100 km N. of Newman	juvenile	-22.4171	119.894
T111456	PE11:2181	Araneae	Selenopidae	*Karaops*	*feedtime*	Bonney Downs, 115 km NNW. of Newman	female	-22.3167	119.733
T100066	S20090825. MSG06MG-04	Araneae	Selenopidae	*Karaops*	*`sp. indet.'*	Mesa G-Warramboo, 22.6 km WSW. of Pannawonica	not recorded	-21.7403	116.135
T97476	SCC09_027	Araneae	Selenopidae	*Karaops*	*`sp. indet.'*	Red Hill Station, ca. 20 km SE. of homestead,Kens Bore site KBRC081	juvenile	-22.0574	116.196
T100067	S20090826. MSG03EMG-01	Araneae	Selenopidae	*Karaops*	*`sp. indet.'*	Mesa G-Warramboo, 22.4 km WSW. of Pannawonica	not recorded	-21.7375	116.13
T97474	SCC09_025	Araneae	Selenopidae	*Karaops*	*`sp. indet.'*	Red Hill Station, ca. 10 km NE. of homestead, Cochrane and Jewell bore site RNRC083	juvenile	-21.932	116.129
T83602		Scorpiones	Buthidae	*Lychas*	*`multipunctatus`*	Marandoo mine extension (MAR08-01)	female	-22.5157	118.171
T97370	HD4-12-1sc	Scorpiones	Buthidae	*Lychas*	*`multipunctatus`*	Hamersley Range, 60 km WNW Newman, Hope Downs 4	male	-23.1056	119.292
T97366	HD4-15-3sc	Scorpiones	Buthidae	*Lychas*	*`multipunctatus`*	Hamersley Range, 60 km WNW Newman, Hope Downs 4	male	-23.092	119.188

Reg. No.	Field No.	Order	Family	Genus	Species	Locality	Sex	Latitude	Longitude
T97367	HD4-15-4sc	Scorpiones	Buthidae	*Lychas*	*`multipunctatus`*	Hamersley Range, 60 km WNW Newman, Hope Downs 4	female	-23.092	119.188
T91704		Scorpiones	Buthidae	*Lychas*	*`multipunctatus`*	Hope Downs 4, ca. 100 km NW. of Newman, HD4-Camp	female	-23.1309	119.275
T97368	HD4-15-1sc	Scorpiones	Buthidae	*Lychas*	*`pilbara 1`*	Hamersley Range, 60 km WNW Newman, Hope Downs 4	male	-23.092	119.188
T93459		Scorpiones	Buthidae	*Lychas*	*`pilbara 1`*	Hope Downs 4, ca. 30 km NW. of Newman, HD4-2, 8	male	-23.1459	119.526
T93452		Scorpiones	Buthidae	*Lychas*	*`pilbara 1`*	Hope Downs 4, ca. 30 km NW. of Newman, HD4-15, 25	male	-23.0919	119.188
T116878	S20110706. MUD17-01	Scorpiones	Buthidae	*Lychas*	*`sp. indet.'*	Mudlark, 98 km WNW. of Newman, ca. 26 km SE. of Mt Meharry	not recorded	-23.0731	118.82
T116876	S20110705. MUD29-01	Scorpiones	Buthidae	*Lychas*	*`sp. indet.'*	Mudlark, 96 km WNW. of Newman, ca. 28 km ESE. of Mt Meharry	not recorded	-23.0403	118.852
T116877	S20110705. MUD29-02	Scorpiones	Buthidae	*Lychas*	*`sp. indet.'*	Mudlark, 96 km WNW. of Newman, ca. 28 km ESE. of Mt Meharry	not recorded	-23.0403	118.852
T91919		Scorpiones	Buthidae	*Lychas*	*`sp. indet.'*	Hamersley Range, Weeli Wolli Creek region, Area C, site 10-10C	juvenile	-22.9105	118.966

Conclusions

The main objectives were to use DNA barcoding to: 1) determine the taxonomic identity of the arachnid specimens where possible; and 2) determine the distribution and thus SRE status of the queried specimens.

1) Selenopidae

DNA barcoding (COI) data identify two distinct species in the two queried specimens of Selenopidae. The barcoding results for the first specimen are inconclusive. According to currently available data it is unclear whether the queried specimen (T141164) and another specimen (T122639) related to *K. feedtime* (Crews: Zootaxa, 2013) represent a single widespread species or multiple potentially short range species. More genetic sampling/ adult morphological analyses are required to test the species status of T141164 in relation to *K. feedtime* and T122639 and relatives.

The second specimen of Selenopidae (T141165) aligns with other specimens that have not officially been described yet (Karaops 'sp. indet'). As specimens within this undescribed species are all located within <10,000 km^2, *Karaops 'sp. indet*.' (including T141165) represents a potential SRE (Potential SRE- D Molecular Evidence).

2) Nemesiidae

According to currently available data, and the COI data generated in this study, one of the queried Nemesiidae specimens (T141166) is identified as *Aname mellosa*, an unusually widespread and genetically diverse genus of Mygalomorph spiders (not an SRE). The second of the two Nemesiidae specimens was unable to be amplified so its taxonomic status could not be determined.

3) Buthidae

In six queried scorpion specimens, three distinct species were recognised; two of the three species have been sequenced for the first time.

One of these two new species (*L. sp. nov 1*) is represented by two specimens (T141171, T141174). They are distinct from but related to *Lychus 'hairytail'* and Lychus '*sp. indet'*, two species that have not been formally described in the literature, one previously recognised by E.S. Volschenk (*L. 'hairytail'*). Given the low average genetic distances within all other *L. 'hairytail'* and *L. 'indet*.' compared to the large divergence to the queried specimens: T141171 and T141174 should be recognised as representatives of a distinct species. Being the only two known specimens from this species, according to currently available evidence they are recognised as potential SREs (D-Molecular Evidence).

The second new species, *L. 'sp. nov 2'*, represented by T141172, is a distinct species but related to *Lychus 'multipunctatus' and Lychus 'pilbara 1'*, two species that have not been formally described in the literature yet, but have previously been recognised by E.S. Volschenk. *Lychus 'sp. nov. 2'* could possibly represent *L. `gracilimanus`* another species informally described by E.S. Volschenk, but we have no DNA sequences for this morpho-type and we have no other specimens in the database recognised by

this informal name. As *L. 'sp. nov 2'* is the only specimen that can be assigned to this species, it must currently be considered a potential SRE (D- Molecular Evidence).

According to currently available barcoding data and data generated in this study, two specimens (T141176, T141177) are identified as *Lychus 'multipunctatus'*. This species has not been formally described in the literature, but has previously been recognised by E.S. Volschenk. If all barcoding sequenced *L. 'multipunctatus'* were included in a distribution analysis, *L. 'multipunctatus'* would be within 10,000 km^2 and would represent a potential SRE (D- Molecular Evidence). If all specimens, morphologically identified and molecularly identified are included in a distribution analysis, *L. 'multipunctatus'* occupies an area greater than $10,000^2$ km and therefore is not be considered an SRE. The rigour of this taxonomy is yet to be determined. Other specimens are available for sequencing if rigorous confirmation is required.

Appendix 1. Specimen data for ten queried specimens

Reg. No.	Field No.	Order	Family	Genus	Species	Locality	Collection method	Habitat
T141164	ESV16:027	Araneae	Selenopidae	*Karaops*	*feedtime*	Mesa H, 12.5 km SW Pannawonica	Hand collected	Railway culvert
T141165	ESV16:026	Araneae	Selenopidae	*Karaops*	*Sp. indet.*	Mesa H, 19 km SW Pannawonica	Leaf/soil sieving	Drainage / Breakaway
T141166	ESV16:028	Araneae	Nemesiidae	*Aname*	*mellosa*	Mesa H, 15.7 km WSW Pannawonica	Pitfall trap	Stony Plain
T141167	ESV16:029	Araneae	Nemesiidae	PCR amplification failed		Mesa H, 18 km SW Pannawonica	Pitfall trap (dry)	Low Hills and Slopes
T141171	ESV16:025	Scorpiones	Buthidae	*Lychas*	*Lychus 'sp. nov 1'*	Mesa H, 17.9 km WSW Pannawonica	Pitfall trap (dry)	Riparian
T141172	ESV16:023	Scorpiones	Buthidae	*Lychas*	*Lychus 'sp. nov 2'*	Mesa H, 17.8 km SSW Pannawonica	Pitfall trap (dry)	Loamy/Stony Plain
T141173	ESV16:009	Scorpiones	Buthidae	Pseudogene amplified		Mesa H, 15.7 km WSW Pannawonica	Pitfall trap (dry)	Loamy/Stony Plain
T141174	ESV16:021	Scorpiones	Buthidae	*Lychas*	*Lychus 'sp. nov 1'*	Mesa H, 14.6 km SW Pannawonica	Pitfall trap (dry)	Riparian
T141176	ESV16:024	Scorpiones	Buthidae	*Lychas*	*'multipunctatus'*	Mesa H, 15.7 km WSW Pannawonica	Pitfall trap	Stony Plain
T141177	ESV16:022	Scorpiones	Buthidae	*Lychas*	*'multipunctatus'*	Mesa H, 15.7 km WSW Pannawonica	Pitfall trap	Stony Plain

Appendix 2. WAM Short-Range Endemic Categories

	Taxonomic Certainty	Taxonomic Uncertainty
Distribution < 10 000km^2	**Confirmed SRE** • *A known distribution of < 10 000km².* • *The taxonomy is well known.* • *The group is well represented in collections and/ or via comprehensive sampling.*	**Potential SRE** • *Patchy sampling has resulted in incomplete knowledge of the geographic distribution of the group.* • *We have incomplete taxonomic knowledge.* • *The group is not well represented in collections.* • *This category is most applicable to situations where there are gaps in our knowledge of the taxon.* **Sub-categories for this SRE designation are outlined below**
Distribution > 10 000km^2	**Widespread (not an SRE)** • *A known distribution of > 10 000km².* • *The taxonomy is well known.* • *The group is well represented in collections and/ or via comprehensive sampling.*	

SRE SUB-CATEGORIES

If a taxon is determined to be a "Potential SRE", the following sub-categories will further elucidate this status.

A. <u>*Data Deficient:*</u>
- There is insufficient data available to determine SRE status.
- Factors that fall under this category include:
  - Lack of geographic information.
  - Lack of taxonomic information.
  - The group may be poorly represented in collections.
  - The individuals sampled (e.g. juveniles) may prevent identification to species level.

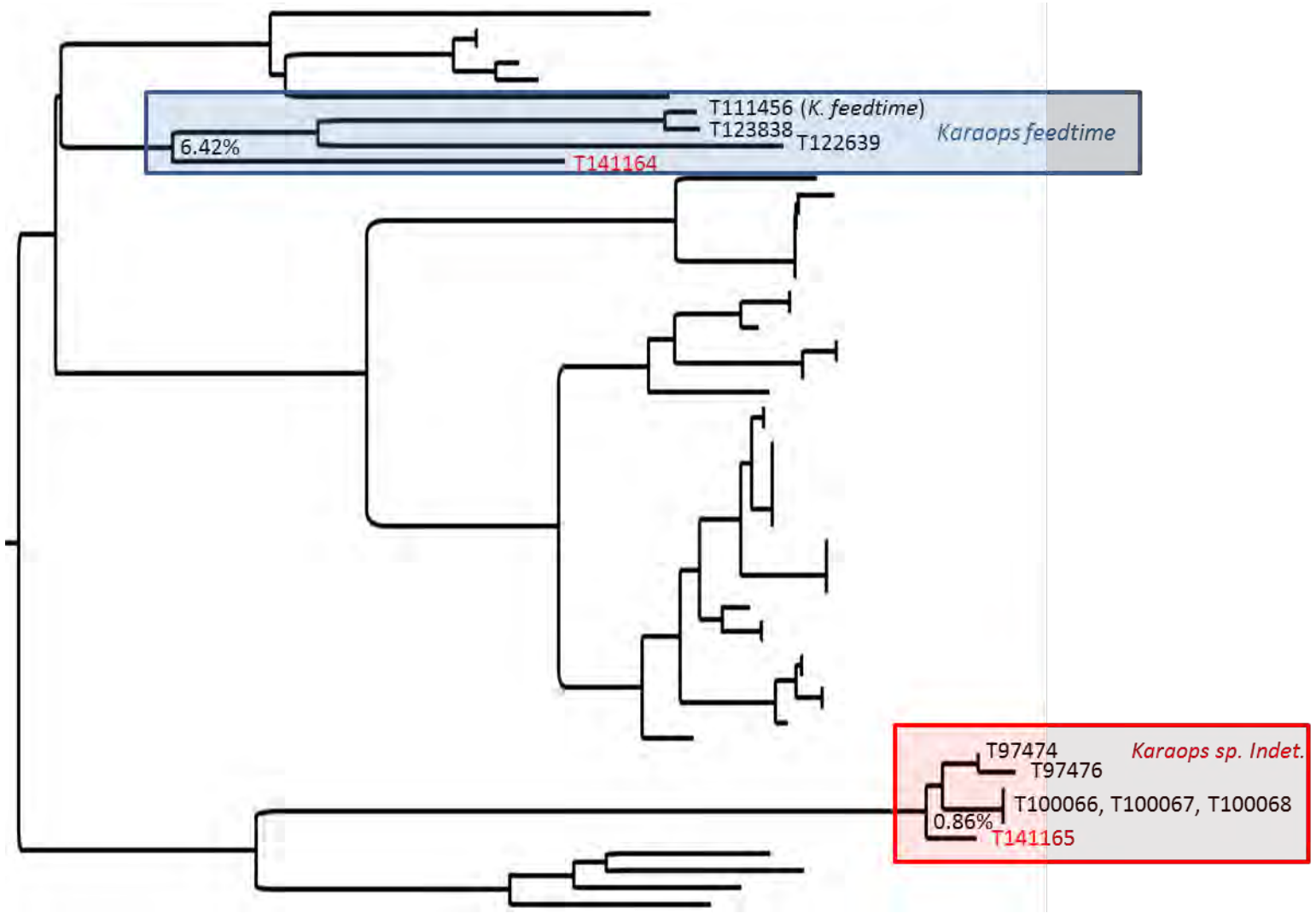
B. <u>*Habitat Indicators:*</u>
- It is becoming increasingly clear that habitat data can elucidate SRE status.
  - Below are some examples of habitats that are currently known to be associated with SRE taxa and vice versa.

C. <u>*Morphology Indicators:*</u>
- A suite of morphological characters are characteristic of SRE taxa.
- Below are some examples of morphological characters associated with SRE taxa and vice-versa.

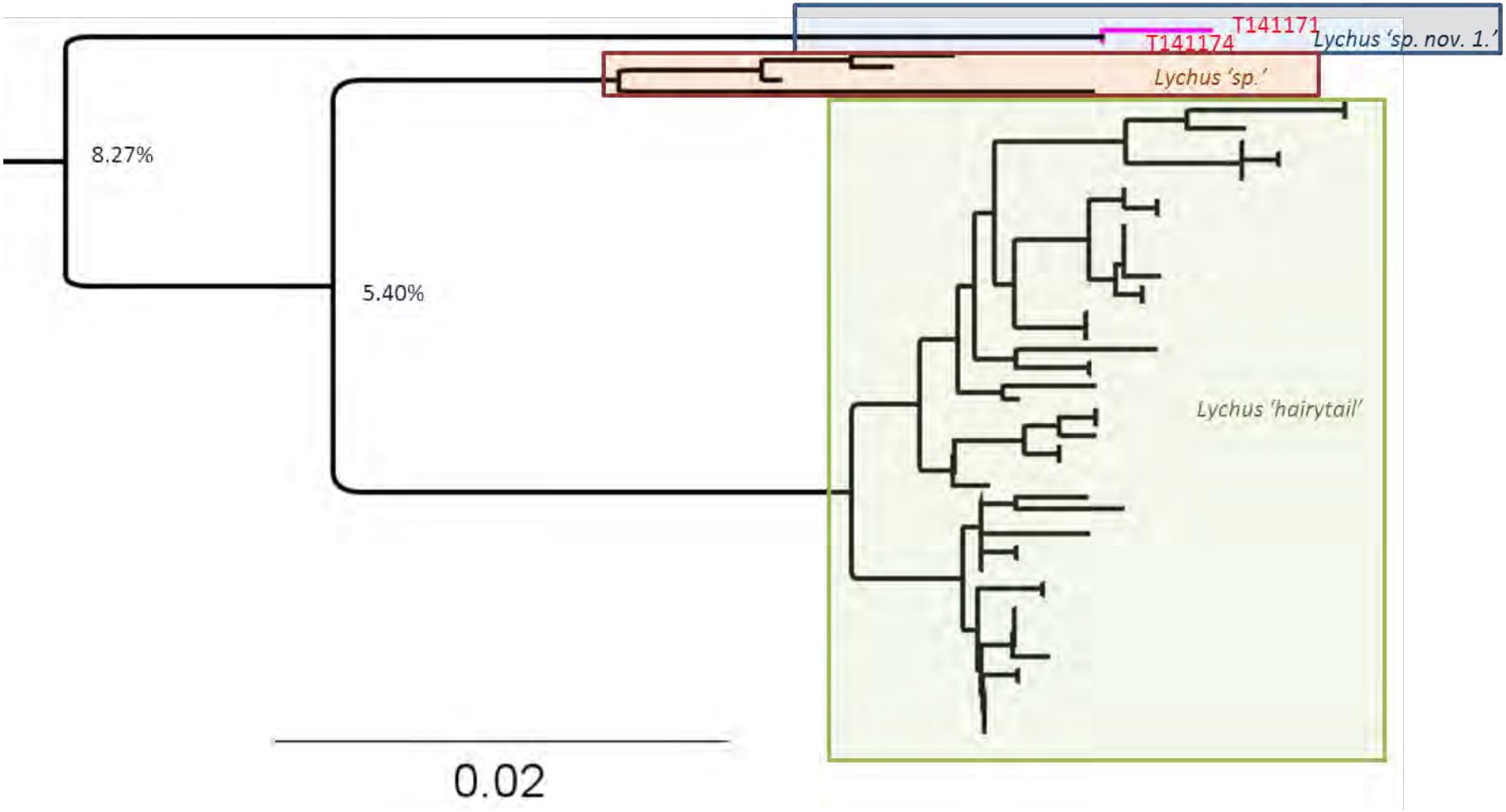
D. <u>*Molecular Evidence:*</u>
- If molecular work has been done on this taxon (or a close relative), it may reveal patterns congruent or incongruent with SRE status.
- Below are some examples of phylogenetic patterns associated with SRE taxa and vice-versa.

E. <u>*Research & Expertise:*</u>
- Previous research and/ or WAM expertise elucidates taxon SRE status.
- This category takes into account the expert knowledge held within the WAM.

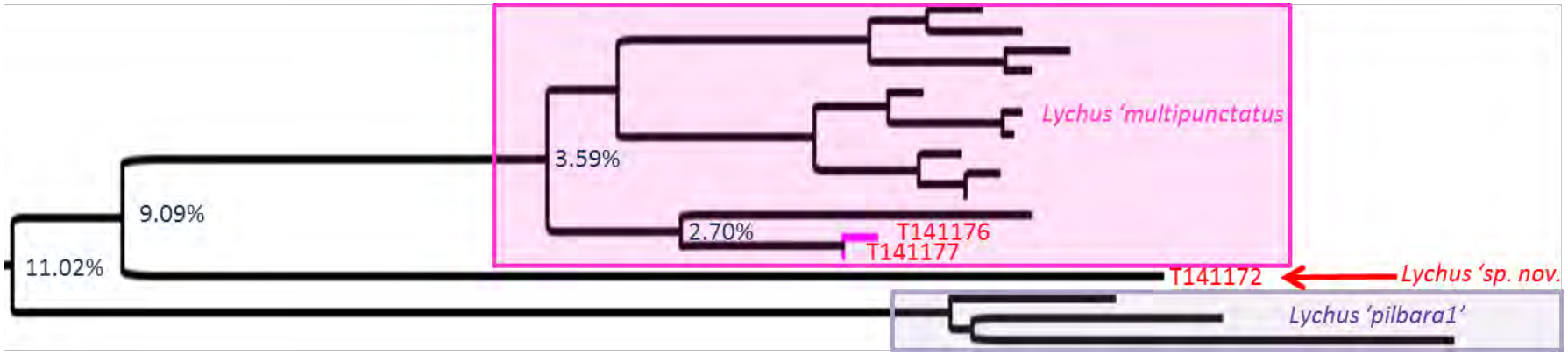
Appendix 3. Simple Neighbour-Joining (distance based) tree to be used *ONLY* for visualisation of genetic distance relationships (not a comprehensive analysis using appropriate molecular models and search algorithms).



a) Selenopidae



b) Scorpiones (T141171, T141174)



c) Scorpiones (T141172, T141176, T141177)

Appendix 4. COI DNA sequence data for queried Selenopidae, Nemesiideae and Buthidae specimens

>T141164
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>T141165
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>T141166
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>T141172
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>T141174
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>T141177
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Appendix F: Fauna Species Lists

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Table F.1: Amphibian species list – results of database searches, literature reviews and Astron survey results.

Scientific name	Common name	Introduced	Conservation codes			Nature Map	EPBC Protected Matters Search	Birdlife	Previous surveys	Current survey
			EPBC Act	WC Act	Parks and Wildlife					
HYLIDAE										
Cyclorana maini	Sheep Frog					x			x	
Litoria rubella	Little Red Tree Frog					x			x	x
MYOBATRACHIDAE										
Pseudophryne douglasi	Gorge Toadlet								x	
Uperoleia russelli	Northwest Toadlet					x			x	
Uperoleia saxatilis	Pilbara Toadlet					x			x	x
BUFONIDAE										
Platyplectrum spenceri	Centralian Burrowing Frog					x				

Table F.2: Reptile species list – results of database searches, literature reviews and Astron survey results.

Scientific name	Common name	Introduced	Conservation codes			Nature Map	EPBC Protected Matters Search	Birdlife	Previous surveys	Current survey
			EPBC Act	WC Act	Parks and Wildlife					
AGAMIDAE										
Amphibolurus longirostris	Long-Nosed Dragon					x			x	x
Ctenophorus caudicinctus	Ring-tailed Rock Dragon					x			x	x
Ctenophorus femoralis	Dune Dragon					x				
Ctenophorus isolepis isolepis	Military Sand Dragon					x			x	x
Ctenophorus nuchalis	Central Netted Dragon					x			x	
Ctenophorus reticulatus	Western Netted Dragon					x				
Pogona minor minor	Bearded Dragon					x			x	
DIPLODACTYLIDAE										
Crenadactylus ocellatus	Clawless Gecko					x			x	
Diplodactylus bilybara	Western Fat-tailed Gecko					x			x	x
Diplodactylus galaxias						x			x	
Diplodactylus mitchelli						x				
Diplodactylus savagei						x			x	
Lucasium stenodactylum	Pale-snouted Ground Gecko					x			x	x
Lucasium wombeyi						x			x	
Oedura marmorata	Marbled Velvet Gecko					x			x	x
Rhynchoedura ornata	Beaked Gecko					x			x	x
Strophurus ciliaris						x				
Strophurus elderi	Jewelled Gecko					x			x	x
Strophurus wellingtonae						x				
CARPHODACTYLIDAE										
Nephrurus levis pilbarensis									x	
Nephrurus wheeleri cinctus	Banded Knob-tailed Gecko					x			x	x
Nephrurus wheeleri wheeleri	Banded Knob-tailed Gecko					x			x	
GEKKONIDAE										
Gehyra pilbara						x			x	x
Gehyra punctata	Spotted Rock Dtella					x			x	x

Scientific name	Common name	Introduced	Conservation codes			Nature Map	EPBC Protected Matters Search	Birdlife	Previous surveys	Current survey
			EPBC Act	WC Act	Parks and Wildlife					
Gehyra variegata	Variegated Tree Dtella					x			x	x
Hemidactylus frenatus	Asian House Gecko	*				x			x	
Heteronotia binoei	Bynoe's Gecko					x			x	x
Heteronotia spelea	Pilbara Cave Gecko					x			x	
PYGOPODIDAE										
Delma butleri									x	x
Delma elegans						x			x	
Delma nasuta						x			x	x
Delma pax						x			x	x
Delma tincta						x			x	
Lialis burtonis	Burrton's Legless Lizard					x			x	x
Pygopus nigiceps						x			x	x
EUGONGYLIDAE										
Carlia munda						x			x	x
Carlia triacantha						x				
Cryptoblepharus plagiocephalus									x	
Cryptoblepharus buchananii						x				
Cryptoblepharus ustulatus						x			x	x
Menetia greyii						x			x	x
Menetia surda surda						x			x	
Morethia ruficauda exquisita	Fire-tailed Skink					x			x	x
AGAMIDAE										
Ctenotus brooksi						x				
Ctenotus calurus						x				
Ctenotus duricola						x			x	
Ctenotus grandis titan						x			x	x
Ctenotus hanloni						x			x	
Ctenotus helenae						x			x	
Ctenotus pantherinus	Leopard Ctenotus					x			x	x
Ctenotus rubicundus						x			x	

Scientific name	Common name	Introduced	Conservation codes			Nature Map	EPBC Protected Matters Search	Birdlife	Previous surveys	Current survey
			EPBC Act	WC Act	Parks and Wildlife					
Ctenotus quattuordecimlineatus						x				
Ctenotus saxatilis	Rock Ctenotus					x			x	x
Ctenotus schomburgkii						x			x	
Ctenotus serventyi						x			x	x
Eremiascincus fasciolatus										x
Eremiascincus isolepis						x			x	x
Lerista bipes						x			x	
Lerista flammicauda						x			x	
Lerista ips						x				
Lerista muelleri						x			x	x
Lerista verhmens						x				
Notoscincus butleri	Lined Soil-crevice Skink				P4	x			x	x
Notoscincus ornatus						x			x	
EGERNIIDAE										
Cyclodomorphus melanops	Slender Blue-tongue					x			x	
Egernia cygnitos						x				
Ergenia depressa						x				
Ergenia formosa						x			x	x
Ergenia pilbarensis	Pilbara Skink					x			x	x
Tiliqua multifasciata	Central Blue-tongue					x			x	x
VARANIDAE										
Varanus acanthurus	Spiny-tailed Monitor					x			x	x
Varanus brevicauda	Short-tailed Pygmy Monitor					x			x	x
Varanus bushi	Pilbara Mulga Monitor					x			x	
Varanus caudolineatus						x				
Varanus eremius	Pygmy Desert Monitor					x			x	
Varanus giganteus	Perentie					x			x	x
Varanus gouldii	Bungarra					x			x	

Scientific name	Common name	Introduced	Conservation codes			Nature Map	EPBC Protected Matters Search	Birdlife	Previous surveys	Current survey
			EPBC Act	WC Act	Parks and Wildlife					
Varanus hamersleyensis	Southern Pilbara Rock Monitor					x			x	x
Varanus panoptes panoptes						x			x	x
Varanus pilbarensis										x
Varanus tristis tristis	Racehorse Monitor					x			x	x
TYPHLOPIDAE										
Anilios ammodytes						x			x	x
Anilios ganei					P1	x			x	
Anilios grypus	Beaked Blind snake					x			x	x
Anilios hamatus									x	x
Anilios pilbarensis						x			x	x
BOIDAE										
Antaresia perthensis	Pygmy Python					x			x	
Antaresia stimsoni stimsoni	Stimson's Python					x			x	x
Aspidites melanocephalus	Black-headed python					x			x	
Liasis olivaceus barroni	Pilbara Olive Python		VU	S3		x	x		x	x
ELAPIDAE										
Acanthopis wellsi	Pilbara Death Adder					x			x	x
Brachyurophis approximans						x			x	x
Demansia psammophis cupreiceps	Yellow-faced Whipsnake					x			x	x
Demansia rufescens	Rufous Whipsnake					x			x	
Furina ornata	Moon Snake					x			x	
Parasuta monachus						x			x	
Pseudechis australis	Mulga Snake					x			x	x
Pseudonaja mengdeni	Western Brown Snake					x			x	
Pseudonaja modesta	Ringed Brown Snake					x			x	x
Pseudonaja nuchalis	Gwardar; Northern Brown Snake					x				
Simoselaps anomalus	Desert Banded Snake					x				
Suta fasciata	Rosen's Snake					x			x	
Suta punctata	Spotted Snake					x				

Table F.3: Bird species list – results of database searches, literature reviews and Astron survey results.

Scientific name	Common name	Introduced	Conservation codes			Nature Map	EPBC Protected Matters Search	Birdlife	Previous surveys	Current survey
			EPBC Act	WC Act	Parks and Wildlife					
DROMAIIDAE										
Dromaius novaehollandiae	Emu					x		x	x	
PHASIANIDAE										
Coturnix ypsilophora	Brown Quail					x			x	x
ANATIDAE										
Anas gracilis	Grey Teal					x		x	x	
Anas superciliosa	Pacific Black Duck					x		x	x	x
Aytha australis	Hardhead					x		x		
Cygnus atratus	Black Swan					x		x	x	
Chenonetta jubata	Australian Wood Duck					x			x	
Dendrocygna eytoni	Plumed Whistling Duck					x				
Dendrocygna arcuata	Wandering Whistling Duck								x	x
Nettapus pulchellus	Green Pygmy Goose								x	
PODICIPEDIDAE										
Tachybaptus novaehollandiae	Australasian Grebe					x		x	x	x
Poliocephalus poliocephalus	Hoary-headed Grebe					x		x	x	
COLUMBIDAE										
Columba livia	Domestic Pigeon	*				x	x			
Geopelia cuneata	Diamond Dove					x		x	x	x
Geopelia striata placida	Peaceful Dove					x		x	x	x
Geophaps plumifera	Spinifex Pigeon					x		x	x	x
Ocyphaps lophotes	Crested Pigeon					x		x	x	x
Phaps chalcoptera	Common Bronzewing					x		x	x	x
Phaps histrionica	Flock Bronzewing					x				
PODARGIDAE										
Podargus strigoides	Tawny Frogmouth					x		x	x	
CAPRIMULGIDAE										
Eurostopodus argus	Spotted Nightjar					x			x	x

Scientific name	Common name	Introduced	Conservation codes			Nature Map	EPBC Protected Matters Search	Birdlife	Previous surveys	Current survey
			EPBC Act	WC Act	Parks and Wildlife					
AEGOTHELIDAE										
Aegotheles cristatus	Australian Owlet-nightjar					x			x	x
APOPDIDAE										
Apus pacificus	Fork-tailed Swift		Mi	S5			x		x	
ANHINGIDAE										
Anhinga novaehollandiae	Darter					x		x	x	
PHALACROCORACIDAE										
Phalacrocorax melanoleucos	Little Pied Cormorant							x	x	x
Phalacrocorax varius	Pied Cormorant							x	x	x
Phalacrocorax sulcirostris	Little Black Cormorant								x	
PELECANIDAE										
Pelecanus conspicillatus	Australian Pelican					x		x	x	x
CICONIIDAE										
Ephippiorhynchus asiaticus	Black-necked stork								x	
ARDEIDAE										
Ardea ibis	Cattle Egret		Mi	S5			x		x	
Ardea intermedia	Intermediate Egret					x	x		x	x
Ardea modesta	Eastern Great Egret		Mi	S5		x	x	x	x	
Ardea garzetta	Little Egret					x			x	
Ardea novaehollandiae	White-faced Heron					x		x	x	x
Ardea pacifica	White-necked Heron					x		x	x	x
Butorides striata	Striated Heron							x		
Nycticorax caledonicus	Nankeen Night-heron					x		x	x	x
THRESKIORNITHIDAE										
Platalea flavipes	Yellow-billed Spoonbill								x	
Threskiornis spinicollis	Straw-necked Ibis					x		x	x	x
ACCIPITRIDAE										
Accipiter cirrocephalus	Collared Sparrowhawk					x			x	
Accipiter fasciatus fasciatus	Brown Goshawk					x		x	x	x
Aquila audax	Wedge-tailed Eagle					x		x	x	x

Scientific name	Common name	Introduced	Conservation codes			Nature Map	EPBC Protected Matters Search	Birdlife	Previous surveys	Current survey
			EPBC Act	WC Act	Parks and Wildlife					
Circus approximans	Swamp Harrier					x				
Circus assimilis	Spotted Harrier					x		x	x	x
Elanus scriptus	Letter-winged Kite				P4	x				
Elanus caeruleus	Black-shouldered Kite					x			x	x
Lophoictinia isura	Square-tailed Kite					x		x		
Haliaeetus leucogaster	White-bellied Sea Eagle						x	x	x	
Haliastur sphenurus	Whistling Kite					x		x	x	x
Haliastur indus	Brahminy Kite							x		
Hieraaetus morphnoides	Little Eagle					x		x	x	x
Milvus migrans	Black Kite					x		x	x	x
Panidon haliaetus	Eastern Osprey		Mi	S5			x			
FALCONIDAE										
Falco cenchroides cenchroides	Australian Kestrel					x		x	x	x
Falco berigora berigora	Brown Falcon					x		x	x	x
Falco longipennis	Australian Hobby					x		x	x	
RALLIDAE										
Gallirallus philippensis	Buff-banded Rail					x				
Fulica atra	Eurasian Coot					x		x	x	
Porzana tabuensis	Spotless Crake					x				x
Tribonyx ventralis	Black-tailed Native-hen								x	x
OTIDIDAE										
Ardeotis australis	Australian Bustard					x		x	x	
BURHINIDAE										
Burhinus grallarius	Bush Stone-curlew					x			x	x
RECURVIROSTRIDAE										
Himantopus himantopus	Black-winged Stilt					x			x	
CHARADRIIDAE										
Charadrius veredus	Oriental Plover		Mi	S5			x			
Charadrius ruficapillus	Red-capped Plover							x		
Charadrius leschenaultii	Greater Sand Plover		Mi	S5				x		

Scientific name	Common name	Introduced	Conservation codes			Nature Map	EPBC Protected Matters Search	Birdlife	Previous surveys	Current survey
			EPBC Act	WC Act	Parks and Wildlife					
Elseyornis melanops	Black-fronted Dotterel					x		x	x	x
Erythrogonys cinctus	Red-kneed Dotterel								x	
Vanellus tricolor	Banded Lapwing					x		x		
CINCLOSOMATIDAE										
Psophodes occidentalis	Chiming Wedgebill					x				
ROSTRATULIDAE										
Rostratula benghalensis australis	Australian Painted Snipe		EN	S2			x			
SCOLOPACIDAE										
Actitis hypoleucos	Common Sandpiper					x		x		
Calidris acuminata	Sharp-tailed Sandpiper			S5		x				
Calidris ferruginea	Curlew Sandpiper		CR/Mi	S3/S5			x			
Numenius madagascariensis	Eastern Curlew		CR	S3/S5			x			
Numenius phaeopus	Whimbrel			S5				x		
Tringa glareola	Wood Sandpiper			S5		x		x	x	
Tringa nebularia	Common Greenshank			S5				x		
TURNICIDAE										
Turnix velox	Little Button-quail					x		x	x	x
GLAREOLIDAE										
Glareola maldivarum	Oriental Pratincole		Mi	S5			x			
PSITTACIDAE										
Platycercus zonarius zonarius	Australian Ringneck					x		x	x	x
Melopsittacus undulatus	Budgerigar					x		x	x	x
Nymphicus hollandicus	Cockatiel					x		x	x	x
Pezoporus occidentalis	Night Parrot		EN	S1		x	x			
CACATUIDAE										
Cacatua sanguinea	Little Corella					x		x	x	x
Cacatua roseicapilla	Galah					x		x	x	x
CUCULIDAE										
Cacomantis pallidus	Pallid Cuckoo					x		x	x	x
Chrysococcyxs basalis	Horsfield's Bronze Cuckoo					x		x	x	x

Scientific name	Common name	Introduced	Conservation codes			Nature Map	EPBC Protected Matters Search	Birdlife	Previous surveys	Current survey
			EPBC Act	WC Act	Parks and Wildlife					
Chrysococcyxs osculans	Black-eared Cuckoo								x	
Centropus phasianinus	Pheasant Coucal							x	x	
STRIGIDAE										
Ninox connivens	Barking Owl					x				x
Ninox boobook boobook	Southern Boobook Owl					x		x	x	x
TYTONIDAE										
Tyto javanica	Eastern Barn Owl					x				
ACLEDINIDAE										
Dacelo leachii leachii	Blue-winged Kookaburra					x		x	x	x
Todiramphus pyrrhopygia	Red-backed Kingfisher					x		x	x	x
Todiramphus sanctus	Sacred Kingfisher					x		x	x	x
MEROPIDAE										
Merops ornatus	Rainbow Bee-eater		Mi	S5		x	x	x	x	x
PTILONORHYNCHIDAE										
Ptilonorhynchus maculatus guttatus	Western Bowerbird					x			x	x
MALURIDAE										
Amytornis striatus	Striated Grasswren					x		x	x	x
Malurus lamberti assimilis	Variegated Fairy-wren					x		x	x	x
Malurus leucopterus	White-winged Fairy-wren					x		x	x	x
Stipiturus ruficeps	Rufous Crowned Emu-wren								x	
ACANTHIZIDAE										
Acanthiza apicalis	Inland Thornbill					x			x	
Acanthiza uropygialis	Chestnut-rumped Thornbill					x			x	
Gerygone fusca	Western Gerygone					x			x	
Gerygone tenebrosa	Dusky Gerygone							x		
Smicrornis brevirostris	Weebill					x		x	x	x
PARDALOTIDAE										
Pardalotus punctatus	Spotted Pardalote					x				
Pardalotus rubricatus	Red-browed Pardalote					x		x	x	x

Scientific name	Common name	Introduced	Conservation codes			Nature Map	EPBC Protected Matters Search	Birdlife	Previous surveys	Current survey
			EPBC Act	WC Act	Parks and Wildlife					
Pardalotus striatus	Striated Pardalote					x			x	x
MELIPHAGIDAE										
Acanthagenys rufogularis	Spiny-cheeked Honeyeater					x		x	x	x
Certhionyx variegatus	Pied Honeyeater					x			x	
Epthianura tricolor	Crimson Chat					x			x	
Ptilotula keartlandi	Grey-headed Honeyeater							x	x	x
Ptilotula penicillatus	White-plumed Honeyeater							x	x	x
Gavicalis virescens	Singing Honeyeater							x	x	x
Lichmera indistincta	Brown Honeyeater					x		x	x	x
Manorina flavigula	Yellow-throated Miner					x		x	x	x
Melithreptus gularis	Black-chinned Honeyeater					x			x	
Sugomel niger	Black Honeyeater					x			x	
POMATOSTOMIDAE										
Pomatostomus supercilious	White-browed Babbler					x				
Pomatostomus temporalis	Grey-crowned Babbler					x		x	x	x
CAMPEPHAGIDAE										
Coracina maxima	Ground Cuckoo-shrike					x				
Coracina novaehollandiae	Black-faced Cuckoo-shrike					x		x	x	x
Lalage tricolor	White-winged Triller					x		x	x	x
PACHYCEPHALIDAE										
Colluricincla harmonica	Grey Shrike-thrush					x		x	x	x
Oreoica gutturalis	Crested Bellbird					x		x	x	x
Pachycephala melanura	Mangrove Golden Whistler							x		
Pachycephala lanioides	White-breasted Whistler							x		
Pachycephala rufiventris	Rufous Whistler					x		x	x	x
Cincloramphus cruralis	Brown Songlark					x		x	x	
Cincloramphus mathewsi	Rufous Songlark					x		x	x	
ARTAMIDAE										
Artamus cinereus melanops	Black-faced Woodswallow					x		x	x	x

Scientific name	Common name	Introduced	Conservation codes			Nature Map	EPBC Protected Matters Search	Birdlife	Previous surveys	Current survey
			EPBC Act	WC Act	Parks and Wildlife					
Artamus leucorynchus	White-breasted Woodswallow							x	x	x
Artamus minor	Little Woodswallow					x			x	x
Artamus personatus	Masked Woodswallow					x			x	x
CRACTICIDAE										
Cracticus torquatus	Grey Butcherbird								x	
Cracticus nigrogularis	Pied Butcherbird					x		x	x	X
Cracticus tibicen	Australian Magpie					x		x	x	x
DICRURIDAE										
Rhipidura albiscapa	Grey Fantail					x			x	x
Rhipidura phasiana	Mangrove Grey Fantail							x		
Rhipidura leucophrys leucophrys	Willie Wagtail					x		x	x	x
Grallina cyanoleuca	Magpie-lark					x		x	x	x
CORVIDAE										
Corvus bennetti	Little Crow					x		x	x	
Corvus orru	Torresian Crow					x		x	x	x
PETROICIDAE										
Melanodryas cucullata	Hooded Robin					x			x	x
Petroicas goodenovii	Red-capped Robin					x			x	
ALAUDIDAE										
Mirafra javanica	Horsfield's Bushlark					x		x	x	
Mirafra cantillans	Singing Bushlark									x
ACROCEPHALIDAE										
Acrocephalus australis	Australian Reed Warbler								x	x
LOCUSTELLIDAE										
Eremiornis carteri	Spinifex-bird					x		x	x	x
TIMALIIDAE										
Zosterops luteus	Yellow White-eye							x		
HIRUNDINIDAE										
Cheramoeca leucosternus	White-backed swallow					x				

Scientific name	Common name	Introduced	Conservation codes			Nature Map	EPBC Protected Matters Search	Birdlife	Previous surveys	Current survey
			EPBC Act	WC Act	Parks and Wildlife					
Hirundo neoxena	Welcome Swallow							x	x	
Hirundo rustica	Barn Swallow		Mi	S5			x			
Petrochelidon ariel	Fairy Martin					x		x	x	x
Petrochelidon nigricans	Tree Martin					x		x	x	x
DICAEIDAE										
Dicaeum hirundinaceum	Mistletoebird					x		x	x	x
ESTRILDIDAE										
Emblema pictum	Painted Finch					x		x	x	x
Neochmia ruficauda subclarescens	Star Finch (Western)					x		x	x	X
Taeniopygia guttata	Zebra Finch					x		x	x	x
MOTACILLIDAE										
Anthus australis	Australian Pipit					x		x	x	
Motacilla cinerea	Grey Wagtail		Mi	S5			x			
Motacilla flava	Yellow Wagtail		Mi	S5			x			

Table F.4: Mammal species list – results of database searches, literature reviews and Astron survey results.

Scientific name	Common name	Introduced	Conservation codes			Nature Map	EPBC Protected Matters Search	Birdlife	Previous surveys	Current survey
			EPBC Act	WC Act	Parks and Wildlife					
TACHYGLOSSIDAE										
Tachyglossus aculeatus	Short-beaked Echidna					x			x	x
DASYURIDAE										
Dasycercus blythi	Brush-tailed Mulgara				P4	x				
Dasykaluta rosamondae	Little Red Kaluta					x			x	x
Dasyurus hallucatus	Northern Quoll		EN	S2		x	x		x	x
Ningaui ridei	Wongai Ningaui					x				
Ningaui timealeyi	Pilbara Ningaui					x			x	x
Planigale ingrami	Long-tailed Planigale					x			x	
Planigale maculata	Common Planigale					x				
Planigale 'species 1'	Pilbara Planigale								x	x
Pseudantechinus roryi	Rory's Pseudantechinus								x	
Pseudantechinus woolleyae	Woolley's Pseudantechinus					x			x	
Pseudantechinus sp.										x
Sminthopsis longicaudata	Long-tailed Dunnart				P4	x				
Sminthopsis macroura	Stripe-faced Dunnart					x			x	x
Sminthopsis youngsoni	Lesser Hairy-footed Dunnart					x			x	
THYLACOMYIDAE										
Macrotis lagotis	Greater Bilby, Dalgyte		VU	S3		x	x			
NOTORYCTIDAE										
Notoryctes caurinus	Northern Marsupial Mole		EN				x			
MACROPODIDAE										
Osphranter robustus erubescens	Euro, Biggada					x			x	x
Osphranter rufus	Red Kangaroo, Marlu					x			x	x
Petrogale rothschildi	Rothschild's Rock-wallaby					x			x	x
PHALANGERIDAE										
Trichosurus vulpecula arnhemensis	Northern Brushtail Possum					x				

Scientific name	Common name	Introduced	Conservation codes			Nature Map	EPBC Protected Matters Search	Birdlife	Previous surveys	Current survey
			EPBC Act	WC Act	Parks and Wildlife					
MEGADERMATIDAE										
Macroderma gigas	Ghost Bat		VU	S3		x	x		x	x
HIPPOSIDERIDAE										
Rhinonicteris aurantia	Pilbara Leaf-nosed Bat		VU	S3		x	x		x	x
EMBALLONURIDAE										
Sacclaimus flaviventris	Yellow-bellied Sheathtail-bat					x			x	x
Taphozous georgaianus	Common Sheathtail-bat					x			x	x
VESPERTILIONIDAE										
Chalinolobus gouldii	Gould's Wattled Bat					x			x	x
Nyctophilus daedalus	Northwestern Long-eared Bat								x	
Nyctophilus geoffroyi	Lesser Long-eared Bat					x			x	x
Scotorepens greyii	Little Broad-nosed Bat					x			x	x
Vespadelus finlaysoni	Finlayson's Cave Bat					x			x	x
MOLOSSIDAE										
Chaerephon jobensis colonicus	Greater Northern Free-tailed Bat					x			x	x
Ozimops lumsdenae	Northern Free-tailed Bat					x			x	
Tadarida australis	White-striped Freetail-bat					x			x	
MURIDAE										
Leggadina lakedownensis	Short-tailed Mouse				P4	x	x			
Mus musculus	House Mouse	*				x	x		x	x
Notomys alexis	Spinifex Hopping-mouse					x			x	
Pseudomys chapmani	Western Pebble-mound Mouse				P4	x	x		x	x
Pseudomys delicatus	Delicate Mouse					x			x	
Pseudomys desertor	Desert Mouse					x			x	x
Pseudomys hermannsburgensis	Sandy Inland Mouse					x			x	x
Zyzomys argurus	Common Rock-rat					x			x	x
LEPORIDAE										
Oryctolagus cuniculus	Rabbit	*				x	x			
CANIDAE										

Scientific name	Common name	Introduced	Conservation codes			Nature Map	EPBC Protected Matters Search	Birdlife	Previous surveys	Current survey
			EPBC Act	WC Act	Parks and Wildlife					
Canis dingo	Dingo	*				x			x	x
Canis familiaris	Dog	*							x	
Vulpes vulpes	Red Fox	*				x	x			
FELIDAE										
Felis catus	Cat	*				x	x		x	x
CAMELIDAE										
Camelus dromedarius	Dromedary, Camel	*				x				
EQUIDAE										
Equus asinus	Donkey	*				x	x			
BOVIDAE										
Bos taurus	European Cattle	*				x			x	x
Capra hircus	Goat	*					x			

Previous surveys

Astron 2011, Mesa J Tail Track Extension Vegetation, Flora and Fauna Survey
Astron 2014, Mesa H Level 1 Flora, Vegetation and Fauna Assessment
Astron 2015, Mesa H Flora, Vegetation and Fauna Survey – Phase 1 Summary
Astron 2016a, Bungaroo Iron Ore Mine and Infrastructure Project, Level 2 Fauna Survey
Astron 2015b, Middle Robe and East Deepdale Level 2 Fauna Assessment
Biologic 2014, Yarraloola Targeted Fauna Survey
Biota 2005, Fauna Habitats and Fauna Assemblage of Mesa A and Mesa G
Biota 2006, Fauna Habitats and Fauna Assemblage of the Mesa A Transport Corridor and Warramboo
Biota 2007, Bungaroo Trial Pit and Transport Corridor to Mesa J, near Pannawonica
Biota 2009, Mesa G Baseline Fauna Survey
Biota 2010, Greater Bungaroo Seasonal Fauna Survey
Biota 2011, Robe Valley Mesas Fauna Survey
Ecologia Environment 2013, Middle Robe and East Deepdale Flora, Vegetation, Vertebrate and Invertebrate Fauna Survey

Table F.5: Potential and confirmed SRE species list – results of database searches and literature review.

Taxonomic group	Species [1]	Records	SRE category	Source	Remarks
ARACHNIDA					
Araneae: Mygalomorphae (Trapdoor Spiders and Allies)					
Actinopodidae	*Missulena* 'MYG040'	Warramboo	Potential	WA Museum; Biota 2006; Harms and Framenau 2013	
	Missulena 'MYG110'	Millstream-Chichester NP	Potential	WA Museum; Phoenix 2014	
	Missulena sp. indet.	Robe Valley (Mesa A), Warramboo, Delphine, Eliwana-Flying Fish, Bungaroo Trial Pit	Potential	WA Museum; Biota 2007; Phoenix 2012, 2014; Harms and Framenau 2013	Probably multiple species
Barychelidae	*Aurecocrypta* 'Barrow sp. 1'	Barrow Island	Potential	WA Museum	Probably endemic to Barrow Is.
	Aurecocrypta 'MYG057'	South-west of Pannawonica	Potential	WA Museum	
	Aurecocrypta 'MYG319-DNA'	Aquila Onslow, south-east of Onslow	Potential	WA Museum; Castalanelli et al. 2014	
	Aurecocrypta 'po3'	12 km north-east of Mardie	Potential	WA Museum	
	Idiommata 'MYG110'	Cane River Conservation Park	Potential	WA Museum	
	Synothele butleri	Barrow Island	Confirmed	WA Museum, Raven 1994	Endemic to Barrow Is.
	Synothele 'MYG313-DNA'	Aquila, south-south-west of Pannawonica	Potential	WA Museum	
	Synothele 'preston'	18 km south-east of Mardie	Potential	WA Museum	
	Synothele sp. 'pseudidiommata'	Warramboo	Potential	WA Museum; Biota 2006	
	Synothele sp. indet.	Bungaroo Valley, Bungaroo South, Robe Valley (Mesa G), Delphine, Eliwana-Flying Fish, Mardie Station	Potential	WA Museum; Biota 2010; Phoenix 2012, 2014	Probably multiple species; listed as Barychelidae in Biota 2006
Ctenizidae	*Conothele* sp. 'Barrow 1'	Barrow Island	Potential	WA Museum	Probably endemic to Barrow Is.
	Conothele sp. 'Barrow 2'	Barrow Island	Potential	WA Museum	Probably endemic to Barrow Is.
	Conothele sp. 'Barrow 3'	Barrow Island	Potential	WA Museum	Probably endemic to Barrow Is.
	Conothele '295-DNA'	Barrow Island	Potential	WA Museum	Probably endemic to Barrow Is.
	Conothele '297-DNA'	Barrow Island	Potential	WA Museum	Probably endemic to Barrow Is.

Taxonomic group	Species [1]	Records	SRE category	Source	Remarks
Ctenizidae	*Conothele* sp. indet.	Robe Valley (Mesa G), Balla Balla, Eliwana-Flying Fish, Emu Siding, Zebra Hill	Potential	WA Museum; Phoenix 2012, 2014	Probably multiple species
Idiopidae	*Aganippe* sp. 'MYG302-DNA'	Robe Valley (Mesa K)	Potential	WA Museum	
	Aganippe sp. indet.	Warramboo	Potential	Biota 2006	May belong to *Aganippe* sp. 'MYG302-DNA'
	Eucyrtops sp. indet.	Robe Valley	Potential	Phoenix 2012	Not lodged with the WAM
	Euoplos 'MYG082'	Mt Minnie	Potential	WA Museum	
	Euoplos 'MYG218'	Barrow Island	Potential	WA Museum	Maybe endemic to Barrow Is.
	Euoplos 'MYG307-DNA'	Mesa A Transport Corridor	Potential	WA Museum	
Nemesiidae	*Aname* 'MYG079'	Barrow Island	Potential	WA Museum	Probably endemic to Barrow Is.
	Aname 'MYG093'	Mt Elvire, Mt Florance, Serenity Valley	Potential	WA Museum	
	Aname 'MYG102'	Aquila Onslow, south-east of Onslow	Potential	WA Museum	
	Aname 'MYG271-DNA'	Aquila, south-west of Pannawonica	Potential	WA Museum	
	Aname 'MYG275'	Barrow Island	Potential	WA Museum	Probably endemic to Barrow Is.
	Aname 'MYG328-DNA'	Barrow Island	Potential	WA Museum	Probably endemic to Barrow Is.
	Aname 'MYG369-DNA'	Aquila, south-south-east of Pannawonica	Potential	WA Museum	
	Aname sp. indet.	Aquila, Onslow, Bungaroo Valley, Bungaroo South, Cane River, Robe Valley, Mt Amy, Mt Brockman, Mt Farquhar, Warramboo, Delphine, Eliwana-Flying Fish	Potential	WA Museum; Phoenix 2014	Probably multiple species
	Chenistonia 'MYG090'	21 km south-east of Onslow	Potential	WA Museum	Pilbara Survey
	Kwonkan 'MYG274'	Barrow Island	Potential	WA Museum	Probably endemic to Barrow Is.
	Kwonkan 'po2'	Mardie Station	Potential	WA Museum; Main 1983; Phoenix 2014	
	Yilgarnia sp. indet.	Brickwood Reserve, Robe Valley, Delphine, Eliwana-Flying Fish, Mt Farquhar, Barrow Island	Potential	WA Museum; Main 1986; Phoenix 2012, 2014	
Araneae: Araneomorphae ("Modern" Spiders)					
Oonopidae	*Grymeus* sp. indet.	Mt Elvire, Barrow Island	Potential	WA Museum	Likely multiple species

Taxonomic group	Species [1]	Records	SRE category	Source	Remarks
Oonopidae	*Myrmopopaea* spp.	Barrow Island	Potential	WA Museum	Probably multiple species
	Opopaea callani	Barrow Island	Confirmed	Baehr and Harvey 2013	
	Opopaea harmsi	Barrow Island	Confirmed	WA Museum; Baehr and Harvey 2013	Endemic to Barrow Is.
	Opopaea johannae	Barrow Island, Whim Creek Hotel, Marda Pool, Bandicoot Bay	Confirmed	WA Museum; Baehr and Harvey 2013	Barrow Island and Pilbara
	Opopaea rugosa	Barrow Island	Confirmed	Baehr and Harvey 2013	Endemic to Barrow Is.
	Orchestina spp.	Barrow Island	Potential	WA Museum	Probably multiple species
	Pelicinus saaristoi	Barrow Island	Confirmed	Ott and Harvey 2008	Endemic to Barrow Is.
	Xestaspis 'inconspiqua'	Barrow Island	Potential	WA Museum	Probably endemic to Barrow Is.
Selenopidae	*Karaops burbidgei*	Varanus Island	Confirmed	Crews and Harvey 2011;Crews 2013	Endemic to Varanus Is.
	Karaops sp. 'Bungaroo'	Bungaroo Creek Valley	Potential	Astron 2016a	Known from Juveniles only
	Karaops sp. 'Middle Robe 1'	Robe River Valley	Potential	Astron 2016b	Known from Juveniles only
	Karaops sp. 'Middle Robe 2'	South-east and south-west of Pannawonica	Potential	Astron 2016b	Known from Juveniles only
	Karaops sp. indet.	Bungaroo South, Red Hill Station, Karratha, Middle Robe (Mesa G), Mt Edith, Millstream-Chichester NP, Python Pool, Cane River CP	Potential	WA Museum; Biota 2010; Crews and Harvey 2011; Crews 2013; Phoenix 2014	Listed as Selenopidae in Biota 2010; includes multiple genetic species (see Astron 2015b)
Pseudoscorpiones (Pseudoscorpions)					
Cheiridiidae	*Apocheiridium* 'Barrow 1'	Barrow Island	Potential	WA Museum	Probably endemic to Barrow Is.
	Apocheiridium 'Barrow 2'	Barrow Island	Potential	WA Museum	Probably endemic to Barrow Is.
Chthoniidae	*Lagynochthonius* sp. indet.	West Pilbara	Potential	WA Museum	Known from juveniles only
	Tyrannochthonius sp. nov. 'Bungaroo 2'	Bungaroo Creek Valley	Potential	Astron 2016a	Known from a single specimen only
Garypidae	*Anagarypus heatwolei*	Barrow Island	Confirmed	WA Museum; Muchmore 1982	Endemic to Barrow Is.
	Synsphyronus 'PSE032'	Barrow Island	Potential	WA Museum	Likely endemic to Barrow Is.
	Synsphyronus sp. nov. 'CR1'	Cane River Conservation Park	Potential	WA Museum	

Taxonomic group	Species [1]	Records	SRE category	Source	Remarks
Garypinidae	*Synsphyronus* sp. nov. 'CR2'	Cane River Conservation Park	Potential	WA Museum	
	Synsphyronus sp. indet.	Bungaroo Valley, Cane River, Robe Valley	Potential	WA Museum; Biota 2010; Harvey 1987, 2010	Listed as *Synsphyronus* sp. in Biota 2010
	Solinus sp. indet.	Bungaroo Valley	Potential	WA Museum, Biota 2010	Listed as *Solanus* sp. in Biota 2010
Hyidae	*Indohya* sp. indet.	Bungaroo Valley, Exmouth Limestone, Learmonth, Robe Valley	Potential	WA Museum	Known from subterranean and epigean habitats
	Indohya sp. 'PSE002'	South-east and south-west of Pannawonica, Mt Delphine, Bungaroo Creek Valley	Potential	WA Museum; Harvey and Volschenk 2007; Astron 2016a	Probably unresolved species-complex
Olpiidae	*Austrohorus* sp. indet.	Barrow Island, Marra Mamba	Potential	Biota 2013	Listed as *Austrohorus* sp. in Biota 2010
	Austrohorus 'Barrow sp. 1'	Barrow Island, Site 105	Potential	WA Museum	Probably endemic to Barrow Is.
	Austrohorus 'Barrow sp. 2'	Barrow Island, Gorgon Project Footprint	Potential	WA Museum	Probably endemic to Barrow Is.
	Euryolpium sp. 'Bungaroo'	Bungaroo Creek Valley	Potential	Astron 2016a	Known from a single specimen
	Euryolpium sp. indet.	Barrow Island	Potential		
Sternophoridae	*Afrosternophorus* sp. indet.	Cane River Conservation Park	Potential	WA Museum	Multiple species
Syarinidae	*Ideoblothrus* sp. 'Bungaroo'	Bungaroo Creek Valley	Potential	Astron 2016a	
	Ideoblothrus sp. indet.	Robe Valley (Mesas A, B, K), Congo, Cane River, Millstream-Chichester National Park	Potential	WA Museum; Edward & Harvey 2010	Probably represent multiple species
Opiliones (Harvestmen)					
Assamiidae	*Dampetus* sp. 'Middle Robe'	Robe River Valley	Potential	Astron 2016b	Known from a single specimen
	Dampetus sp. indet.	Balla Balla Railway Project, Delphine, Eliwana-Flying Fish, Mt Herbert, Robe Valley (Mesas A, G, and J)	Potential	Phoenix 2014	Unresolved species-complex (see Astron 2015b)
Scorpiones (Scorpions)					
Buthidae	*Isometroides* 'barrow'	Barrow Island	Potential	WA Museum	Potentially endemic to Barrow Is.
	Isometroides sp. indet.	Mesa G	Potential	WA Museum	Known from a single specimen

Taxonomic group	Species [1]	Records	SRE category	Source	Remarks
Buthidae	*Lychas* 'Barrow 2'	Barrow Island	Potential	WA Museum	Potentially endemic to Barrow Is.
	Lychas 'hairy tail'-group	Robe River Valley, East Deepdale, Bungaroo Creek Valley, Bungaroo South	Potential	Phoenix 2012; Astron 2016a, 2016b	Cryptic species-complex
	Lychas 'multipunctatus'-group	Balla Balla, Robe River Valley, East Deepdale, Bungaroo South	Potential	Phoenix 2012, 2014; Astron 2016b	Cryptic species-complex
	Lychas 'nubby'	South-west of Karratha	Potential	WA Museum	
	Lychas 'scottae'	63 km south of Pannawonica	Potential	WA Museum	
	Lychas 'warramboo 1'	Warramboo	Potential	WA Museum; Phoenix 2012	
	Lychas sp. nov.	Middle Robe and East Deepdale	Potential	ecologia Environment 2013	
Urodacidae	*Urodacus* 'saipem1'	Alinta Dampier-Bunbury Natural Gas Pipeline	Potential	WA Museum	Known from several localities
	Urodacus 'sp. 7'	North-north-east of Whim Creek Hotel, Marda Pool	Potential	WA Museum	
	Urodacus 'waramboo'	Waramboo, 50 km west of Pannawonica	Potential	WA Museum	
CRUSTACEA					
Armadillidae	*Acanthodillo* sp. indet.	Eliwana-Flying Fish	Potential	Phoenix 2012,	
	Acanthodillo sp. 6	Karratha to Millstream-Chichester National Park	Potential	Phoenix 2014	
	Armadillidae genus 1 sp. 1	Barrow Island	Potential	Judd and Perina 2013	
	Armadillidae genus 2 sp. 1	Barrow Island	Potential	Judd and Perina 2013	
	Armadillidae genus 3 sp. 1	Barrow Island	Potential	Judd and Perina 2013	
	Armadillidae genus 3 sp. 2	Barrow Island	Potential	Judd and Perina 2013	
	Armadillidae genus 4 sp. 2	Barrow Island	Potential	Judd and Perina 2013	
	Barrowdillo pseudopyrgoniscus	Barrow Island	Confirmed	Judd and Perina 2013	
	Barrowdillo sp. nov. 5	Middle Robe	Potential	ecologia Environment 2013	
	cf. *Barrowdillo* sp. 3	Karratha to Millstream-Chichester National Park	Potential	Phoenix 2014	
	cf. *Barrowdillo* sp. 9	Central Pilbara	Potential	Phoenix 2014	
	cf. *Barrowdillo* sp. 10	Central Pilbara	Potential	Phoenix 2014	

Taxonomic group	Species [1]	Records	SRE category	Source	Remarks
Armadillidae	cf. *Barrowdillo* sp. 11	Central Pilbara	Potential	Phoenix 2014	
	Buddelundia hirsuta	Barrow Island	Confirmed	Judd and Perina 2013	Collected at a cave entrance, may be subterranean fauna
	Buddelundia '10'	Central Pilbara	Potential	Phoenix 2014	
	Buddelundia '10 1016a'	Balla Balla Railway Project	Potential	Phoenix 2014	
	Buddelundia '17'	Central Pilbara	Potential	Phoenix 2014	
	Buddelundia '19'	Central Pilbara	Potential	Phoenix 2014	
	Buddelundia '30'	Bungaroo South, Middle Robe	Potential	ecologia Environment 2013; Phoenix 2012, 2014	
	Buddelundia '33'	Central Pilbara, Karratha to Millstream-Chichester National Park	Potential	Phoenix 2014	
	Buddelundia '54'	Central Pilbara	Potential	Phoenix 2014	
	Buddelundia '61'	Bungaroo Iron ore Mine, Bungaroo South	Potential	Phoenix 2014; Astron 2016a	
	Buddelundia '64'	Mt Farquhar, Nammuldi, Mt Brockman	Potential	Phoenix 2014	
	Buddelundia '66'	Mt Farquhar	Potential	Phoenix 2014	
	Buddelundia '76'	Central Pilbara	Potential	Phoenix 2014	
	Buddelundia '92'	Balla Balla Railway Project	Potential	Phoenix 2014	
	Buddelundia '93'	Balla Balla Railway Project	Potential	Phoenix 2014	
	Buddelundia '94'	Balla Balla Railway Project	Potential	Phoenix 2014	
	Buddelundia '95'	Balla Balla Railway Project	Potential	Phoenix 2014	
	Buddelundia sp. indet.	Bungaroo South, Eliwana-Flying Fish, Delphine, Mt Brockman, Mt Farquhar	Potential	Phoenix 2012	Probably multiple species
	Buddelundia sp. 2	Barrow Island	Potential	Judd and Perina 2013	
	Buddelundiinae sp. indet.	Bungaroo Creek Valley	Potential	Astron 2015a	
	Cubaris sp. 999	Eliwana-Flying Fish, Delphine	Potential	Phoenix 2012, 2014	
	Spherillo sp. indet.	Bungaroo Creek Valley	Potential	Astron 2016a	
	Spherillo '999'	Mt Farquhar, Delphine	Potential	Phoenix 2012, 2014	

Taxonomic group	Species [1]	Records	SRE category	Source	Remarks
Philosciidae	Philosciidae sp. indet.	Middle Robe and East Deepdale	Potential	Astron 2016b	Probably distinct from Philosciidae 'unknown genus'
	Philosciidae 'unknown genus'	Middle Robe and East Deepdale	Potential	Ecologia 2013	
	Philosciidae 'pannawonica'	Pannawonica	Potential	Phoenix 2014	
DIPLOPODA (Millipedes)					
Paradoxosomatidae	*Antichiropus* sp. 'DIP009'	Mt Minnie	Confirmed	WA Museum; Car et al. 2013; Car and Harvey 2014	
	Antichiropus sp. 'DIP024'	Millstream-Chichester National Park	Confirmed	WA Museum; Car et al. 2013; Car and Harvey 2014	
	Antichiropus sp. 'DIP041'	Mt Elvire	Confirmed	WAM; Car et al. 2013; Car and Harvey 2014	
	Antichiropus sp. indet.	Bungaroo South, Cane River Reserve, Marda Pool, Karratha and Mardie Stations, Pannawonica Road	Potential	WA Museum; Car et al. 2013, Car and Harvey 2014; Biota 2006; Phoenix 2014	Almost certainly multiple species
	Boreohesperus delicatus	Marda Pool	Confirmed	Car and Harvey 2013	
	Boreohesperus dubitalis	Barrow Island	Confirmed	Car and Harvey 2013	Endemic to Barrow Is.
	Boreohesperus furcosus	Mt Minnie	Confirmed	Car and Harvey 2013	
	Boreohesperus undulatus	Karratha Station, Mt Minnie	Confirmed	Car and Harvey 2013	
Siphonotidae	*Siphonotidae* sp. indet.	Bungaroo South, near Tom Price (White Quartz Road)	Confirmed	Biota 2007; Phoenix 2014	
CHILOPODA (Centipedes)					
Chilenophilidae	*Sepedonophilus* sp. indet.	Balla Balla, Mt Farquhar	Potential	WA Museum; Phoenix 2014	
Cryptopidae	*Cryptops* sp. indet	Balla Balla, Bungaroo South, Robe Valley (Mesas A and K), Delphine, Eliwana-Flying Fish, Mt Farquhar	Potential	WA Museum; Phoenix 2014	Probably multiple species
Mecistocephalidae	*Mecistocephalus* sp. indet.	Barrow Island, Bungaroo South, Delphine, Eliwana-Flying Fish, Mt Farquhar	Potential	WA Museum; Phoenix 2012	Probably multiple species
Family indet.	Gen indet.	Barrow Island	Potential	WA Museum	At least four morphospecies; taxonomic status of samples unclear

Taxonomic group	Species [1]	Records	SRE category	Source	Remarks
GASTROPODA (Snails)					
Bothriembryontidae	Bothriembryontidae 'Pilbara'-complex	Hamersley Range, Mt Farquhar, Millstream, Tom Price, Wodgina	Potential	WA Museum; Phoenix 2014	Likely multiple species
Camaenidae	New genus cf. 'Mt Robinson'	Bungaroo South, Delphine	Potential	Phoenix 2012, 2014	
	Plectorhagada meilgana	Florrie Station, Minnie Springs, East of Exmouth Road	Confirmed	Solem 1997; Phoenix 2014	
	Rhagada sp. 'Beasley'[#]	Beasley River, Tom Price	Previously listed but not SRE	Biota 2006, 2013	Genetic species; probably same species as *Rhagada* sp. 'Tom Price' (Biota 2013)
	Rhagada barrowensis	Barrow and Boodie Islands	Confirmed	Johnson et al. 2013	
	Rhagada cf. *radleyi*	Millstream, Mt Hebert, Deep Reach Pool, Coolawanyah Station	Previously listed but not SRE	Biota 2006; Ecologia 2013	Widespread in the Western Pilbara; *Rhagada* ?*radleyi* in Biota 2006
	Rhagada plicata	Barrow Island, Lowendal and Montebello Islands	Confirmed	Johnson et al. 2013	
	Rhagada sp. indet.	Millstream-Chichester National Park, Mardie Homestead, Mt Brockman, Mt Hebert, Mt Price, Mt Turner, Pannawonica Road, Whim Creek	Potential	Whisson and Kirkendale 2014	Known mostly from dead-taken shells; may be multiple species
	Rhagada sp. 'Pannawonica'[#]	Pannawonica, Marra Mamba	Previously listed but not SRE	Biota 2006, 2010, 2013, 2010; Hamilton and Johnson 2015	Genetic species; clearly distinct from *Rhagada* sp. 'Beasley' and *R.* 'Tom Price' (Biota 2013)
	Rhagada sp. 'Tom Price'[#]	Beasley River, Tom Price	Previously listed but not SRE	Biota 2013	Genetic species; probably same species as *Rhagada* sp. 'Beasley' (Biota 2013)
	Rhagada sp. indet.	Buckland Hills	Potential	WA Museum	May belong to one of the other listed species
	Quistrachia barrowensis	Barrow Island, Lowendal and Montebello Islands	Confirmed	Johnson et al. 2013	
	Quistrachia cf. 'Barlee Range'	Tom Price, Mt Farquhar	Potential	WA Museum	
	Quistrachia herberti	Bilanoo Hill, Millstream-Chichester National Park, Karratha, Mt Farquhar, Mt Herbert, Fortescue River	Confirmed	Solem 1997; Whisson and Kirkendale 2014	

Taxonomic group	Species [1]	Records	SRE category	Source	Remarks
Camaenidae	*Quistrachia* sp. indet.	Balla Balla, Delphine, Marra Mamba, Mt Hebert, Millstream-Chichester National Park	Potential	Biota 2013; Phoenix 2012, 2014	Known mostly from dead-taken shells; likely multiple species
	Quistrachia 'X'	Cape Preston	Potential	WA Museum	
Glacidorbidae	*Glacidorbis* sp. indet.	Mardie Station	Potential	WA Museum	Aquatic mollusc and probably more widespread
Hydrobiidae	Hydrobiidae sp. indet.	Bungaroo Creek	Potential	WA Museum	Aquatic mollusc and probably more widespread
Hyriidae	*Velesunio* sp.	Millstream-Chichester National Park	Potential	WA Museum	Aquatic mollusc
Lymnaeidae	*Bayardella* cf. johni	Tom Price	Potential	WA Museum	
	Isidorella cf. *egregia*	Middle Robe, Tom Price	Potential	WA Museum	Probably unresolved species complex
Succineidae	*Succinea* sp.	Pannawonica	Potential	WA Museum	

[#] previously referred to as *Rhagada* 'small banded' and thought to be a potential SRE species (WAM data); however recent molecular analyses by Biota Environmental Sciences (2013) have shown that this morphospecies consists of three distinct genetic lineages, all with ranges > 10,000 km^2 (Biota 2013).

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Table F.6: Amphibian species recorded during the current surveys.

Species name	MHT01	MHT02	MHT03	RVM12	RVM13	RVM14	RVM15	RVM16	Other
HYLIDAE									
Litoria rubella	1,0				0,1				0,10
MYOBATRACHIDAE									
Uperoleia saxatilis	13,11				0,9				0,10

Table F.7: Reptile species recorded during the current surveys.

Species name	MHT01	MHT02	MHT03	RVM12	RVM13	RVM14	RVM15	RVM16	Other
AGAMIDAE									
Amphibolurus longirostris	0,3								2,1
Ctenophorus caudicinctus							0,2		2,1
Ctenophorus isolepis isolepis			0,1						2,0
CARPHODACTYLIDAE									
Nephurus wheeleri cinctus			0,5				0,2		
DIPLODACTYLIDAE									
Diplodactylus bilybara		1,9	0,3				0,9		
Lucasium stenodactylum							0,3		
Oedura marmorata									1,2
Strophurus elderi		0,2							
GEKKONIDAE									
Gehyra pilbara									0,1
Gehyra punctata									
Gehyra variegata	3,0								0,1
Heteronotia binoei	12,7	1,1							1,1
Rhynchoedura ornata			1,0				0,1		
PYGOPODIDAE									
Delma butleri						0,1			
Delma nasuta									1,0
Delma pax			1,0						
Lialis burtonis		1,0	1,0			0,1			
Pygopus nigriceps						0,1	0,1		
EGERNIIDAE									
Ergenia formosa				0,1					1,0
Ergenia pilbarensis									1,0
Tiliqua multifasciata		1,1				0,1			
EUGONGYLIDAE									
Carlia munda	0,1	0,2	2,0						

Species name	MHT01	MHT02	MHT03	RVM12	RVM13	RVM14	RVM15	RVM16	Other
Cryptoblepharus ustulatus				0,1					1,0
Menetia greyii	1,0	1,1	2,0						
Morethia ruficauda exquisita	1,0	0,2							
SPHENOMORPHIDAE									
Ctenotus grandis titan		17,21	17,17			0,7	0,12		
Ctenotus pantherinus		4,2				0,1	0,4		
Ctenotus saxatilis	2,2	0,6	5,6			0,5	0,4		
Ctenotus serventyi						0,8	0,1		
Eremiascincus fasciolatus		0,1	0,5						
Eremiascincus isolepis	19,14				0,14				
Lerista muelleri	3,0	1,0	1,0		0,1				
Notoscincus butleri			1,0						
VARANIDAE									
Varanus acanthurus			1,0		0,1				
Varanus brevicauda		1,0	1,0						
Varanus giganteus									2,0
Varanus hamersleyensis									1,0
Varanus panoptes panoptes			0,2						2,0
Varanus pilbarensis									1,0
Varanus tristis tristis		0,2	0,1						1,0
TYPHLOPIDAE									
Anilios ammodytes	1,0								
Anilios grypus							0,1		
Anilios hamatus		1,0							
Anilios pilbarensis			0,1						
BOIDAE									
Antaresia stimsoni stimsoni						0,1			
Liasis olivaceus barroni									0,3[3]
ELAPIDAE									
Acanthophis wellsi						0,1			2,0
Brachyurophis approximans		1,0							

Species name	MHT01	MHT02	MHT03	RVM12	RVM13	RVM14	RVM15	RVM16	Other
Demansia psammophis psammophis			1,0						
Pseudechis australis		0,1							2,0
Pseudonaja mengdeni		0,1	0,1						

Table F.8: Bird species recorded during the current surveys.

Species name	MHT01	MHT02	MHT03	RVM12	RVM13	RVM14	RVM15	RVM16	Other
ANATIDAE									
Anas superciliosa									3,2
Dendrocygna arcuata									0,2
PHASIANIDAE									
Coturnix ypsilophora									8,0
PODICIPEDIDAE									
Tachybaptus novaehollandiae									2,2
THRESKIORNITHIDAE									
Threskornis spinicollis									3,0
ARDEIDAE									
Nycticorax caledonicus									1,0
Ardea intermedia intermedia									1,0
Ardea novaehollandiae									1,0
Ardea pacfica									1,0
PHALACROCORACIDAE									
Phalacrocorax melanoleucos									2,0
Phalacrocorax varius									3,1
PELECANOIDIDAE									
Pelecanus conspicillatus									3,1
ANHINGIDAE									
Anhinga novaehollandiae									1,1
ACCIPITRIDAE									
Accipiter fasciatus					0,1				1,1
Aquila audax									2,2
Circus assimilis	1,0								0,2

Species name	MHT01	MHT02	MHT03	RVM12	RVM13	RVM14	RVM15	RVM16	Other
Elanus caeruleus									0,2
Haliastur sphenurus	1,0								2,4
Hieraaetus morphnoides									0,1
Milvus migrans	1,0								1,1
RALLIDAE									
Porzana tabuensis									0,1
Tribonyx ventralis									1,0
CHARADRIIDAE									
Elseyornis melanops		0,1							4,0
TURNICIDAE									
Turnix velox		0,1							
COLUMBIDAE									
Geopelia cuneata	1,0	2,0	4,2						1,1
Geopelia striata placida									1,1
Geophaps plumifera			1,0						3,1
Ocyphaps lophotes		1,0	2,2						1,1
Phaps chalcoptera									1,1
CAPRIMULGIDAE									
Eurostopodus argus									5,10
AEGOTHELIDAE									
Aegotheles cristatus	0,1								2,0
FALCONIDAE									
Falco cenchroides cenchroides		1,0							1,1
Falco berigora berigora			1,0						1,1
BURHINIDAE									
Burhinus grallarius									2,1

Species name	MHT01	MHT02	MHT03	RVM12	RVM13	RVM14	RVM15	RVM16	Other
CACATUIDAE									
Cacatua roseicapilla	2,0		0,2						2,0
Cacatua sanguinea	16,2	4,0	13,1						0,1
Nymphicus hollandicus			2,1						4,0
PSITTACIDAE									
Platycercus zonarius	0,1								3,3
Melopsittacus undulatus		5,0	1,1			0,1			4,3
CUCULIDAE									
Cacomantis pallidus			2,1						1,0
Chrysococcyx basalis			1,0						0,1
STRIGIDAE									
Ninox boobook boobook									0,1
Ninox connivens									0,1
ALCEDINIDAE									
Dacelo leachii leachii	3,0	1,0							0,2
Todiramphus pyrrhopygius									2,0
Todiramphus sanctus									1,1
MEROPIDAE									
Merops ornatus	3,0	1,1	2,1	0,1	0,1		0,1	0,1	3,12
PTILONORHYNCHIDAE									
Ptilonorhynchus maculatus guttatus							0,1	0,1	1,0
MALURIDAE									
Amytornis striatus									0,1
Malurus lamberti assimilis	8,0	2,1	3,1						3,0
Malurus leucopterus			6,0						0,2
ACANTHIZIDAE									

Species name	MHT01	MHT02	MHT03	RVM12	RVM13	RVM14	RVM15	RVM16	Other
Smicrornis brevirostris	5,0		0,1						3,3
PARDALOTIDAE									
Pardalotus rubricatus	1,0		2,1						0,2
Pardalotus striatus	1,0								1,0
MELIPHAGIDAE									
Ptilotula keartlandi		0,1	0,1						4,2
Ptilotula penicillata	5,1				0,2				2,2
Gavicalis virescens		3,2	3,1		0,1	0,1	0,1		
Lichmera indistincta	2,1	3,2	1,4		0,1	0,1	0,2	0,1	0,1
Manorina flavigula		0,1	3,2						4,13
Acanthagenys rufogularis		0,2					0,1		
POMATOSTOMIDAE									
Pomatostomus temporalis	**5,2**								4,8
CAMPEPHAGIDAE									
Coracina novaehollandiae	1,0	1,0	4,0						1,6
Lalage tricolor			3,0						0,1
PACHYCEPHALIDAE									
Colluricincla harmonica	1,1	1,0		0,2	0,1		0,1		2,2
Pachycephala rufiventris	4,1				0,1				
OREOICIDAE									
Oreoica gutturalis		1,1	1,0			0,1	0,2		
ARTAMIDAE									
Artamus cinereus melanops			0,1						2,1
Artamus leucorynchus									1,2
Artamus minor	1,0								0,3
Artamus personatus		1,0							1,0

Species name	MHT01	MHT02	MHT03	RVM12	RVM13	RVM14	RVM15	RVM16	Other
CRACTICIDAE									
Cracticus nigrogularis		1,0						0,1	1,2
Cracticus tibicen									3,0
RHIPIDURIDAE									
Rhipidura albiscapa									0,2
Rhipidura leucophrys leucophrys	2,1		0,2		0,1	0,1		0,1	1,3
MONARCHIDAE									
Grallina cyanoleuca	1,0								2,2
CORVIDAE									
Corvus orru	1,4	1,1	1,0		0,2	0,1	0,1		1,9
PETROICIDAE									
Melanodryas cucullata									1,0
ALAUDIDAE									
Mirafra cantillans									0,1
HIRUNDINIDAE									
Petrochelidon ariel									7,1
Petrochelidon nigricans									4,7
ACROCEPHALIDAE									
Acrocephalus australis	1,0								1,2
LOCUSTELLIDAE									
Eremiornis carteri		2,0	1,0						0,1
DICAEIDAE									
Dicaeum hirundinaceum	2,1		0,1			0,1			
ESTRILDIDAE									
Emblema pictum	2,0	3,2	**7,1**	0,2			0,1	0,1	0,8
Neochmia ruficauda subclarescens									5,15
Taeniopygia guttata	2,0	1,2	8,1		0,1	0,1	0,1		0,1

Table F.9: Non-volant mammal species recorded during the current survey.

Species name	MHT01	MHT02	MHT03	RVM12	RVM13	RVM14	RVM15	RVM16	Other
TACHYGLOSSIDAE									
Tachyglossus aculeatus									2,1
DASYURIDAE									
Dasykaluta rosamondae	1,0					0,2			
Dasyurus hallucatus	0,1							0,6	13,11
Ningaui timealeyi		5,3	1,3			0,1			
Planigale species 1	8,0	3,2	1,1		0,2				
Pseudantechinus sp.									1,0
Sminthopsis macroura			1,0	1,0					
MACROPODIDAE									
Osphranter robustus erubescens	1,0								3,1
Osphranter rufus									0,1
Petrogale rothschildi									1,1
MURIDAE									
**Mus musculus*			1,0		0,1				
Pseudomys chapmani									10,0
Pseudomys desertor		2,0	1,1						
Pseudomys hermannsburgensis	1,0	2,1	3,2				0,2		
Zyzomys argurus	1,2						0,5	0,3	1,1
CANIDAE									
**Canis dingo*									1,2
FELIDAE									
**Felis catus*									2,0
BOVIDAE									
**Bos taurus*									6,10

Table F.10: Volant mammal (bat) species recorded during the current surveys.

Species Name	BAT01	BAT02	BAT03	BAT04	BAT07	BAT08	BAT09	BAT10	BAT11	BAT12	BAT13	BAT14	Other
MEGADERMATIDAE													
Macroderma gigas								Low					1,0
RHINONYCTERIDAE													
Rhinonicteris aurantia Pilbara form	Low (3 calls)			Low (1 call)		Low (1 call)	Low (10 calls)	Low (9 calls)	Low (1 call)	Low (3 calls)		High (257 calls)	
EMBALLONURIDAE													
Saccolaimus flaviventris		Low	Low	Low	Low								
Taphozous georgaianus	Low	Low	Low	Low	High	High	High	Med	High	Med	Med	Low	5,0
VESPERTILIONIDAE													
Chalinolobus gouldii	Low	Low	Low	Low	Low	Low	Low	Low	High	Med	Low	Low	
Nyctophilus geoffroyi	Low												
Scotorepens greyii	Low		Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	
Vespadelus finlaysoni	Med		Low	Low		Med	Low	Med	High	High	Low	High	
MOLOSSIDAE													
Chaerephon jobensis	Low	Low	Low	Low	Low	Low		Low	Low	Low			
Ozimops lumsdenae													

Table F.11: Collected species in SRE Groups. Potential SRE species are shaded grey and the number of specimens per site is given in the columns.

Species Name	MHT01	MHT02	MHT03	OPP37	OPP38	RVM13	RVM14	RVM15	SRE4	SRE6	SRE8	SRE9	SRE12
ARACHNIDA													
ARANEAE													
Karaops feedtime					1								
Karaops 'sp. idet.'											1		
Aname mellosa		1					1						
PSEUDOSCORPIONES													
Beierolpium 8/4											1		
Indolpium sp. indet.											2	1	
SCORPIONES													
Lychas 'sp. nov 1'	1					1							
Lychas 'multipunctatus'		2											
Lychas 'harveyi'	1					1							
Lychas 'gracilimanus'		2											
Lychas 'sp. nov 2'			1										
Lychas 'pilbara1'								2					
Urodacus megamastigus		2											
CRUSTACEA													
ISOPODA													
Buddelundia 10bf		13											
Buddelundia 14hr	2										2		
Buddelundia '61'				1									4

Appendix G: Threatened and Priority Fauna Species Likelihood of Occurrence within the Survey Area

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Table G.1: Likelihood of occurrence of conservation listed vertebrate fauna species listed as potentially occurring in the vicinity of the survey area.

Scientific name (common name)	Conservation codes			Preferred habitat	Likelihood of occurrence	
	EPBC Act	WC Act	Parks and Wildlife		Pre-survey	Post-survey
Reptiles						
Notoscincus butleri (Lined Soil-crevice Skink)			P4	Arid, rocky, near coastal Pilbara regions. Associated with spinifex-dominated areas near creeks and river margins.	High – previously recorded	Recorded
Anilios ganei (Blindsnake)			P1	Little information is available on this species but it is believed to be associated with moist gorges and gullies.	High	High
Liasis olivaceus barroni (Pilbara Olive Python)	VU	S3		Generally rocky habitats in close association to permanent and semi-permanent water sources.	High	Recorded
Birds						
Apus pacificus (Fork-tailed Swift)	Mi	S5		Largely aerial species independent of the terrestrial environment.	Moderate	Moderate
Ardea ibis (Cattle Egret)	Mi	S5		Largely wetland species however can exploit drier open habitats more than other heron species.	Moderate	Moderate
Ardea modesta (Eastern Great Egret)	Mi	S5		Wide range of wetland habitats (for example inland and coastal, freshwater and saline, permanent and ephemeral).	High – previously recorded	High
Elanus scriptus (Letter-winged Kite)			P4	The Letter-winged Kite is a bird of open country and grasslands in arid and semi-arid Australia, where there are tree-lined streams or water courses.	Moderate	Moderate
Panidon haliaetus (Eastern Osprey)	Mi	S5		Favours coastal areas, especially the mouths of large rivers, lagoons and lakes.	Low	Low
Charadrius veredus (Oriental Plover)	Mi	S5		Breeding habitat includes arid grasslands, saltpans; non-breeding habitat includes grasslands, salt-fields, and coastal regions.	Low	Low

Scientific name (common name)	Conservation codes			Preferred habitat	Likelihood of occurrence	
	EPBC Act	WC Act	Parks and Wildlife		Pre-survey	Post-survey
Charadrius leschenaultii (Greater Sand Plover)	Mi	S5		This species is almost entirely coastal, inhabiting littoral and estuarine habitats. They mainly occur on sheltered sandy, shelly or muddy beaches with large intertidal mudflats or sandbanks, as well as sandy estuarine lagoons.	Low	Low
Rostratula benghalensis (sensu lato) (Australian Painted Snipe)	EN	S2		Shallow terrestrial freshwater wetlands, temporary/permanent lakes, swamps and claypans with emergent grass, sedges, rushes and samphire.	Moderate	Moderate
Actitis hypoleucos (Common Sandpiper)	Mi	S5		Non-breeding migrant to a wide variety of habitats, such as riverbanks, estuaries, freshwater seeps on coastal shores, tidal creeks, mangrove swamps and saltmarshes.	Moderate	Moderate
Calidris acuminata (Sharp-tailed Sandpiper)	Mi	S5		Muddy edges of shallow fresh/brackish wetlands with emergent sedges, saltmarsh, grass and low vegetation.	Moderate	Moderate
Calidris ferruginea (Curlew Sandpiper)	CR/Mi	S3/S5		This species mainly occurs on intertidal mudflats in sheltered coastal areas and also around non-tidal swamps, lakes and lagoons near the coast.	Moderate	Low
Numenius madagascariensis (Eastern Curlew)	CR	S3/S5		This species is most commonly associated with sheltered coasts, especially estuaries, bays, harbours, inlets and coastal lagoons, with large intertidal mudflats or sandflats, often with beds of seagrass.	Low	Low
Numenius phaeopus (Whimbrel)	Mi	S5		Primarily found in coastal habitats such as beaches, dunes, mudflats and mangroves however there are also scattered inland records.	Low	Low

Scientific name (common name)	Conservation codes			Preferred habitat	Likelihood of occurrence	
	EPBC Act	WC Act	Parks and Wildlife		Pre-survey	Post-survey
Tringa glareola (Wood Sandpiper)	Mi	S5		Occurs mainly on freshwater wetlands of the inland interior and arid regions.	Moderate	Moderate
Tringa nebularia (Common Greenshank)	Mi	S5		Inland wetlands and coastal habitats of varying salinity. Typically large mudflats, saltmarsh, mangroves and seagrass	Moderate	Moderate
Glareola maldivarum (Oriental Pratincole)	Mi	S5		Feeds in the air and roosts on bare ground besides water	Moderate	Moderate
Pezoporus occidentalis (Night Parrot)	EN	S1		Most habitat records are from *Triodia* grasslands and/or chenopod shrublands in the arid and semi-arid zones. *Astrebla* spp. (Mitchell grass), shrubby samphire and chenopod associations, scattered trees and shrubs, *Acacia aneura* (Mulga) woodland, treeless areas and bare gibber as associated with sightings of the species.	Low	Low
Merops ornatus (Rainbow Bee-eater)	Mi	S5		Lightly wooded, preferably sandy soil, near drainage channels and creek lines.	High – previously recorded	Recorded
Hirundo rustica (Barn Swallow)	Mi	S5		Coastal open country generally, especially near surface water and man-made structures such as bridges and power wires.	Low	Low
Motacilla cinerea (Grey Wagtail)	Mi	S5		Damp short-grass flats, rice stubbles and edge of swamps, sewage ponds, bore overflows, grazed or mowed grass and irrigated areas.	Low	Low
Motacilla flava (Yellow Wagtail)	Mi	S5		Mainly banks and rocks in fast-running freshwater habitats such as rivers, creeks, streams and around waterfalls.	Low	Low
Mammals						

Scientific name (common name)	Conservation codes			Preferred habitat	Likelihood of occurrence	
	EPBC Act	WC Act	Parks and Wildlife		Pre-survey	Post-survey
Dasycercus blythi (Brush-tailed Mulgara)			P4	Triodia hummock and Acacia shrublands of sand or sandy-loam.	Low	Low
Dasyurus hallucatus (Northern Quoll)	EN	S2		Dissected rocky escarpments and rocky eucalypt woodland.	High – previously recorded	Recorded
Sminthopis longicaudata (Long-tailed Dunnart)			P4	Common in rocky screes with hummock grassland and Acacia shrubs, tall open shrubland and woodlands.	Moderate	Moderate
Macrotis lagotis (Greater Bilby, Dalgyte)	VU	S3		Sand or sandy-loam in hummock grassland (Triodia species) and or Acacia shrublands.	Low	Low
Notoryctes caurinus (Northern Marsupial Mole)	EN			Lives primarily underground of sand dunes and sandy soils along river flats.	Low	Low
Macroderma gigas (Ghost Bat)	VU	S3		A wide range from rainforest, monsoon and vine scrub in the tropics to open woodlands and arid areas.	High – previously recorded	Recorded
Rhinonicteris aurantia (Pilbara form) (Pilbara Leaf-nosed Bat)	VU	S3		Deep warm, humid caves or rock cracks.	High – previously recorded	Recorded
Leggadina lakedownensis (Short-tailed Mouse, Karekanga)			P4	Open tussock and hummock grassland, Acacia shrubland and savannah woodland on alluvial clay / sandy soils.	Moderate	Moderate - previous records from surrounding areas
Pseudomys chapmani (Western Pebble-mound Mouse)			P4	Gentle rocky slopes, hills and spurs with small pebble surface cover and sparse vegetation.	High – previously recorded	Recorded

Table G.2: Likelihood of SRE groups occurring in the vicinity of the survey area.

SRE group	Likelihood of occurrence
Mygalomorph Spiders	The desktop review identified a diverse mygalomorph spider fauna (trapdoor spiders and allies), with at least 33 species in five families. Of these, the wishbone spiders (family Nemesiidae) were most diverse in the western Pilbara with at least 11 species followed by the brush-footed trapdoor spiders (family Barychelidae; 9 species), ctenizid trapdoor spiders (family Ctenizidae; 5) and true trapdoor spiders (family Idiopidae; 5). Mygalomorph spiders generally have a high proportion of SRE species (Castalanelli *et al.* 2013; Harms and Framenau 2013; Harvey *et al.* 2012) but all species that were collected previously near the survey area (*Aname* sp. 'Pannawonica 1', *Aurecocrypta* 'MYG057', Barychelidae indet., and *Missulena* sp. 'Pannawonica 1') were widespread (Biota 2006, ecologia Environment 2013). The most recent fauna survey at Middle Robe and East Deepdale, an area very close to Mesa H, collected only one species of mygalomorph spider: *Aname mellosa*. This species is very widespread in the western Pilbara and genetically very similar specimens are known from elsewhere in the area (Harvey *et al.* 2012; Astron 2016b). The two *Aname* species (*Aname* sp. A and *Aname* sp. C) that were collected during a previous fauna survey at Mesa H (Biota 2011) may also belong to this species but this is not certain. It is possible that *Aname mellosa* and additional mygalomorph spiders occur in the survey area although this fauna is not expected to be rich at a species level.
Araneomoprh Spiders	Two spider families with potential SRE species have been recorded: wall crab spiders (family Selenopidae) and goblin spiders (Oonopidae). Wall crab spiders are habitat specialists that live under rocks and have limited abilities of dispersal (Crews and Harvey 2011, Crews 2013). Two named species, *Karaops yindjibarndi* and *K. yurlburr*, are currently known only from their type locality in the desktop search area and may not occur elsewhere (Crews 2013). Additional selenopid spiders were collected in past surveys at Middle Robe and East Deepdale but could not be identified to species level because they were juveniles. The most recent fauna surveys by Astron at Bungaroo and Middle Robe (Astron 2016 a,b) collected three species of selenopid spdiers that were identified through DNA barcoding because adults were unavailable: *Karaops* sp. 'Bungaroo', *K.* sp. 'Middle Robe 1' and *K.* sp. 'Middle Robe 2'. All three species were assessed as potential SREs but not threatened by economic development because they occurred in habitats that are more widespread in the western Pilbara. Oonopid spiders are very small in body length, usually < 0.4 cm, and live in leaf litter. Some confirmed SRE species in the genus *Opopaea* and one potential SRE *Grymeus* species are known from the wider region and there is a remote possibility that additional species may occur at in the survey area.
Harvestmen	The harvestmen fauna of the western Pilbara region is comparably depauperate but the genus *Dampetrus* (family Assamiidae) is sometimes collected during fauna surveys and almost certainly contains SRE species (e.g. Phoenix 2014). Most specimens were taken from moist leaf litter in relict habitats (e.g. gorges or between large rock boulders) and are likely to be restricted to specific habitats (Shear 2001). One undescribed species of *Dampetrus* was recently collected during a fauna survey at Middle Robe and East Deepdale and assessed as a potential SRE species (Astron 2016b). It was collected from Breakaway habitat similar to those at Mesa H; hence there is a high likelihood that *Dampetrus* also occurs in the survey area.

SRE group	Likelihood of occurrence
Pseudoscorpions	The pseudoscorpion fauna in the desktop search area was moderately diverse with several potential SRE species in six families: Chthoniidae, Garypidae, Garypinidae, Hyidae, Sternophoridae, and Syarinidae. The family Chthoniidae includes species that are usually collected in moist leaf litter and these species may have short ranges. This family has been recorded from subterranean habitats at Middle Robe and additional records from surface habitats in the Bungaroo Valley have recently been established (Astron 2016a,b). *Synsphyronus* species in the family Garypidae are habitat specialists that live under rocks and have been collected previously from the hills and breakaways at Bungaroo (Biota 2010). *Ideoblothrus* and *Indohya* species are known from moist leaf litter in the search area and the available taxonomic literature points to high regional endemism and range restriction in this fauna (Harvey 1993; Harvey and Edward 2007; Harvey and Volschenk 2007). Recent surveys at the Bungaroo Iron Ore Mine collected a moderately diverse fauna of pseudoscorpions and three potential SRE species (Astron 2016a). Two pseudoscorpion species were collected during the survey at Middle Robe and East Deepdale but both species were widespread (Astron 2016b). No pseudoscorpion species were collected at Mesa J (Astron 2016c). It is very likely that pseudoscorpions occur in the survey area but the assessment of ranges is principally on a case-by-case basis.
Scorpions	Two genera of scorpions, *Lychas* and *Urodacus*, have been recorded in the desktop search area. Most scorpions are arid-adapted and considered widespread across the Pilbara (e.g. ecologia Environment 2013). The Pilbara Biodiversity Survey recorded ten morphospecies of *Lychas* but the taxonomic resolution is currently poor and there are likely many more species (Volschenk *et al.* 2010), some of these with short ranges. Ongoing genetic research at the Western Australian Museum has also shown that there are some morphologically cryptic but genetically distinct species of *Lychas* that may have ranges below the current SRE threshold of 10,000 km^2. The recent fauna survey at Middle Robe and East Deepdale collected two potential SRE scorpions in the *Lychas* 'hairy tail' and *Lychas* 'multipunctatus' species complexes (Astron 2016b). These were collected from Breakaway, Riverine and Rocky Hills habitat. All these habitat types are present at Mesa H and there is a high likelihood that a diverse scorpion fauna occurs in the survey area that may contain some SREs.
Terrestrial Slaters	This group is extremely diverse but taxonomically unrevised and species identification is extremely difficult. The desktop review identified a rich and diverse fauna of terrestrial slaters in the survey area with more than 20 potential SRE species. The slater family Armadillidae, slaters that roll up as a ball when disturbed, includes most of the species and includes many potential SREs. Other groups, such as the Philoscidiidae, also occur but seem to be less diverse at a species level, although almost nothing is known about species boundaries and distributions. Slaters were not assessed in a fauna survey at Mesa H (Biota 2011) but more recent surveys at the Bungaroo Iron Mine Project (Astron 2016a), Middle Robe and Deepdale (Astron 2016b) and Mesa J (Astron 2016c) collected several species of slaters. Of these, the four species *Buddelundia* '61', Buddelundiinae sp. indet., Philoscidiidae sp. indet. and *Spherillo* sp. indet. were assessed as potential SRE species. They were collected from habitats that are similar to those at Mesa H. Based on the data available, the presence of potentially range-restricted isopods in the survey area is almost certain.
Millipedes	This group is taxonomically diverse but almost all species in the genera *Antichiropus* and *Boreohesperus* (family Paradoxosomatidae) are confirmed SREs. Three species of *Boreohesperus* have recently been described (Car and Harvey 2013) from the wider search area but their ranges do not overlap with the survey area. At least five species in the genus *Antichiropus* are also known and there are numerous additional records of unidentified juveniles in the search area. However, none of the most recent fauna surveys in the area (Astron 2016a, b, c) recorded millipedes in the survey area or its vicinity, despite favourable climatic conditions and suitable collecting techniques. From the data available, it is unlikely that millipedes are diverse in the survey area and occur with range-restricted species.

SRE group	Likelihood of occurrence
Centipedes	Almost nothing is known about the centipede fauna of the Pilbara but three families, Chilenophilidae, Cryptopidae and Mecistocephalidae, have been recorded and are likely to include SRE species. The records of *Cryptops* sp. indet., *Mecistocephalus* sp. indet. and *Sependophilus* sp. indet. in the search area are likely to represent several range-restricted species. However, none of the recent surveys by Astron (2016a, b, c) in the vicinity of the survey area have provided evidence for the occurrence of centipedes. It is considered unlikely that a diverse centipede community occurs locally.
Snails	Three families of terrestrial snails occur in the search area: the Bothriembryontidae, Camaenidae and Pupillidae. The Pupillidae comprise widespread species but the Camaenidae include some potential and confirmed SREs species. The camaenid genus *Quistrachia* is present in the search area with at least two potential SRE species and a second genus, *Rhagada*, is common and frequently collected during environmental surveys. Species identification in *Rhagada* is often difficult because species are morphologically cryptic, have variable shell morphology, occur in sympatry, and hybridize (Hamilton and Johnson 2015). However, two well-diagnosed morphospecies have been collected from Middle Robe and East Deepdale in a recent SRE survey (*Rhagada convicta* and *R. radleyi*) and one of these (*R. convicta*) has been collected previously from Mesa H (Biota 2011). Both species are widespread (Astron 2016b). A third species of *Rhagada* (*R*. sp. 'Pannawonica') is known from the Bungaroo Creek Valley and this species is also widespread (Astron 2016a). Aquatic snail families in the search area belong to the families Glacidorbidae, Hydrobiidae, Lymnaeidae and Planorbidae and these families include few SRE species. All aquatic snails collected from the Bungaroo Creek Valley in the recent SRE survey (Astron 2016a) were assessed as widespread. In summary, there is a potential for both aquatic snails and terrestrial snails to occur in the survey area but the species present are expected to be widespread.

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Appendix H: Fauna Habitat Mapping and Significant Areas

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Legend

- Survey Area

Significant Areas

Caves

- Diurnal roost
- Nocturnal feeding roost
- Pools

Habitat Type

- Breakaway
- Gorge
- Loamy/stony plain
- Low hills and slopes
- Riverine
- Drainage
- Rocky hills
- Disturbed

H18 (Cave 2)
H18 (Cave 2 and 3)
H18 (Cave 3)

INSET: H18 (Caves 2 and 3)

H.1A
H.1B
H.1C

ROBE RIVER
ROBE RIVER
ROBE RIVER
ROBE RIVER

H27
MH-Opp 2S
H18 (Cave 2)
H18 (Cave 2 and 3)
H18 (Cave 3)

Robe River Mining Co. Pty Ltd

Mesa H – Level 2 Fauna Assessment, May 2016

Figure H.1A : Vertebrate Fauna and SRE Habitat Mapping

Coordinate System: GDA 1994 MGA Zone 50

0 200 400 600 800 1,000 Metres

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ROBE RIVER

MH-Opp 1S
MH16-34 (Cave 1)
MH16-35
MH-Opp 3S
H01-A01 MH15-44
AC04 (Cave 4)
MH15-13 MH15-14
AC05 (Cave 5)

Legend

- Survey Area

Significant Areas

Caves

- Diurnal roost
- Nocturnal feeding roost
- Pools

Habitat Type

- Breakaway
- Gorge
- Loamy/stony plain
- Low hills and slopes
- Riverine
- Drainage
- Rocky hills
- Disturbed

H.1A
H.1B
H.1C

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Figure H.1B : Vertebrate Fauna and SRE Habitat Mapping

Coordinate System: GDA 1994 MGA Zone 50

0 200 400 600 800 1,000 Metres

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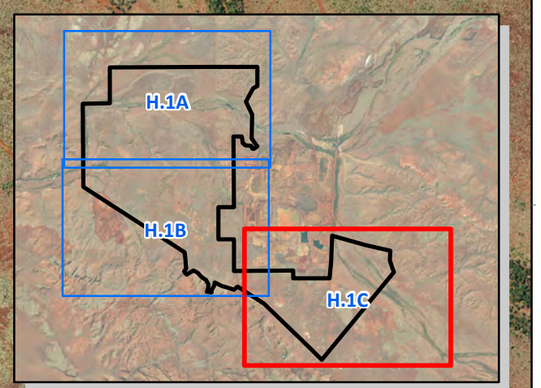
Legend

- Survey Area
- **Significant Areas**
- *Caves*
- Diurnal roost
- Nocturnal feeding roost
- Pools
- **Habitat Type**
- Breakaway
- Gorge
- Loamy/stony plain
- Low hills and slopes
- Riverine
- Drainage
- Rocky hills
- Disturbed

JIMMAWURRADA CREEK



Robe River Mining Co. Pty Ltd

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Figure H.1C : Vertebrate Fauna and SRE Habitat Mapping

Coordinate System: GDA 1994 MGA Zone 50

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Legend

Survey Area

Northern Quoll Habitat Suitability Mapping

Potential shelter and foraging habitat

Suitable foraging and dispersal habitat

Limited foraging and dispersal habitat

H.2A

H.2B

H.2C

ROBE RIVER

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Mesa H – Level 2 Fauna Assessment, May 2016

Figure H.2A: Northern Quoll Habitat Suitability Mapping

Coordinate System: GDA 1994 MGA Zone 50

0 200 400 600 800 1,000 Metres

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ROBE RIVER

Legend

Survey Area

Northern Quoll Habitat Suitability Mapping

Potential shelter and foraging habitat

Suitable foraging and dispersal habitat

Limited foraging and dispersal habitat

H.2A

H.2B

H.2C

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Figure H.2B: Northern Quoll Habitat Suitability Mapping

Coordinate System: GDA 1994 MGA Zone 50

0 200 400 600 800 1,000 Metres

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Survey Area

Northern Quoll Habitat Suitability Mapping

Potential shelter and foraging habitat

Suitable foraging and dispersal habitat

Limited foraging and dispersal habitat

JIMMAWURRADA CREEK

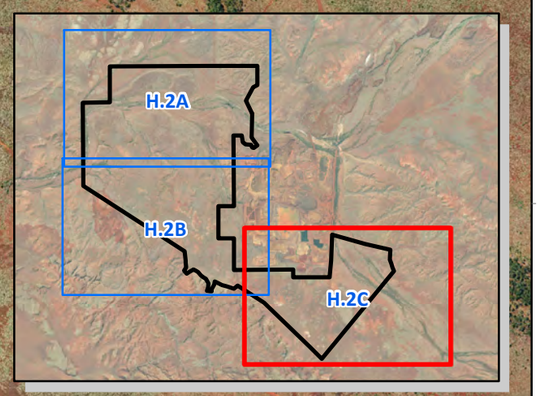

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Figure H.2C: Northern Quoll Habitat Suitability Mapping

Coordinate System: GDA 1994 MGA Zone 50

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Legend

Survey Area

Ghost Bat Habitat Suitability Mapping

Potential shelter and foraging habitat

Suitable foraging and dispersal habitat

Limited foraging and dispersal habitat

H.3A

H.3B

H.3C

ROBE RIVER

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Figure H.3A: Ghost Bat Habitat Suitability Mapping

Coordinate System: GDA 1994 MGA Zone 50

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ROBE RIVER

Legend

Survey Area

Ghost Bat Habitat Suitability Mapping

Potential shelter and foraging habitat

Suitable foraging and dispersal habitat

Limited foraging and dispersal habitat

H.3A

H.3B

H.3C

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Figure H.3B: Ghost Bat Habitat Suitability Mapping

Coordinate System: GDA 1994 MGA Zone 50

0 200 400 600 800 1,000 Metres

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Legend

- Survey Area

Ghost Bat Habitat Suitability Mapping

- Potential shelter and foraging habitat
- Suitable foraging and dispersal habitat
- Limited foraging and dispersal habitat

JIMMAWURRADA CREEK

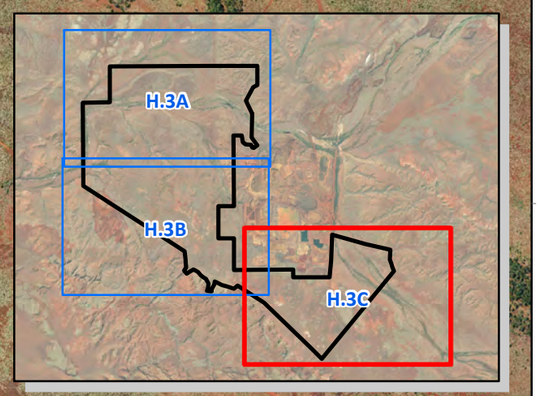

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Figure H.3C: Ghost Bat Habitat Suitability Mapping

Coordinate System: GDA 1994 MGA Zone 50

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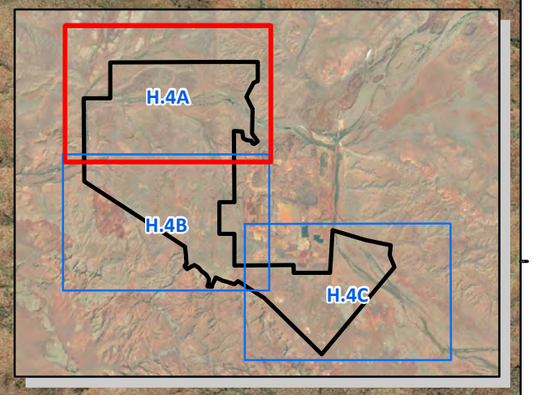
Survey Area

Pilbara Leaf-nosed Bat Habitat Suitability Mapping

Potential shelter and foraging habitat

Suitable foraging and dispersal habitat

Limited foraging and dispersal habitat



ROBE RIVER

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Figure H.4A: Pilbara Leaf-nosed Bat Habitat Suitability Mapping

Coordinate System: GDA 1994 MGA Zone 50

0 200 400 600 800 1,000 Metres

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ROBE RIVER

Legend

Survey Area

Pilbara Leaf-nosed Bat Habitat Suitability Mapping

Potential shelter and foraging habitat

Suitable foraging and dispersal habitat

Limited foraging and dispersal habitat

H.4A
H.4B
H.4C

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Mesa H – Level 2 Fauna Assessment, May 2016

Figure H.4B: Pilbara Leaf-nosed Bat Habitat Suitability Mapping

Coordinate System: GDA 1994 MGA Zone 50

Metres

0 200 400 600 800 1,000

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Survey Area

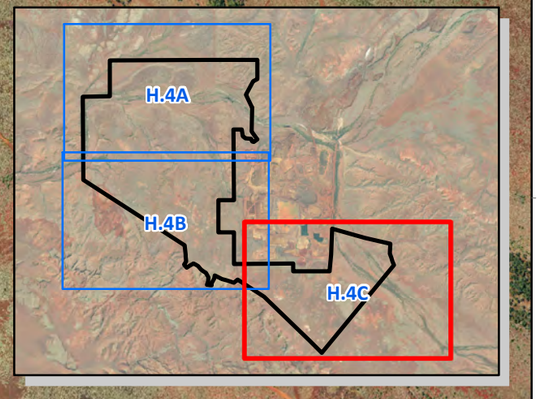
Pilbara Leaf-nosed Bat Habitat Suitability Mapping

Potential shelter and foraging habitat

Suitable foraging and dispersal habitat

Limited foraging and dispersal habitat

JIMMAWURRADA CREEK



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Mesa H – Level 2 Fauna Assessment, May 2016

Figure H.4C: Pilbara Leaf-nosed Bat Habitat Suitability Mapping

Coordinate System: GDA 1994 MGA Zone 50

0 200 400 600 800 1,000 Metres

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Survey Area

Pilbara Olive Python Habitat Suitability Mapping

Potential shelter and foraging habitat

Suitable foraging and dispersal habitat

Limited foraging and dispersal habitat

H.5A

H.5B

H.5C

ROBE RIVER

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Mesa H – Level 2 Fauna Assessment, May 2016

Figure H.5A: Pilbara Olive Python Habitat Suitability Mapping

Coordinate System: GDA 1994 MGA Zone 50

0 200 400 600 800 1,000 Metres

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414000 416000 418000 420000

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ROBE RIVER

Legend

Survey Area

Pilbara Olive Python Habitat Suitability Mapping

Potential shelter and foraging habitat

Suitable foraging and dispersal habitat

Limited foraging and dispersal habitat

H.5A

H.5B

H.5C

Robe River Mining Co. Pty Ltd

Mesa H – Level 2 Fauna Assessment, May 2016

Figure H.5B: Pilbara Olive Python Habitat Suitability Mapping

Coordinate System: GDA 1994 MGA Zone 50

0 200 400 600 800 1,000 Metres

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Legend

Survey Area

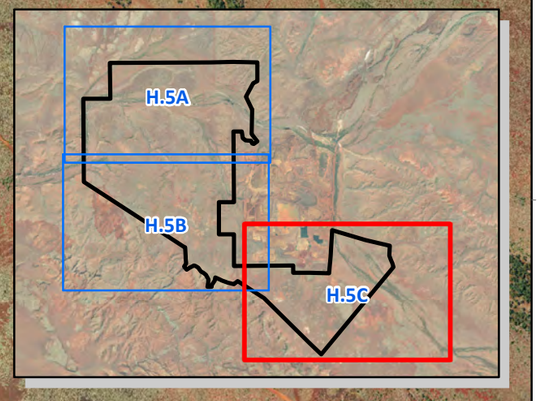
Pilbara Olive Python Habitat Suitability Mapping

Potential shelter and foraging habitat

Suitable foraging and dispersal habitat

Limited foraging and dispersal habitat

JIMMAWURRADA CREEK



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Mesa H – Level 2 Fauna Assessment, May 2016

Figure H.5C: Pilbara Olive Python Habitat Suitability Mapping

Coordinate System: GDA 1994 MGA Zone 50

0 200 400 600 800 1,000 Metres

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Table H.1: Location of significant areas recorded during the Astron field surveys.

Site ID	Survey	MGA Zone 50 K		Reason	Assessed Ghost Bat roost type (Bat Call WA 2017)	Photograph
		Easting (mE)	Northing (mE)			
Caves						
Cave 1	Level 1 survey (Astron 2014)	415802	7595656	Large deep cave with single entrance facing into a small gorge. Ghost Bat scats present. Northern Quoll scat present.	Diurnal roost. Possible maternal roost.	
MH16-34	Mesa H Cave Assessment (Bat Call WA 2017)	415815	7595655	Deep cave with a single internal dome. No Ghost Bats present.		
Cave 4	Level 1 survey (Astron 2014)	417586	7594895	Significant deep cave facing into a small gorge. Ghost Bat scats present.	Diurnal roost. Occasional use as a maternal roost possible but no current evidence of use this year.	
AC04	Mesa H Cave Assessment (Bat Call WA 2017)			Cave with multiple internal domes. Ghost Bat scats present.		

Site ID	Survey	MGA Zone 50 K		Reason	Assessed Ghost Bat roost type (Bat Call WA 2017)	Photograph
		Easting (mE)	Northing (mE)			
Cave 2 and 3 (multiple caves)	Level 1 survey (Astron 2014)	415149 415168	7596502 7596492	Series of significant deep caves. Deep, dark, with series of openings and in the vicinity (200 m to 300 m of permanent water). Ghost Bats present – scats and remains of Ghost Bat.	Nocturnal feeding roost.	
H18	Mesa H Cave Assessment (Bat Call WA 2017)	415164	7596495	Shallow cave with two low domes. No Ghost Bat guano present.		
Cave 5	Level 1 survey (Astron 2014)	417109	7593285	Significant deep cave facing into a small gorge. Ghost Bat scats present.	Nocturnal feeding roost.	
AC05	Mesa H Cave Assessment (Bat Call WA 2017)			Cave with a single internal dome. Ghost Bat scats present.		

Site ID	Survey	MGA Zone 50 K		Reason	Assessed Ghost Bat roost type (Bat Call WA 2017)	Photograph
		Easting (mE)	Northing (mE)			
H01-A01 MH15-44	Mesa H Cave Assessment (Bat Call WA 2017)	417270	7595276	Shelter with a low internal dome. Several overhangs to the north and south. Ghost Bat guano present.	Nocturnal feeding roost.	
H27	Mesa H Cave Assessment (Bat Call WA 2017)	416587	7596590	Deep shelter with two low internal domes. Several overhangs to the north and south. No Ghost Bat guano present.	Nocturnal feeding roost.	

Site ID	Survey	MGA Zone 50 K		Reason	Assessed Ghost Bat roost type (Bat Call WA 2017)	Photograph
		Easting (mE)	Northing (mE)			
MH15-13 MH15-14	Mesa H Cave Assessment (Bat Call WA 2017)	417252	7594383	Shelter with a high pipe in roof. Ghost Bat guano present.	Nocturnal feeding roost.	
MH16-35	Mesa H Cave Assessment (Bat Call WA 2017)	415782	7595640	Shelter with overhangs to west and opposite. No Ghost Bat guano present.	Nocturnal feeding roost.	No photo
MH-Opp 1S	Mesa H Cave Assessment (Bat Call WA 2017)	415625	7595659	Deep shelter with several overhangs to the east and west. No Ghost Bat guano present.	Nocturnal feeding roost.	No photo
MH-Opp 2S	Mesa H Cave Assessment (Bat Call WA 2017)	416948	7596585	Deep shelter with several overhangs to the north. No Ghost Bat guano present.	Nocturnal feeding roost.	No photo
MH-Opp 3S	Mesa H Cave Assessment (Bat Call WA 2017)	417330	7595332	Deep shelter with several overhangs to the south. No Ghost Bat guano present.	Nocturnal feeding roost.	No photo

Site ID	Survey	MGA Zone 50 K		Reason	Assessed Ghost Bat roost type (Bat Call WA 2017)	Photograph
		Easting (mE)	Northing (mE)			
Cave 6 AC06	Level 1 survey (Astron 2014) Mesa H Cave Assessment (Bat Call WA 2017)	418068	7592683	Series of t deep caves. Deep, dark opening into small gorge. Ghost Bat scats present. Shelter with overhangs at creek level to the east. No Ghost Bat guano present.	Shelter only. Not regularly used.	
Cave 7 H16	Level 1 survey (Astron 2014) Mesa H Cave Assessment (Bat Call WA 2017)	415265 415266	7596486 7596488	Large deep cave with single entrance facing into a small gorge. Ghost Bat scats present. Shelter with low roof. No Ghost Bat guano present. Additional overhangs nearby and on opposite side of gully with no Ghost Bat evidence	Overhang only. Not used.	
H2		414628	7597699	Overhang. No Ghost Bat guano present.	Overhang only. Not used.	No photo
H3,H4,H5,H6,H7		414730	7597728	A series of overhangs along cliff face. No Ghost Bat guano present.	Overhang only. Not used.	

Site ID	Survey	MGA Zone 50 K		Reason	Assessed Ghost Bat roost type (Bat Call WA 2017)	Photograph
		Easting (mE)	Northing (mE)			
H19		415126	7596488	Shelter with low roof. No Ghost Bat guano present.	Shelter only. Not used.	
H24		416776	7596072	Overhang. No Ghost Bat guano present.	Overhang only. Not used.	No photo
H34		415315	7595811	Shelter with several overhangs to the east and west. No Ghost Bat guano present.	Shelter only. Not regularly used.	
H36		415667	7595692	Unable to approach due to steep cliff. Assessed from opposite side of gully.	Shallow shelter only. Not used.	No photo

Site ID	Survey	MGA Zone 50 K		Reason	Assessed Ghost Bat roost type (Bat Call WA 2017)	Photograph
		Easting (mE)	Northing (mE)			
MH15-25 H29		416571	7597124	Shelter with overhangs to west and east. No Ghost Bat guano present.	Shelter only. Not regularly used.	
MH15-47		417248	7595912	Shelter with low roof. No Ghost Bat guano present.	Not used.	No photo
MH15-95		414938	7597150	Shelter with low roof. No Ghost Bat guano present. Has additional overhangs nearby and on opposite face with no Ghost Bat evidence.	Not regularly used.	No photo
MH15-96		414925	7597127	Shelter with low roof. No Ghost Bat guano present.	Not used.	

Site ID	Survey	MGA Zone 50 K		Reason	Assessed Ghost Bat roost type (Bat Call WA 2017)	Photograph
		Easting (mE)	Northing (mE)			
MH15-97		414899	7597103	Shelter with low roof. No Ghost Bat guano present.	Not used.	

Site ID	Survey	MGA Zone 50 K		Reason	Photograph
		Easting (mE)	Northing (mE)		
Water Sources					
Pool 1	Level 1 survey (Astron 2014)	414390	7597485	Permanent pool of the Robe River, likely to support MNES bat species, migratory bird species and other conservation significant fauna species.	

Site ID	Survey	MGA Zone 50 K		Reason	Photograph
		Easting (mE)	Northing (mE)		
Pool 2	Level 1 survey (Astron 2014)	414415	7596570	Permanent pool of the Robe River, likely to support MNES bat species, migratory bird species and other conservation significant fauna species.	
Pool 3	Phase 1 Level 2 survey (Astron 2016)	414405	7596615	Permanent Pool of the Robe River with abundant Typha. Important habitat for migratory listed birds. Fortescue Grunter recorded.	
Pool 4	Phase 1 Level 2 survey (Astron 2016)	417192	7598072	Permanent Pool of the Robe River with abundant Typha. Important habitat for migratory listed birds.	

Site ID	Survey	MGA Zone 50 K		Reason	Photograph
		Easting (mE)	Northing (mE)		
Pool 5	Phase 1 Level 2 survey (Astron 2016)	418060	7598016	Permanent Pool of the Robe River with abundant Typha. Important habitat for migratory listed birds.	

Appendix I: Conservation Listed and SRE Fauna Locations

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414000 416000 418000 420000

7600000 7598000 7596000

Legend

Conservation Significant Fauna (Previous Surveys)

Survey Area

Conservation Significant Vertebrate Fauna Locations

Reptiles

Liasis olivaceus barroni (Pilbara Olive Python)

Notoscincus butleri (Lined Soil-crevice Skink)

Birds

Merops ornatus (Rainbow Bee-eater)

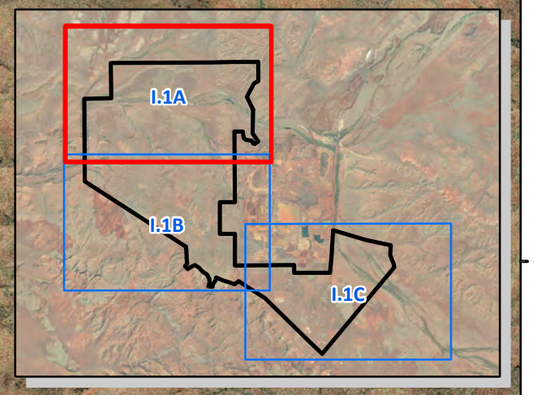
Mammals

Rhinonicteris aurantia (Pilbara Leaf-nosed Bat)

Macroderma gigas (Ghost Bat)

Pseudomys chapmani (Western Pebble-mound Mouse)

Dasyurus hallucatus (Northern Quoll)



Rainbow Bee-eater
Rainbow Bee-eater
Rainbow Bee-eater
Northern Quoll
Pilbara Leaf-nosed Bat
Rainbow Bee-eater
Ghost Bat
Rainbow Bee-eater
Western Pebble-mound Mouse
Rainbow Bee-eater
Western Pebble-mound Mouse
Eastern Great Egret
Rainbow Bee-eater
ROBE RIVER
Pilbara Leaf-nosed Bat
Pilbara Olive Python
Rainbow Bee-eater
Pilbara Leaf-nosed Bat
Pilbara Leaf-nosed Bat
Ghost Bat
Northern Quoll
Northern Quoll
Pilbara Leaf-nosed Bat
Ghost Bat
Rainbow Bee-eater
Northern Quoll
Pilbara Leaf-nosed Bat
Rainbow Bee-eater
Northern Quoll
Northern Quoll
Pilbara Olive Python
Rainbow Bee-eater
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Rainbow Bee-eater
Northern Quoll
Northern Quoll
Rainbow Bee-eater
Northern Quoll
Northern Quoll
Rainbow Bee-eater
Rainbow Bee-eater
Rainbow Bee-eater
Ghost Bat
Rainbow Bee-eater
Pilbara Leaf-nosed Bat
Ghost Bat
Rainbow Bee-eater
Ghost Bat

Robe River Mining Co. Pty Ltd

Mesa H – Level 2 Fauna Assessment, May 2016

Figure I.1A: Current and previous conservation significant vertebrate fauna locations

Coordinate System: GDA 1994 MGA Zone 50

0 200 400 600 800 1,000 Metres

N

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Author: J. Trainer | Drawn: C. Dyde | Date: 15-08-2017 | Figure Ref: 14269-16-BIDR-3Rev1_170815_FigI1A

414000 416000 418000 420000

7596000 7594000 7592000

ROBE RIVER

Rainbow Bee-eater
Ghost Bat
Pilbara Leaf-nosed Bat
Ghost Bat
Rainbow Bee-eater
Rainbow Bee-eater
Lined Soil-crevice Skink
Rainbow Bee-eater
Western Pebble-mound Mouse
Pilbara Leaf-nosed Bat
Ghost Bat
Lined Soil-crevice Skink
Western Pebble-mound Mouse
Northern Quoll
Rainbow Bee-eater
Rainbow Bee-eater
Lined Soil-crevice Skink
Lined Soil-crevice Skink
Pilbara Leaf-nosed Bat
Rainbow Bee-eater
Ghost Bat
Northern Quoll
Northern Quoll
Northern Quoll
Ghost Bat
Lined Soil-crevice Skink
Rainbow Bee-eater
Rainbow Bee-eater
Pilbara Leaf-nosed Bat
Western Pebble-mound Mouse
Western Pebble-mound Mouse
Western Pebble-mound Mouse
Western Pebble-mound Mouse
Ghost Bat
Northern Quoll
Northern Quoll
Northern Quoll
Pilbara Leaf-nosed Bat
Pilbara Leaf-nosed Bat

I.1A
I.1B
I.1C

Legend

Conservation Significant Fauna (Previous Surveys)

Survey Area

Conservation Significant Vertebrate Fauna Locations

Reptiles

Liasis olivaceus barroni (Pilbara Olive Python)

Notoscincus butleri (Lined Soil-crevice Skink)

Birds

Merops ornatus (Rainbow Bee-eater)

Mammals

Rhinonicteris aurantia (Pilbara Leaf-nosed Bat)

Macroderma gigas (Ghost Bat)

Pseudomys chapmani (Western Pebble-mound Mouse)

Dasyurus hallucatus (Northern Quoll)

Robe River Mining Co. Pty Ltd

Mesa H – Level 2 Fauna Assessment, May 2016

Figure I.1B: Current and previous conservation significant vertebrate fauna locations

Coordinate System: GDA 1994 MGA Zone 50

0 200 400 600 800 1,000 Metres

N

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422000 424000 426000 428000

7592000

7590000

Rainbow Bee-eater
Rainbow Bee-eater
Rainbow Bee-eater
Rainbow Bee-eater

ebble-mound Mouse
le-mound Mouse
e-mound Mouse

Lined Soil-crevice Skink
Pilbara Leaf-nosed Bat
Lined Soil-crevice Skink
Western Pebble-mound Mouse
Western Pebble-mound Mouse
Western Pebble-mound Mouse

I.1A
I.1B
I.1C

JIMMAWURRADA CREEK

Legend

- Conservation Significant Fauna (Previous Surveys)
- Survey Area

Conservation Significant Vertebrate Fauna Locations

Reptiles

- *Liasis olivaceus barroni* (Pilbara Olive Python)
- *Notoscincus butleri* (Lined Soil-crevice Skink)

Birds

- *Merops ornatus* (Rainbow Bee-eater)

Mammals

- *Rhinonicteris aurantia* (Pilbara Leaf-nosed Bat)
- *Macroderma gigas* (Ghost Bat)
- *Pseudomys chapmani* (Western Pebble-mound Mouse)
- *Dasyurus hallucatus* (Northern Quoll)

Robe River Mining Co. Pty Ltd

Mesa H – Level 2 Fauna Assessment, May 2016

Figure I.1C: Current and previous conservation significant vertebrate fauna locations

Coordinate System: GDA 1994 MGA Zone 50

0 200 400 600 800 1,000 Metres

N

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Author: J. Trainer | Drawn: C. Dyde | Date: 15-08-2017 | Figure Ref: 14269-16-BIDR-3Rev1_170815_FigI1A

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Table I.1 Locations of vertebrate conservation listed species recorded during the Astron Phase 1 and 2 field surveys.

Species name (common name)	Status	Site ID	MGA Zone 50 K		Observation type (number of records)	Habitat	Photograph
			Easting (mE)	Northing (mN)			
Reptiles							
Liasis olivaceus barroni (Pilbara Olive Python)	VU / S3	OPP08	416809	7597283	Scat	Breakaway	No photo
		OPP09	417156	7597953	Scat	Breakaway	
		NOC01	418583	7597957	Individual (1)	Riverine	
Notoscincus butleri (Lined Soil-crevice Skink)	P4	MHT03	419172	7592794	Individual (1)	Loamy/Stony Plain	No photo
Birds							
Merops ornatus (Rainbow Bee-eater)	Mi / S5	HA01	414405	7596614	Individuals (3)	Loamy/Stony Plain	
		HA22	423929	7592643	Individual (1)	Drainage Line	
		HA23	424018	7592961	Individual (1)	Drainage Line	
		MHT01	414614	7597885	Individuals (3)	Riverine	
		MHT02	416302	7599273	Individuals (2)	Loamy/Stony Plain	
		MHT03	419172	7592794	Individuals (3)	Loamy/Stony Plain	
		RVM12	416226	7598927	Individual (1)	Breakaway	
		RVM13	418743	7598258	Individual (1)	Riverine	
		RVM15	417456	7593904	Individual (1)	Low Hills and Slopes	
		RVM16	414917	7596337	Individual (1)	Breakaway	
		OPP17	419135	7597353	Individual (1)	Loamy/Stony Plain	
		OPP23	414409	7597627	Individual (1)	Riverine	
		OPP29	416182	7598967	Individual (1)	Low Hills and Slopes	
		OPP30	419406	7595180	Individual (1)	Loamy/Stony Plain	
		OPP31	419880	7592150	Individual (1)	Loamy/Stony Plain	
		OPP32	423840	7592884	Individual (1)	Drainage Line	

Species name (common name)	Status	Site ID	MGA Zone 50 K		Observation type (number of records)	Habitat	Photograph
			Easting (mE)	Northing (mN)			
		OPP33	423897	7593106	Individual (1)	Drainage Line	
		OPP34	416114	7596572	Individual (1)	Low Hills and Slopes	
		OPP35	414436	7596222	Individual (1)	Riverine	
		SRE06	415332	7596472	Individual (1)	Gorge	
Mammals							
Dasyurus hallucatus (Northern Quoll)	EN / S2	MHT01	414614	7597885	Individual (1)	Riverine	
		RVM16	414917	7596337	Individuals (3)	Breakaway	
		RVM16	414917	7596337	Scat	Breakaway	
		HA21	419109	7591092	Scat	Gorge	
		CAM11	417716	7593081	Sighted on camera (1)	Gorge	
		CAM12	417951	7593003	Sighted on camera (2)	Gorge	
		CAM13	418099	7599090	Sighted on camera (1)	Gorge	
		CAM17	414384	7596548	Sighted on camera (2)	Riverine	
		CAM18	414384	7596626	Sighted on camera (4)	Gorge	
		CAM20	415163	7596516	Sighted on camera (1)	Gorge	
		CAM32	414360	7597586	Sighted on camera (2)	Breakaway	
		CAM33	414412	7597587	Sighted on camera (1)	Breakaway	
		CAM34	414390	7597588	Sighted on camera (1)	Breakaway	
		CAM37	414395	7597589	Sighted on camera (1)	Breakaway	
		CAM38	419085	7591202	Sighted on camera (2)	Breakaway	

Species name (common name)	Status	Site ID	MGA Zone 50 K		Observation type (number of records)	Habitat	Photograph
			Easting (mE)	Northing (mN)			
Dasyurus hallucatus (Northern Quoll)	EN / S2	CAM39	419092	7591197	Sighted on camera (1)	Breakaway	
		CAM40	415252	7596465	Sighted on camera (2)	Breakaway	
		CAM41	416117	7596650	Sighted on camera (1)	Breakaway	
		OPP03	414337	7596627	Scat	Breakaway	
		OPP04	415146	7596479	Scat	Breakaway	
Rhinonicteris aurantia (Pilbara Leaf-nosed Bat)	VU / S3	BAT01	419610	7599052	Acoustic recording (1)	Low Hills and Slopes	No photo
		BAT04	421971	7591055	Acoustic recording (1)	Low Hills and Slopes	
		BAT08	416698	7593658	Acoustic recording (1)	Gorge	
		BAT09	419102	7591026	Acoustic recording (1)	Gorge	
		BAT10	419092	7591197	Acoustic recording (1)	Gorge	
		BAT11	414380	7597584	Acoustic recording (1)	Riverine	
		BAT12	414397	7597585	Acoustic recording (1)	Riverine	
		BAT14	418220	7591848	Acoustic recording (1)	Gorge/Drainage Line	
Macroderma gigas (Ghost Bat)	VU / S3	BAT10	419092	7591197	Acoustic recording (4)	Gorge	No photo
		OPP02	419408	7596586	Scat	Breakaway	

Species name (common name)	Status	Site ID	MGA Zone 50 K		Observation type (number of records)	Habitat	Photograph
			Easting (mE)	Northing (mN)			
Pseudomys chapmani (Western Pebble-mound Mouse)	P4	HA03	418084	7598558	Inactive mound (1)	Low Hills and Slopes	
		OPP11	419812	7591745	Inactive mound (1)	Low Hills and Slopes	
		OPP12	419773	7591728	Inactive mound (1)	Low Hills and Slopes	
		OPP13	419772	7591659	Inactive mound (1)	Low Hills and Slopes	
		OPP14	419729	7591766	Inactive mound (1)	Low Hills and Slopes	

414000 416000 418000 420000

7598000 7596000 7594000 7592000

Lychas sp. nov 2

Buddelundia 61

Karaops feedtime

Lychas sp. nov 1

Lychas sp. nov 1

Buddelundia 61

Lychas sp. nov 2

Karaops sp. idet.

Legend

Survey Area

Potential SRE locations

Scorpions

Slaters

Spiders

Robe River Mining Co. Pty Ltd

Mesa H – Level 2 Fauna Assessment, May 2016

Figure I.2: Potential SRE locations

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Author: J. Trainer	Date: 27-09-2017
Drawn: C. Dyde	Figure Ref: 14269-16-BIDR-3Rev2_170927_FigI2

Coordinate System: GDA 1994 MGA Zone 50

0 500 1,000 1,500 2,000 Metres

N

Table I.2 Locations of Potential SRE species recorded during the Astron Phase 1 and 2 field surveys.

Species	WAM SRE Category	Site(s)	Landform	MGA Zone 50 K		Status
				Easting (mE)	Northing (mE)	
Slaters						
Buddelundia '61'	Potential SRE – Research and Expertise	OPP37	Breakaway	420591	7599033	Also known from Bungaroo.
		SRE12	Gorge	415606	7595708	
Scorpiones						
Lychas sp. nov. 1	Potential SRE – Molecular Evidence	MHT01	Riparian	414614	7597592	Probably more widespread.
		RVM13	Riparian	418784	7597593	
Lychas sp. nov. 2	Potential SRE – Molecular Evidence	MHT02	Loamy/Stony Plains	416302	7599270	Sequenced for the first time. Possibly conspecific with the more widespread *Lychas* 'gracilimanus'
		MHT03		419181	7592799	
Spiders						
Karaops sp. indet.	Potential SRE – Molecular Evidence	SRE08	Breakaway	418236	7591842	Unresolved taxonomy, additional records from outside the survey area
Karaops feedtime	Potential SRE – Data Deficient	OPP38	Disturbed Areas	420512	7598718	Unresolved taxonomy, additional records from outside the survey area

Appendix J: Bat Call WA Pty Ltd Report

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Mesa H survey,
Pilbara WA,
September-October 2015 / May-June 2016

Echolocation Survey of Bat Activity.

Prepared for Astron Environmental Services

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Prepared by:
R. D. Bullen – Bat Call WA
Issue !
23 August 2017

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Document Revision History

Issue	Date	Revision History
A	10 October 2015	Initial draft prepared for Astron
B	18 May 2016	Phase 2 results from May 2016 added
C	14 June 2016	Additional Areas results from June 2016 added
1	23 Aug 2017	Formal Issue

Summary
Bat species presence, with an estimate of activity level, is presented for seventeen sites at Mesa H near Pannawonica in the Pilbara, WA. Astron Environmental Services (Astron) carried out an echolocation based survey in two phases during September-October 2015 and May-June 2016. Bat Call WA has reviewed the recordings made and provided species lists for the bats present.

Ten species of echolocating bats were recorded including the two EPBC Act listed species in the Pilbara, the Orange Leaf-nosed Bat, Pilbara form (*Rhinonicteris aurantia*) (PLNb) and the Ghost bat (*Macroderma gigas*). PLNb calls were detected foraging in high numbers at site Bat 14, in medium numbers at Bat A4 and in low numbers at ten sites. A summary of call numbers and timing is provided. Ghost bat calls were detected at three sites. Activity levels for the common species are provided by site.

Habitats
The sites for the survey were chosen by Astron. Details of the sites are presented in Table 1. All sites are in the vicinity of Mesa H deposit. Five are on low stony hills or plains, four are in gorges, two are in cave entrances, two are under overhangs, two are within the Robe River riparian zone, two are in drainage lines and two are on breakaways. The locations are shown in relation to Mesa H features in Figure 1. This range of sites is adequate to provide an accurate species list for the area and to indicate the probable direction toward the originating PLNb roost.

Characteristics of the calls recorded are presented in Table 2.

Bat Fauna
An assemblage of ten echolocating species was confirmed as present at the study sites including the PLNb and the Ghost bat, Tables 2 and 3. Species activity levels were low to high, which is expected for the study area habitat and the time of year, see criteria below.

PLNb were detected at twelve of the nineteen sites. One, site Bat 14, had a high activity level with 257 calls recorded in spite of the night receiving heavy rainfall. The majority of these calls were recorded during the period of light rainfall after midnight, see below. Site ‘A4 had a medium activity level with a total of 140 calls being recorded over six nights. Ten sites had low activity levels.

Detections within 60 minutes of dusk civil twilight were recorded at four sites. The earliest call differentials from dusk civil twilight (CT) were at site Bat A4, 30 minutes on the 6th June (an overcast night with rainfall periods), 35 minutes at ‘14 and ‘A2, and 50 minutes at ‘A3. The latest calls were between 25 and 45 minutes before dawn CT, on the 6th June at ‘A4, and at sites ‘A3 and ‘A1, Figure 1. These time differentials, including that of 25 minutes at ‘A4 and 35 minutes at ’14 (both during overcast conditions) together with the progressively increasing time differentials from south to north indicates that the PLNb probably originate from a known roost approximately10 km south of the study area.

Multiple Ghost bat calls were detected at one site, Bat 10, on all four nights of the survey at that location. Calls were also detected at sites Bat ‘A1 and ‘A4 although the pattern of calls at these two sites were interrupted by nights with extensive rainfall and also probably impacted by the two cold nights in June, see below.

Taxonomy presented herein is after Reardon *et al.* (2014) and Jackson and Groves (2015).

Survey Timing, Moon Phase and Weather
The echolocation survey was conducted between 26th September and 1st October 2015, between 1st and 5th May 2016 and between 3rd and 8th June 2016.

In September-October 2015, sampling evenings were warm and dry with minimum overnight temperatures around 15^{O}C. The moon in this period was full. In May 2016, the first four sampling evenings were also warm and dry with minimum overnight temperatures between 20 and 25^{O}C. Heavy rain was experienced on the 5th May beginning at approximately 19:00 and continuing until dawn with a period of light rainfall between midnight and 02:00. The moon was between third quarter and new. In June 2016, the first four sampling evenings were warm with minimum overnight temperatures between 15 and 20^{O}C while the last two were cold with temperatures around 10^{O}C. Rain fell on the nights of 4th , 5th and 6th June. The moon in this period was new. On the warm nights, other than the four wet nights, these conditions correspond to typical levels of bat echolocation detection for the season. Activity levels are expected to be low on the two cold nights.

During the September-October survey, sunset, sunrise, dusk and dawn civil twilight times were within two minutes of 18:13, 06:00, 18:35 and 05:37. During May the respective times were 17:50, 06:54, 18:13 and 06:11. During June the respective times were 17:39, 06:49, 18:03 and 06:25.

Survey Team
Sites were chosen and detectors placed by Astron ecologists. Bob Bullen of Bat Call WA completed analysis of echolocation recordings.

Sampling
The survey consisted of completing a total of 47 overnight bat sound recordings, beginning at twilight, at seventeen locations within the survey area. Detectors were deployed but failed to record at two additional locations. The recordings were "continuous" (Hyder *et al.* 2010) made using SM2BAT+ SongMeter (Wildlife Acoustics Inc, USA) detectors. The jumper and audio settings used followed the manufacturer's recommendations for bat detection contained in the user manual (Wildlife Acoustics 2010).

For the recordings, once reformatted as .wav files, COOL EDIT 2000 (now available as AUDITION from Adobe Systems Inc.) was used to display each sequence for identification. Calls were identified manually. Only good quality call sequences were used. Details of calls analysed are provided in Table 2 as recommended by Australasian Bat Society (ABS 2006). Reference data for the species identified are available in Bullen and McKenzie 2002, McKenzie and Bullen 2003 and McKenzie and Bullen 2009.

Bat activity was then characterised as "Low", "Medium" or "High" based on the rate of call sequences recorded.

- Low species activity is referred when a species is recorded with call spacing less often than ten minutes,
- Medium species activity refers to call recordings more often than 10 minutes but less often than two minutes apart for a at least an hour followed by sporadic records for the remainder of the session.
- High species activity refers to call recording more often than two minutes apart for at least two hours followed by reasonably regular records for the remainder of the session.

Survey Limitations

The sites surveyed were accessible on foot and the SM2, using an omnidirectional microphone, was set on the ground with the microphone horizontal. Species are unlikely to be under-represented as a result.

Bat species density away from cave or adit entrances is impossible to estimate from echolocation records. Bat activity is therefore substituted as an approximate guide to the relative numbers of each species using the study area.

No data was collected from two Phase 1sites (due to battery failure) but seventeen sites remained functional.

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Table 1 Site Specific details.

	Date	Recording Time & SM2 unit	Habitat	Easting	Northing
Phase 1 2015					
Bat 1	26-27 Sept	Two overnight recordings using SM2 SN 7634	Low stony hill site	419610	7599052
Bat 2	26-27 Sept	Two overnight recordings using SM2 SN 8027	Drainage line site	419524	7595067
Bat 3	28 Sept	One overnight recording using SM2 SN 8027	Low stony hill site	417682	7599195
Bat 4	28-29 Sept	Two overnight recordings using SM2 SN 7634	Low stony hill site	421971	7591055
Bat 5	30 Sept	Note 2	Breakaway site	419432	7596595
Bat 6	30 Sept	Note 2	Stony plain site	419868	7592798
Bat 7	1 Oct	One overnight recording using SM2 SN 8027	Low stony hill site	416988	7593520
Bat 8	1 Oct	One overnight recording using SM2 SN 7634	Gorge site	416698	7593658
Phase 2 2016					
Bat 9	1-4 May	Four overnight recordings using SM2 SN 11040	Gorge site	419102	7591026
Bat 10	1-4 May	Four overnight recordings using SM2 SN 12791	Gorge site	419092	7591197
Bat 11	3-5 May	Three overnight recordings using SM2 SN 8027	Drainage line riparian	414380	7597584
Bat 12	2-4 May	Three overnight recordings using SM2 SN 7634	Drainage line riparian	414397	7597585
Bat 13	5 May	One overnight recording using SM2 SN 11040	Breakaway	416235	7596587
Bat 14	5 May	One overnight recordings using SM2 SN 12791	Major drainage line	418220	7591848

	Date	Recording Time	Habitat	Easting	Northing
Phase 2 2016 Additional area,					
Bat A1	3-6 June	Four overnight recordings using SM2 SN 15289	Overhang in gorge	417714	7591311
Bat A2	3-8 June	Four overnight recordings using SM2 SN 13947	Perm't pool in gorge	417078	7590311
Bat A3	3-8 June	Six overnight recordings using SM2 SN 14909	Overhang in gorge	417723	7589676
Bat A4	3-8 June	Six overnight recordings using SM2 SN 15281	Cave entrance	419326	7588792
Bat A5	7-8 June	Two overnight recording using SM2 SN 15289	Cave entrance	417641	7591471

Note 1: Coordinates are Zone 50K

Note 2: Detector failed to record data due to battery failure

Table 2: Summary of Echolocation call characteristics for microbat species present.

Genus species Authority	Common name	Typical F_{peak} kHz Note 1	Ave. Q Note 1	Typical Duration msec	Typical Call Shape
Austronomus australis (Gray 1838) Note 2	White-striped free-tailed bat	12	7	12 - 23	CF– shallow FM
Chaerephon jobensis (Miller 1902)	Northern free-tailed bat	22	5	8 - 15	Shallow FM
Chalinolobus gouldii (Grey 1841)	Gould's wattled bat	32	10	7 - 11	FM
Macroderma gigas (Dobson 1880)	Ghost bat	20 – 52 variable	2 – 20 variable	variable	Complex FM
Nyctophilus geoffroyi Leach 1821	Lesser long-eared bat	48	3	5	Steep FM
Rhinonicteris aurantia (Gray 1845)	Pilbara leaf-nosed bat	120	30	5 - 8	CF
Saccolaimus flaviventris (Peters 1867)	Yellow-bellied sheath-tailed bat	18	9	12 - 21	CF - FM
Scotorepens greyii (Gray 1843)	Little broad-nosed bat	38	10	7 - 13	FM
Taphozous georgianus Thomas 1915	Common sheath-tailed bat	24.5	14	9 - 18	CF– shallow FM
Vespadelus finlaysoni (Kitchener, Jones and Caputi 1987)	Inland cave bat	55	14	4 - 8	FM

Note 1: Fpeak and Q are defined in McKenzie and Bullen 2003, 2009.
Note 2: Taxonomy follows Jackson and Groves (2015). Until recently *A. australis* was known as *Tadarida australis*.

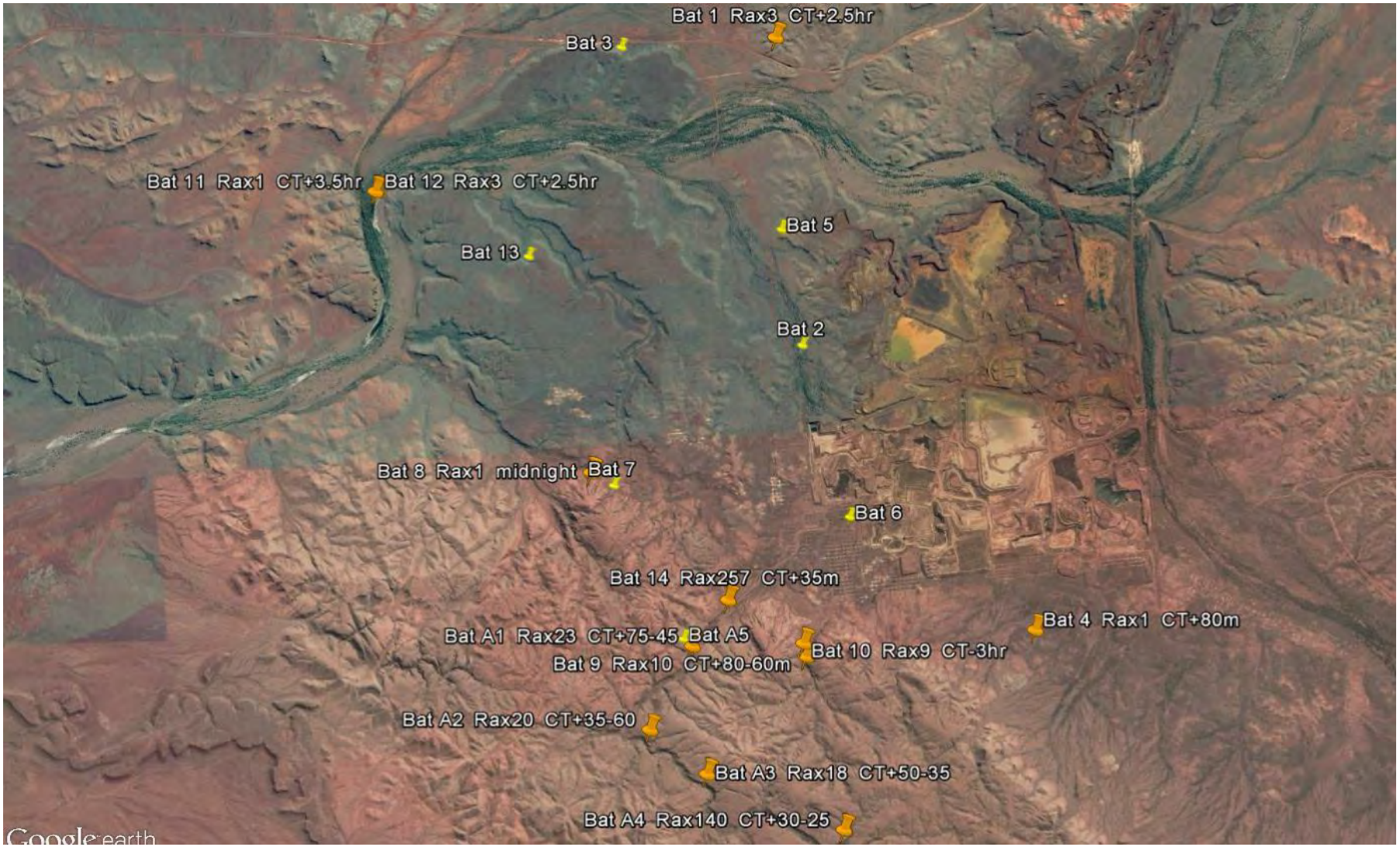
Table 3. Survey microbat lists presented by site.

Site	*Austronomus australis*	*Chaerephon jobensis*	*Chalinolobus gouldii*	*Macroderma gigas*	*Nyctophilus geoffroyi*	*Rhinonicteris aurantia* Note 1	*Saccolaimus flaviventris*	*Scotorepens greyii*	*Taphozous georgianus*	*Vespadelus finlaysoni*
Phase 1 2015										
Bat 1		Low	Low		Low	Low (3 calls)		Low	Low	Med
Bat 2		Low	Low				Low		Low	
Bat 3		Low	Low				Low	Low	Low	Low
Bat 4		Low	Low			Low (1call)	Low	Low	Low	Low
Bat 5 - Note 2										
Bat 6 - Note 2										
Bat 7		Low	Low				Low	Low	High	
Bat 8		Low	Low			Low (1call)		Low	High	Med
Phase 2 2016										
Bat 9			Low			Low (10calls)		Low	High	Low
Bat 10		Low	Low	Low (Multiple calls each night)		Low (9calls)		Low	Med	Med
Bat 11		Low	High			Low (1call)		Low	High	High
Bat 12		Low	Med			Low (3calls)		Low	Med	High
Bat 13			Low					Low	Med	Low
Bat 14			Low			High (257 calls)		Low	Low	High

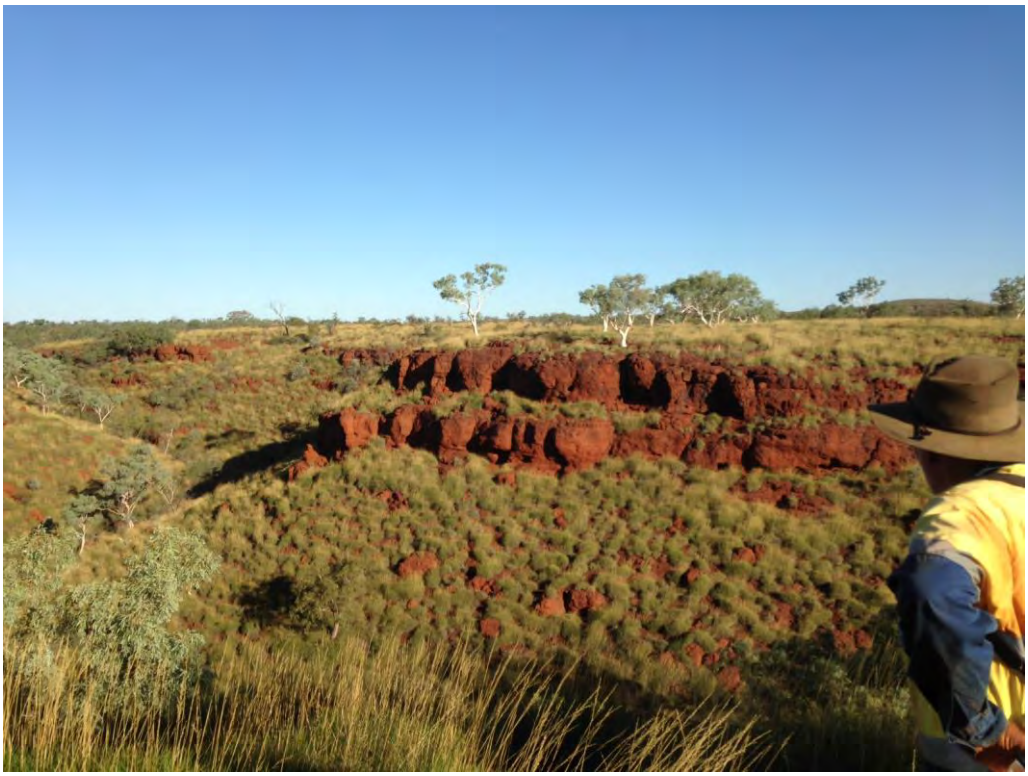
Site	*Austronomus australis*	*Chaerephon jobensis*	*Chalinolobus gouldii*	*Macroderma gigas*	*Nyctophilus geoffroyi*	*Rhinonicteris aurantia*	*Saccolaimus flaviventris*	*Scotorepens greyii*	*Taphozous georgianus*	*Vespadelus finlaysoni*
Phase 2 Additional area										
Bat A1	Low	Low	Low	Low (Multiple calls detected)		Low (23 calls)	Low	Low	High	High
Bat A2	Low		Low			Low (20 calls)		Low	High	High
Bat A3	Low					Low (18 calls)	Low	Low	High	Low
Bat A4	Low	Low	Low	Low (Multiple calls detected)		Med (140 calls)		Low	High	High
Bat A5		Low						Low	Low	Low

Note 1: Total number of calls detected during the recording period at the site
Note 2: No bats were detected due to detector battery failure.

Figure 1. Detector sites in relation to features in the study area. Orange pins denote sites where PLNb were detected. Total PLNb call numbers and timing of the closest calls to civil twilight are also noted. Multiple Ghost bat calls were also detected at sites Bat 10, 'A1 and 'A4. Note that the detector failed to record at sites Bat 5 and Bat 6.



Robe Valley Mesa H,
Ghost bat roost cave assessment,
April 2017



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Peer review: Mr Norman L McKenzie, Senior Principal Research Scientist (ret)

Document Revision History

Issue	Date	Revision History
A	21 April 2017	Initial draft prepared for Rio Tinto review
B	29 April 2017	Second draft incorporating initial review comments.
C	22 May 2017	Third draft incorporating client's comments
1	20 June 2017	First formal issue
Final	7 July 2017	Final issue

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Executive Summary

Rio Tinto commissioned Bat Call WA (Bat Call) to undertake a targeted assessment of bat conservation values of caves at Mesa H. This resource is located in the Robe River valley 17 km south west of Pannawonica, in the Pilbara region of Western Australia. This assessment was completed in parallel with a broader assessment of bat conservation values across the entire Robe River that is the subject of a separate report.

Level one and two fauna surveys have been conducted in the area previously, most recently by Astron Environmental Services in 2015/16. Two bat species of conservation significance have been recorded within the area, namely Pilbara leaf-nosed bat (*Rhinonicteris aurantia*) (Pilbara form of the Orange leaf-nosed bat) (PLNb) and Ghost bat (*Macroderma gigas*), both listed as Vulnerable under Federal and State legislation. PLNb have been assessed as using Mesa H for foraging while originating from a yet to be discovered roost further to the south or east (e.g. Bat Call 2016, 2017). Multiple Ghost bat records including echolocation recordings, visual observations and cave middens have been detected within and adjacent to the study area (e.g. Biota 2009; Astron 2016; Astron 2017).

This survey was designed to provide an assessment of the conservation value of caves associated with the presence of Ghost bats at Mesa H. A visual assessment of cave environments and an extensive search for Ghost bat presence, including roosting bats, was carried out. Ghost bat presence on Mesa H was determined to be irregular with the mesa being used for nocturnal foraging and occasional diurnal roosting. Ghost bat presence, in the form of guano and middens, was recorded across all of the different areas inspected. Eleven of twenty four sites were found to be used or suitable for use by the species. No colonies of diurnally roosting Ghost bats were found. Two caves on Mesa H (MH16-34 and AC04) were found to have the characteristics of diurnal roosts for the species with the possibility of occasional use as maternity roosts. Eight sites on Mesa H were assessed to be nocturnal feeding sites. One site south of Mesa H in the nearby Buckland Hills was also assessed to be a nocturnal feeding site. Thirteen sites on Mesa H were determined to be not currently used by Ghost bats and not suitable for regular occupancy. A number of additional overhangs nearby the caves and shelters were also assessed for signs of Ghost bat use but none were found.

The caves and surrounding environments at Mesa H were found to be supporting foraging Ghost bats originating from either the Buckland Hills to the south, Yeera Bluff between mesas G and H or the Three Peak Hills to the north-west. Two diurnal roost caves with maternity cave potential

have been confirmed. These are located in productive gullies and are associated with a number of near-by caves and shelters providing a series of escape and nocturnal foraging opportunities, including the presence of the Robe River riparian zone, required by the species for successful reproduction.

1.0 Introduction.

1.1 Project Background

Rio Tinto commissioned Bat Call to undertake a targeted assessment of bat conservation values at the Mesa H deposit located approximately 17 kilometres (km) south-west of Pannawonica in the Robe River valley, in the Pilbara region of Western Australia (WA), figure 1. Rio Tinto is considering sustaining its Robe Valley operations by including additional deposits to replace ore supply from the Mesa J operations as it nears the end of its mine life. In summary, the planned mining operation would involve the following main components and activities in addition to the existing approved operations:

- progressive open pit mining of ore and overburden from Mesa H using similar open pit mining techniques to those currently used at Mesa J. These operations are planned to remove the inner core of the mesa while leaving the rocky face of the perimeter intact to a width of at least 20m at the mesa surface,
- placement of overburden in out-of-pit waste dumps adjacent to the mesa, and
- construction and use of haul and access roads to the mine areas within the mesa.

Recent surveys have identified that two species of cave roosting bat of conservation significance are present in the area, the Ghost bat (*Macroderma gigas*) and the Pilbara leaf-nosed bat (*Rhinonicteris aurantia*) (PLNb). PLNb have been assessed as using the Mesas for foraging while originating from a yet to be discovered roost further to the south or east (Bat Call 2016, 2017). Multiple Ghost bat records including echolocation recordings, visual observations and cave middens have been detected within and adjacent to the study area (Biota 2009; Astron 2016; Astron 2017).

The purpose of this survey was to assess the conservation values of caves potentially associated with Ghost bats at Mesa H that had been previously identified by both external and internal resources. This involved a visual assessment of cave geometry and environments and an extensive search for Ghost bat presence, including bat colonies and/or middens. The study area is shown in figure 1. It includes the perimeter of Mesa H including its major central gully.

1.2 Existing Environment at Robe Valley Mesas and Surrounds

Topography

The Robe River Valley mesas cover an extensive area beginning at Mesa A and running approximately 100 km upstream. Mesa H lies immediately adjacent to that river riparian zone. It is roughly circular and is 3.5 km in diameter and stands approximately 50 m higher than a flat plain that is crossed by the river. It is bisected by a major gully running south to north toward the Robe River riparian zone.

Geology

Mesa H is a tertiary Robe Pisolite iron ore deposit, also known as a Channel Iron Deposit (CID), incised with deep gullies around the perimeter. It has overhangs, shelters and caves along extensive lengths of the perimeter and the central gully, e.g. plate 1.

Overhangs, shelters and caves are defined herein as:

- Overhangs are shallow hollows in a rock wall with a distinct roof structure. Their shape is such that they are fully lit by sunlight to their back wall. Their depth is typically 2 to 5 m.
- Shelters are deeper hollows or shallow caves in the rock wall that have ceiling structures from 1.0 to >5 m. They offer significant protection from predators and the weather, are typically 5 to 15 m deep and have dark twilight conditions at their rear extremities. Some have domed areas in their ceilings offering nocturnal roosting and feeding opportunities to Ghost bats. Some are occasionally used diurnally.
- Caves are defined as deep structures of various heights, widths and depths that are very dark in their deeper recesses. They often have additional rear chamber(s) separated from the entrance by a constriction point(s). Those chambers that have ceiling heights of over 2.5m offer excellent roosting opportunities for Ghost bats.
- All three can have cracks or voids that continue back from their rear walls that may lead to additional internal cavities within the rock strata behind or above. If these cavities are almost fully enclosed, have entrance cracks large enough, and can retain high levels of humidity, they provide roosting opportunities for PLNb and Ghost bats.

Overhang and shelter density is high along the majority of the mesa perimeters with the rock strata forming numerous shallow shelters in mid and higher levels of the walls. There are a

number of deeper caves formed in the Pisolite at mid and higher levels of the mesa walls but these rarely extend beyond 15 m in depth. Most shelters and caves were found on the mesa's cliff walls at or just above the top of the talus slope.

Land Systems (after Van Vreeswyk *et al.* 2004)

Mesas H including the gullies and the surrounding gravelly plains are elements of the Robe Land System. It is a low limonite mesa that support spinifex grasslands and scattered Snappy Gums. The lower slopes and adjacent gravelly plains support spinifex grasslands with sparse Acacia and Eucalypt shrubs with low trees that sometimes form thickets.

The adjacent Robe River is a very complex and productive linear river channel and flood plain with a Eucalyptus and Melaleuca woodland over tall Acacia and Petalostylis shrubland. It is an element of the Pilbara's River Land System

The Buckland Hills to the south of Mesa H and Yeera Bluff to the west are rugged jaspilite ridges and mountains of the Newman Land System supporting open shrublands and open low woodlands of Grevillia and Eucalypt over hummock grasses.

Climate

The climate in the district is semi-desert tropical. Mean monthly minimum and maximum temperatures in the lower Robe Valley range from 12 to 41 degrees Celsius (^{o}C). Annual rainfall is extremely variable and averages 400 mm, usually in cyclonic or thunderstorm events during the northern wet season. The northern dry season lasts from May to November and winter rainfall is uncommon.

Water Sources

Drainage systems in the immediate area are associated with ephemeral gullies on the perimeters of the mesas that run into the Robe River drainage system. That riparian zone has a number of permanent and ephemeral pools along its length such as Gnieraoora Pool at the base of Yeera Bluff.

Plate 1. Example of the presence of overhangs and shelters along the perimeters and within the incised gullies on Mesa H. This view is of the Cave H18, H19 complex.

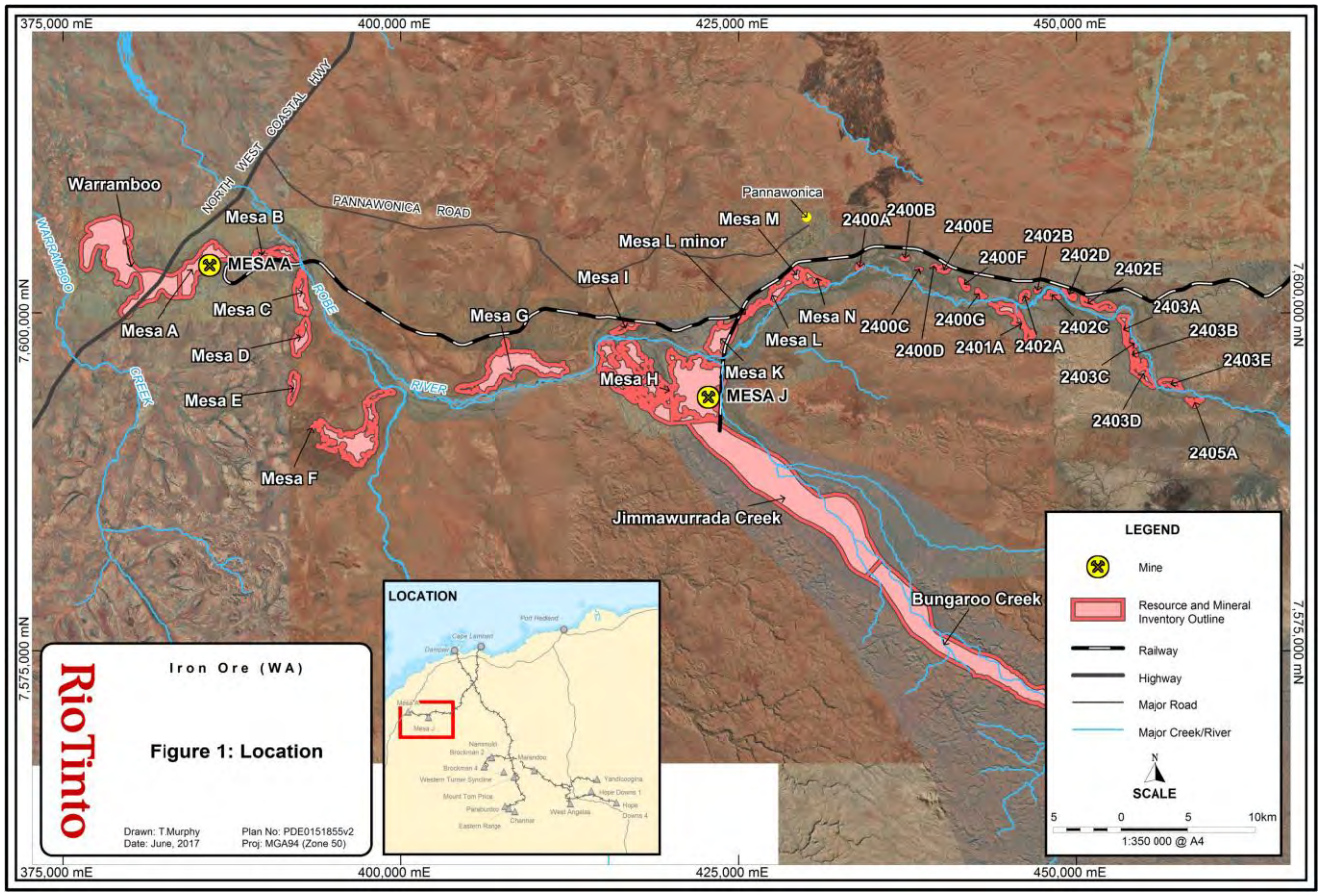

Figure 1. General Arrangement of Robe River valley mining area.

1.3 Bats of Conservation Significance

The Pilbara region contains 17 species of microbat, and of these, 13 have the potential to be found in the Mesa G-H vicinity (Van Dyke and Strahan 2008, McKenzie and Bullen 2009). A number of fauna surveys including targeted bat surveys have been previously conducted in the area, most recently by Astron in 2015 and 2016 and internal Rio Tinto ecologists in 2016-17, see table 1. Two Pilbara bat species of conservation significance have been recorded in the area, the Ghost bat (*Macroderma gigas*) and the PLNb (*Rhinonicteris aurantia*).

The Ghost bat is a large (130 g) carnivorous predator and the PLNb is a small (10 g) insectivore. Both are endemic to northern Australia and are obligate cave roosting species requiring specific cave environments for permanent roosting especially for their maternity colonies. The Ghost bat's foraging strategy and high trophic niche, as a top night-time carnivorous predator, is unique in Australian microbats. The Pilbara's Ghost bat and PLNb populations are isolated from Australia's other populations that are extant across the mesic tropics by the uninhabitable arid zone of the Great Sandy Desert to the north and east. Both species are "conservation significant" as they are semi-desert adapted populations that have specific roosting requirements. The Ghost bat has suffered significant range loss in historical times. The reasons for the range contraction are open to speculation but it is known that the species is sensitive to disturbance (e.g. Richards *et al*. 2008, Woinarski *et al.* 2014)).

The PLNb has been detected foraging across the mesas in the Middle Robe valley. A roost has not been identified on Mesa H and echolocation records indicate that it lies to the south or east of Mesa H or J.

The Ghost bat has also been detected within the study area.

1.3.1 Ghost bat (*Macroderma gigas*)

The Ghost bat is listed as Vulnerable under the commonwealth *Environment Protection and Biodiversity Act 1999* (EPBC Act), Vulnerable under the Western Australian *Wildlife Conservation Act* (1950) and Vulnerable C1 (a vulnerable species numbering less than 10,000 and in decline) under the IUCN Redlist (IUCN 2017). The listing is on the basis of the impact of loss of suitable roost opportunities. The Pilbara Ghost bat population is estimated at 1500-2000 based on recently published estimates (approximately 600, N.L. McKenzie pers. comm. in IUCN 2016; approximately 1200, Armstrong and Anstee 2000; "more common than previously supposed", McKenzie and Bullen 2009) and author's unpublished database summarising data from a range of surveys carried out in recent years by Pilbara mining companies, including Rio

Tinto and other organisations, supplemented by author's own data (summarised in Threatened Species Scientific Committee (TSSC 2016). These recent data (estimates less than 15 years old) cover the entire Pilbara bioregion. Current population estimates in the Hamersley and Chichester subregions are approximately 350 and 1500 respectively (author's unpublished database summarised in TSSC (2016)).

Ghost bats hunt their prey in two primary ways. They hunt birds and bats "air-to-air" at cave entrances and elsewhere by swooping from above or from a perch. They also hunt ground level prey in their target food size range by dropping onto the prey from a perch, either tree branch or rock outcrop. Their diet includes small mammals including other bats, birds, reptiles, frogs and large insects. The proportion of food items in the diet varies with availability and reported foraging areas vary from a few to 10 km from the roost cave. One Ghost bat carcass was found recently entangled in a barbed wire fence in the Fortescue Marsh over 12 km from the nearest cave forming rocky strata suitable for roosting (Stephen Van Leeuwen pers. comm.).

Along the lower Robe River valley multiple Ghost bat records including visual observations and the presence of cave middens have been detected on the various mesas within and adjacent to the study area (table 1).

Ghost bat breeding colonies are known from a small number of maternity roosts in the Pilbara and reproduce during the northern wet season. The largest of these colonies are in abandoned mines in the Chichester subregion and number up to several hundred (Armstrong and Anstee 2000). Hamersley Range populations are typically between 5 and 25 individuals in local groups (author's unpublished database). There is one known large, permanent maternity roost (unpublished assessment by the author) numbering over 70 bats in the lower Robe River valley of the Hamersley subregion. For these groups to persist the bats need an "apartment block" of roosting opportunities, at least one deep cave with characteristics of a maternity roost, multiple caves/shelters and overhangs in close proximity offering nocturnal feeding and refuge opportunities, a productive set of gullies and gorges locally, a productive foraging area within 5 to 10 km radius, usually including a good quality riparian corridor or ephemeral fresh water lake bed and appropriate protection from human interference (author's unpublished data base). These groups are known to reproduce in good years using suitable natural roost caves. Examples are a group numbering 5 to 10 including reproducing females at West Angeles caves in 1980 (Dr Nic Dunlop pers. comm.), a small group including reproducing females at caves at Nammuldi/Silvergrass area (Hamersley Iron 1999), observation of a heavily pregnant female at a cave near Mt Robinson by the author in 2013 and a group numbering 14 including four juveniles

at another cave near Mt Robinson in 2015 (Mr. Morgan O'Connell pers. comm.). The Ghost bat is also known to spread great distances on an annual cycle from these locations depending upon seasonal weather conditions and availability of suitable day roosts. Sporadic records of Pilbara Ghost bats have been identified in the Gascoyne (author's unpublished data) and the Little Sandy Desert (sightings by W.H. Butler at Durba Spring in 1971 and others since). Genetic work by Worthington Wilmer and Armstrong (summarised in Woinarski *et al.* 2014) suggests that the females remain or return to their birthplace and that the males can move between districts.

Ghost bats use three types of roost regularly, these being nocturnal roosts or feeding sites, diurnal or day roosts that may be permanent or semi-permanent sites and maternity roosts that are diurnal roosts with the range of characteristics allowing regular or permanent occupancy.

Nocturnal roosts or feeding sites are only used at night, either habitually or for transitory visits. They are typically shallow caves and shelters that are well lit during the day. They are often high in the strata and may be well or poorly insulated from the elements. They often contain guano scatters and/or midden(s) of various sizes containing guano and food scraps but these remains are sometimes removed by rainfall and/or varieties of "dung beetle" that are known to forage on the scats (author's unpublished observations).

Diurnal roosts are caves and mine adits that are deeper and more complex. They typically have one or more large chambers at or beyond the twilight area with additional fissures or chambers at the rear in the fully dark regions. They have a minimum roof height in the chambers of 2 to 3 m providing protection from attack by terrestrial predators. They are often at mid-levels or lower in the strata and are well insulated overhead providing a stable temperature environment. They typically contain multiple scat piles and middens of guano and food remains that include feathers and skeletal material.

Maternity roosts are diurnal roosts that provide additional features to those listed above that are able to support a reproducing population. These features usually include an interior chamber that is rising toward the rear thereby trapping warmer and more humid air at the top allowing suitable conditions to form during the period when reproductive females and pups are present.

Being predators, during a night's foraging they may also hang for short periods in any deep overhang, shelter or cave with a high enough ceiling or tree branch above a cleared patch of ground for feeding or resting on an opportunistic basis. These sites are not routinely visited and usually show no evidence of Ghost bat presence.

1.3.2 Pilbara leaf-nosed bat (*Rhinonicteris aurantia*)

The PLNb is listed as 'Vulnerable' under the federal *Environment Protection and Biodiversity Act 1999* (EPBC Act) and by the Western Australian *Wildlife Conservation Act* (1950). This listing is on the basis of the impact on its population of the loss of suitable roosts with the correct microclimate.

The PLNb requires roosts with very specific requirements of high temperature and humidity for survival in the Pilbara. These are warm deep and humid caves and historical underground mines. The humidity required is higher than the Ghost bat, approaching 100%. The species is subject to rapid dehydration and death within a day if removed from its roost. It is known to have a usual foraging range up to 20 km from its primary roost caves (Bullen 2013). It also appears to spread from these roosts to satellite roosts when wet season conditions allow and to consolidate back to permanent sites during dry periods.

1.4 Summary of Previous Bat Surveys

Prior to 2017, a number of the fauna surveys commissioned by Rio Tinto in the lower Robe River valley have included microbat species listings. These indicated the presence of both significant species foraging across the area (e.g. Bat Call 2010). More recent surveys carried out since 2015, summarised in table 1 below, indicated that the Ghost bat may be roosting locally and may include a maternity colony at Mesa H and that the PLNb was foraging generally across all Robe valley mesas but not roosting on Mesa H.

Table 1. Summary of Fauna Surveys that Include Ghost Bat records in the Mesa H District

Date	Reference	Ghost bat activity detected.
2009	Biota (2009)	• Ghost bats harp trapped at Mesa G
2015	Astron (2016)	• Ghost bat echolocation calls detected at Mesa H and a number of shelters/caves with scats recorded
2016	Astron (2017)	• Ghost bat echolocation calls detected at Mesa G and a number of shelters/caves with scats recorded
2017	RTIO internal ecologists	• Ghost bat seen at cave H27on Mesa H.

2.0 Survey and Assessment Methods

A survey consisting of three days field work was completed in April 2017 (9th to 11th April) on Mesa H. Twenty four sites were assessed plus nearby overhangs and shallow shelters.

The fieldwork focussed on the assessment of potential roosting habitat of Ghost bat that previous surveys had indicated were important for this species. Eight sites listed as Ghost bat habitat were assessed. In addition, 13 caves/shelters on Mesa H that the Rio Tinto heritage surveys had recorded with depths greater than 10m were also included in the survey. Three previously unrecorded deep shelters suitable for Ghost bat use were also found and assessed.

On an opportunistic basis, a secondary set of overhangs and shelters recorded by the heritage surveys (often within 100m of the primary caves) were also searched.

2.1 Survey Team, Timing and Weather

The survey team consisted of two experienced ecologists. Ms Tenielle Brown (Rio Tinto) was team leader and Mr Robert Bullen (Bat Call) acted as principal ecologist.

The northern wet season of 2016-17 was wetter than average in the Pilbara region. Heavy rain fell in the district in the three months prior to the survey with 535 mm being recorded at the Bureau of Meteorology station at Pannawonica (Bureau of Meteorology station No 5069) between January and March. This rain continued until a week prior to the survey. The weather during the assessment was typical late wet season conditions being hot and dry with temperatures between 20 and 40^{O}C.

Sunset and sunrise were at 18:09 and 06:26 during the survey while dusk and dawn civil twilight were at 18:31 and 06:04 respectively. The moon phase was full.

2.2 Survey Techniques

The survey was designed to assess all Ghost bat (and any PLNb) roost cave candidates, to review cave morphology, geology and cave conditions, and to narrow down the list of potential Ghost bat maternity and/or PLNb roost caves. These visits were completed during daylight hours. Caves and shelters were entered after a rigorous safety inspection that assessed potential hazardous rock structures. Each was then measured for height, width and depth using a hand held laser (Bosch model PLR-50). Some caves and gorges had been surveyed earlier by Astron, for evidence of Ghost bat activity including the presence of middens and scats. Along the perimeter of Mesa H, twenty four sites were visited and were assessed by their attributes as probable night

feeding locations, seasonal day roost candidates or permanent day/maternity roost candidates. Numerous overhangs and shallow shelters identified by the Rio Tinto heritage surveyors near these sites were also assessed. These combined totals constituted all potential Ghost bat roost caves and shelters previously known or identified during the survey on the two mesas.

The presence of Ghost bat was confirmed by either of the following observations:

- Visual observation of a large pale bat entering or departing the cave. Note that the Ghost bat is distinctive in being much larger than any other cave dwelling bat in the region; or
- Detection of Ghost bat scats or middens on the floor of the caves or shelters entered, plate 2.

Plate 2. Typical Ghost bat midden containing scats and feathers on the floor of a cave

Caves and Shelters were then classified as maternal, diurnal, nocturnal or "not used" based on the cave characteristics and evidence found. The "not used" classification was applied when there is unsuitable characteristics such as low ceilings (typically <1.5m) and/or shallow depth (typically < 5m) with no physical evidence or other record such as a sighting or echolocation recording.

Observations of bat species other than the two conservation significant species were not recorded during this assessment.

2.3 Survey Effort

Sites previously identified were approached from either the top rim or from the plain below and scanned visually for the presence of caves. Caves were assessed for safe entry and sections of the perimeter that showed cave forming strata were then walked at the height of the top of the talus slope where the caves were most common. Twenty four caves and shelters were visited, see figure 2, and assessed for Ghost bat presence. One ecologist entered each cave following agreed Rio Tinto health and safety guidelines covering personal protective equipment (PPE), access limitations and communication strategies. The cave interior was searched for evidence of Ghost bat roosting including the presence of middens and adult Ghost bats. The team's second member remained at the entrance to observe any Ghost bat that might depart the cave behind the observer inside, a common behaviour of this species. Any Ghost bats that departed and/or entered the caves or were seen flying close to the entrance were thereby recorded visually. Any that departed could be tracked visually to record the alternative cave or shelter that they re-entered.

Figure 2 Mesa H with locations of caves and shelters assessed during the survey.

2.4 Survey Limitations

The primary objective of the survey was the characterisation of Ghost bat activity on Mesa H. All aspects of the survey including site access using 4WD, team make-up and experience levels, equipment used, logistics and safety support provided by Rio Tinto were suitable for the task.

No activities were undertaken that could cause harm to the bats present.

Detailed internal dimensions of a cave and its daytime use by bats cannot be reliably determined from the entrance or by the size of the entrance. Entry of candidate caves was therefore necessary to confirm internal characteristics including the bat species present. (Note that distinctive Ghost bat social calls heard from the entrance, or Ghost bats seen departing caves in daylight following the approach of survey parties, serve to confirm the presence of Ghost bats but do not provide information on their numbers or maternity status).

Detailed interior searches of caves were carried out under the guidelines of the Rio Tinto safety procedures. These prohibited entry into any cave that was deemed to have an unstable ceiling as characterised by loose rocks overhead or around the entrance, heavy cracking or the presence of fresh slab like roof material fallen to the floor. These procedures also prohibited entry into any chamber that required sliding on stomach or back or that required climbing or descending 2 m using rock-climbing techniques. The rear areas of some caves could therefore not be searched completely and the possible presence and number of Ghost bats in such caves was therefore not confirmed absolutely.

Due to the porous nature of the Robe Pisolite and the very high number of cracks and sinuous tubes and pipes throughout the strata, the floors of a number of caves had been washed clean of any evidence of Ghost bat occupation by the preceding heavy rain. In addition most caves were inhabited by a species of beetle that is known to act as a scat cleaner thereby removing Ghost bat scats. This combination resulted in fewer caves being identified with scats than expected from the previous surveys.

3.0 Results

A number of observations of Ghost bats middens and scat piles were made during this assessment with Ghost bat presence and foraging activity confirmed generally around the perimeter. In addition two diurnal roost caves with the characteristics of occasional maternity roosts have been located on Mesa H, figure 3.

Assessments of each cave and observations of Ghost bat activity are provided below, table 2, with detailed characteristics of the caves examined including floorplans and dimensions in Attachment A. Most caves were found to be less than 20 m deep and therefore not expected to be impacted by the mining behind the facade. Caves MH16-34 and AC4 were found to be over 30 m deep, depths that are significant when planning the facade to be retained.

Eleven sites were assessed as being suitable for roosting by Ghost bats including two diurnal roost caves and nine nocturnal roost shelters. Note that this total includes shelter AC05 that is in the Buckland Hills BIF strata (Newman land system) adjacent to Mesa H. The two assessed as diurnal roost caves are MH16-34 (50K 415815 7595655), a simple linear chamber 30 m deep with a single high dome at the distal end, and cave AC04 (50K 417586 7594895), a more complex cave with six ceiling domes between 2.5 and 3.9 m high along its length. Both were assessed as being maternity cave candidates although no evidence of significant Ghost bat use of this type was found during the survey. Cave AC04 had a number of scats present.

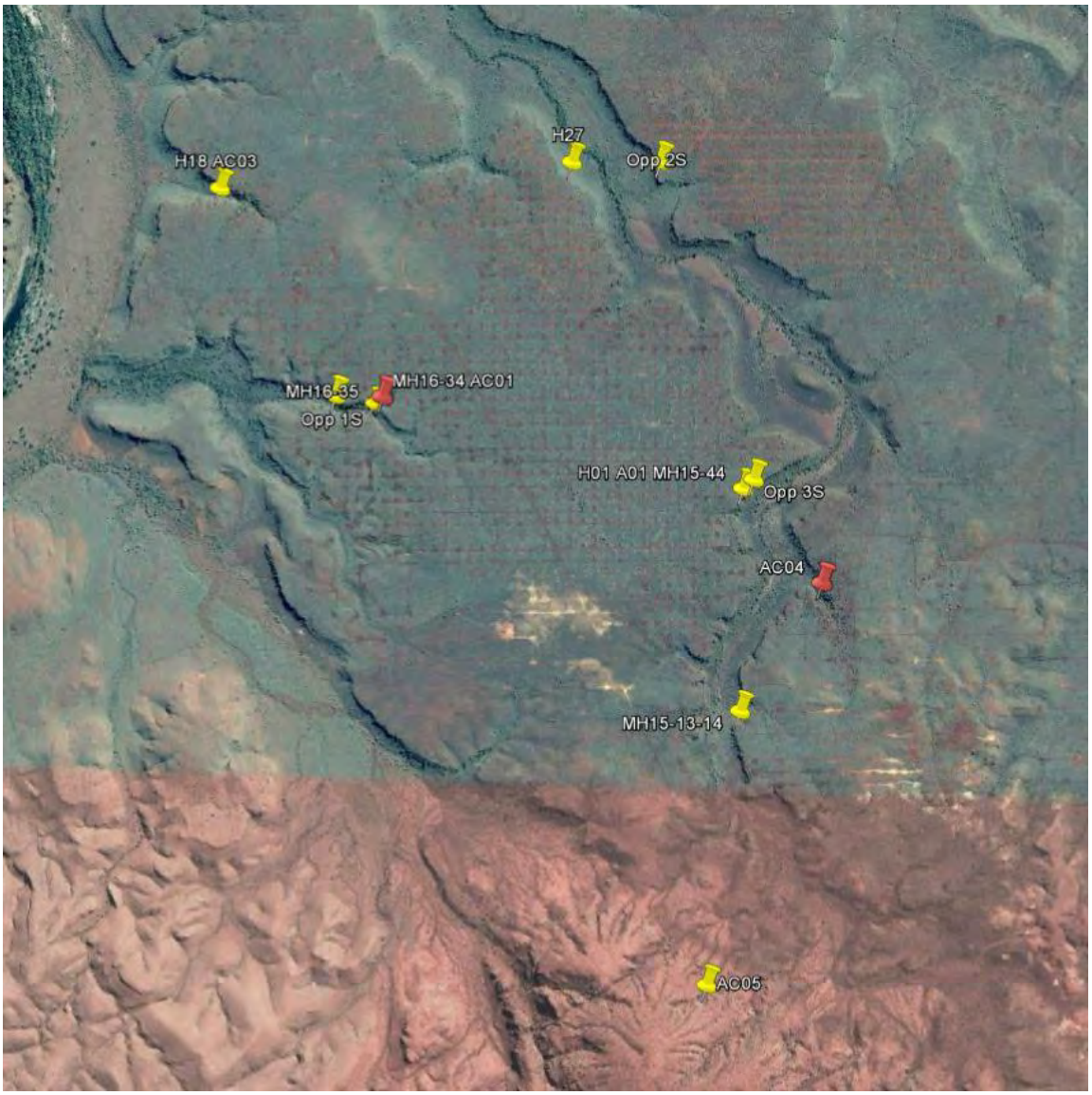

Figure 3. Mesa H caves and shelters where positive Ghost bat assessments were made. The red dots denote the diurnal caves MH16-34 and AC04. Yellow dots denote caves/shelters assessed as nocturnal feeding roosts.

Table 2. Summary of caves visited on Mesa H and assessed for Ghost bat usage.

Cave	Easting	Northing	Observations	Assessed Ghost Bat roost type
H01-A01 MH15- 44	417270	7595276	Shelter with a low internal dome. Several overhangs to the north and south. Ghost bat guano present	Nocturnal feeding roost
H2	414628	7597699	Overhang. No Ghost bat guano present	Overhang only. Not used
H3,H4,H5,H6,H7	414730	7597728	A series of overhangs along cliff face. No Ghost bat guano present	Overhang only. Not used
H16	415266	7596488	Shelter with low roof. No Ghost bat guano present. Additional overhangs nearby and on opposite side of gully with no Ghost bat evidence.	Shelter only. Not used
H18	415164	7596495	Shallow cave with two low domes. No Ghost bat guano present	Nocturnal feeding roost
H19	415126	7596488	Shelter with low roof. No Ghost bat guano present	Shelter only. Not used
H24	416776	7596072	Overhang. No Ghost bat guano present	Overhang only. Not used
H27	416587	7596590	Deep shelter with two low internal domes. Several overhangs to the north and south. No Ghost bat guano present	Nocturnal feeding roost
H34	415315	7595811	Shelter with several overhangs to the east and west. No Ghost bat guano present	Shelter only. Not regularly used
H36	415667	7595692	Unable to approach due to steep cliff. Assessed from opposite side of gully.	Shallow shelter only. Not used
MH15-13 MH15-14	417252	7594383.	Shelter with a high pipe in roof. Ghost bat guano present	Nocturnal feeding roost
MH15-25 H29	416571	7597124	Shelter with overhangs to west and east. No Ghost bat guano present	Shelter only. Not regularly used
MH15-47	417248	7595912	Shelter with low roof. No Ghost bat guano present	Not used
MH15-95	414938	7597150	Shelter with low roof. No Ghost bat guano present. Has additional overhangs nearby and on opposite face with no Ghost bat evidence.	Not regularly used
MH15-96	414925	7597127	Shelter with low roof. No Ghost bat guano present	Not used

Cave	Easting	Northing	Observations	Assessed Ghost Bat roost type
MH15-97	414899	7597103	Shelter with low roof. No Ghost bat guano present	Not used
MH16-34	415815	7595655	Deep cave with a single internal dome. No Ghost bats present	Diurnal roost. Possible maternal roost
MH16-35	415782	7595640	Shelter with overhangs to west and opposite. No Ghost bat guano present	Nocturnal feeding roost
AC04	417586	7594895	Cave with a multiple internal domes. Ghost bat scats present	Diurnal roost. Occasional use as a maternal roost possible but no current evidence of use this year
AC05	417109	7593285	Cave with a single internal dome. Ghost bat scats present	Nocturnal feeding roost
AC06	418068	7592683	Shelter with overhangs at creek level to the east. No Ghost bat guano present	Shelter only. Not regularly used
MH-Opp 1S	415625	7595659	Deep shelter with several overhangs to the east and west. No Ghost bat guano present	Nocturnal feeding roost
MH-Opp 2S	416948	7596585	Deep shelter with several overhangs to the north. No Ghost bat guano present	Nocturnal feeding roost
MH-Opp 3S	417330	7595332	Deep shelter with several overhangs to the south. No Ghost bat guano present	Nocturnal feeding roost

Note: All coordinates are zone 50K.

4.0 References

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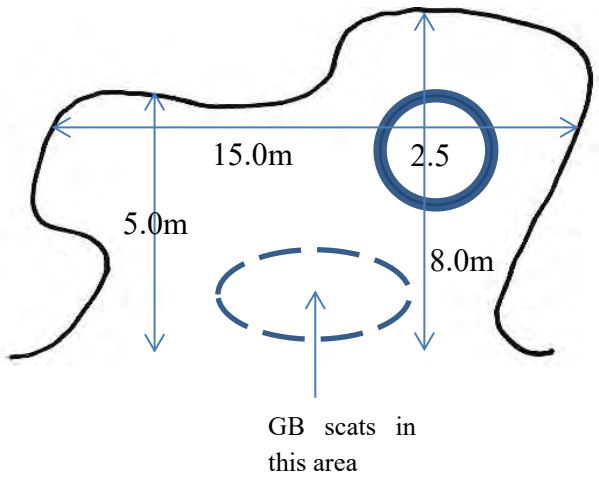
Attachment A: Characteristics of caves examined during this study.

Note that unboxed dimensions indicate cave/shelter width and depth and boxed or "dome height" (solid circles) dimensions indicate ceiling heights. Dotted ellipses indicate the locations of Ghost bat middens or scat piles.

Mesa H Shelter H01-A01 MH15-44:

Assessed Ghost bat usage: Nocturnal shelter with Ghost bat scats.	**Coordinates:** 50K 417270 7595276
Entrance safe or unsafe to approach: Assessed safe	**Basic Geology: Land system at site** Robe Pisolite mesa: Robe
Entrance type and dims – WxH (m): Single wide entrance 9.0 x 1.5 m.	**Entrance Orientation:** South
Cave Grouping: Shelter has additional shallow overhangs along gully wall to the north and south.	**Insulation from surface above:** Middle of local landscape
Cave Type: Shelter is 8 m deep with low roof and one low dome.	**Internal domed chamber:** Yes. 2.5 m high
Rear passages that may have roosts: No.	**Internal temp. and relative humidity:** Ambient
Local foraging opportunities: Excellent, In central Mesa H gully that opens onto the Robe River riparian zone.	**Current distance to disturbance:** Mesa J mine is 2.5 km distant. Resource evaluation drilling nearby on mesa top.

Cave floorplan and entrance photo:



Mesa H Shelter H2:

Assessed Ghost bat usage: Shallow shelter/Overhang only. No Gb guano present. Not used.	**Coordinates:** 50K 414628 7597699
Entrance safe or unsafe to approach: Assessed safe	**Basic Geology: Land system at site** Robe Pisolite mesa: Robe
Entrance type and dims – WxH (m): Wide shallow shelter.	**Entrance Orientation:** North
Cave Grouping: Shelter is a part of a complex of shelters and overhangs overlooking the Robe River.	**Insulation from surface above:** Middle of local landscape
Cave Type: Shallow shelter ~5 m deep.	**Internal domed chamber:** No
Rear passages that may have roosts: No.	**Internal temp. and relative humidity:** Ambient
Local foraging opportunities: Excellent, Mesa H is adjacent to Robe River riparian zone.	**Current distance to disturbance:** Mesa J mine is 6 km distant. Resource evaluation drilling nearby on mesa top.
Cave floorplan and entrance photo:	

Mesa H Shelters H3, H4, H5, H6, H7:

Assessed Ghost bat usage: Shallow shelter/Overhang only. No GB guano present. Not used	**Coordinates:** 50K 414730 7597728
Entrance safe or unsafe to approach: Assessed safe	**Basic Geology: Land system at site** Robe Pisolite mesa: Robe
Entrance type and dims – WxH (m): A series of wide shallow overhangs.	**Entrance Orientation:** North
Cave Grouping: A complex of shelters and overhangs along cliff face.	**Insulation from surface above:** Middle of local landscape
Cave Type: Shallow shelter ~5 m deep.	**Internal domed chamber:** No
Rear passages that may have roosts: No	**Internal temp. and relative humidity:** Ambient
Local foraging opportunities: Excellent, Mesa H is adjacent to Robe River riparian zone.	**Current distance to disturbance:** Mesa J mine is 6 km distant. Resource evaluation drilling nearby on mesa top.

Cave floorplan and entrance photo:

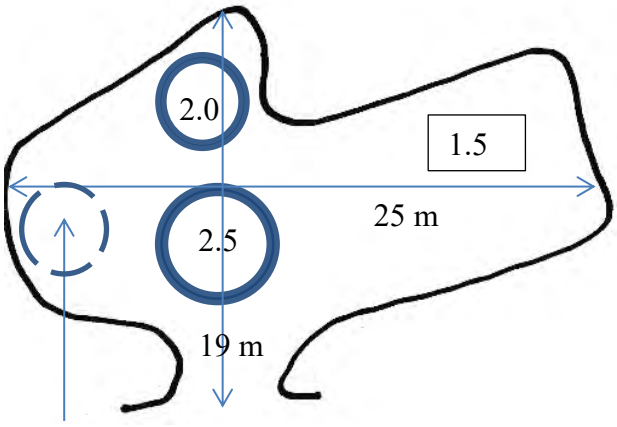
Mesa H Shelter H16:

Assessed Ghost bat usage:	**Coordinates:**
Shallow shelter/Overhang only. No GB guano present. Not used	50K 415266 7596488
Entrance safe or unsafe to approach:	**Basic Geology: Land system at site**
Assessed safe	Robe Pisolite mesa: Robe
Entrance type and dims – WxH (m):	**Entrance Orientation:**
A wide shallow shelter among a group of caves, shelters and overhangs.	North
Cave Grouping:	**Insulation from surface above:**
Shelter is a part of a complex of shelters and overhangs along both sides of gully.	Middle of local landscape
Cave Type:	**Internal domed chamber:**
Shallow shelter ~5 m deep.	No
Rear passages that may have roosts:	**Internal temp. and relative humidity:**
No	Ambient
Local foraging opportunities:	**Current distance to disturbance:**
Excellent, Mesa H is adjacent to Robe River riparian zone.	Mesa J mine is 6 km distant. Resource evaluation drilling nearby on mesa top.
Cave floorplan and entrance photo:	

Mesa H Cave H18:

Assessed Ghost bat usage: Nocturnal Roost. No GB guano present but cave was recently washed through by heavy rainfall.	**Coordinates:** 50K 415164 7596495
Entrance safe or unsafe to approach: Assessed safe	**Basic Geology: Land system at site** Robe Pisolite mesa: Robe
Entrance type and dims – WxH (m): Single small entrance 2.6 x 1.7 m.	**Entrance Orientation:** North
Cave Grouping: Cave is a part of a complex of shelters and overhangs along both sides of gully.	**Insulation from surface above:** Middle of local landscape
Cave Type: Cave 19.0 m deep with low roof and two low domes.	**Internal domed chamber:** Yes. 2.5 m and 2.0 m high
Rear passages that may have roosts: Has multiple pipes through to the surface above.	**Internal temp. and relative humidity:** Ambient
Local foraging opportunities: Excellent, Mesa H is adjacent to Robe River riparian zone.	**Current distance to disturbance:** Mesa J mine is 6 km distant. Resource evaluation drilling nearby on mesa top.

Cave floorplan and entrance photo:



Multiple pipes through to surface in this area

Mesa H Shelter H19:

Assessed Ghost bat usage: Shallow shelter/Overhang only. No GB guano present. Not used	**Coordinates:** 50K 415126 7596488
Entrance safe or unsafe to approach: Assessed safe	**Basic Geology: Land system at site** Robe Pisolite mesa: Robe
Entrance type and dims – WxH (m): A wide shallow shelter among a group of caves, shelters and overhangs.	**Entrance Orientation:** North
Cave Grouping: Shelter is a part of a complex of shelters and overhangs along both sides of gully.	**Insulation from surface above:** Middle of local landscape
Cave Type: Shallow shelter ~5 m deep.	**Internal domed chamber:** No
Rear passages that may have roosts: No	**Internal temp. and relative humidity:** Ambient
Local foraging opportunities: Excellent, Mesa H is adjacent to Robe River riparian zone.	**Current distance to disturbance:** Mesa J mine is 6 km distant. Resource evaluation drilling nearby on mesa top.

Cave floorplan and entrance photo:

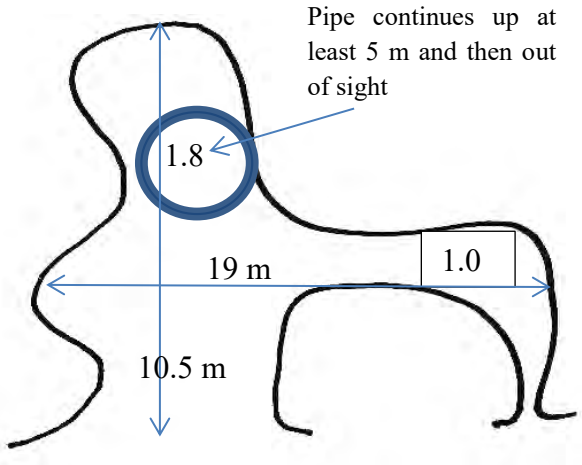
Mesa H Shelter H24:

Assessed Ghost bat usage:	**Coordinates:**
Shallow shelter/Overhang only. No GB guano present. Not used	50K 416776 7596072
Entrance safe or unsafe to approach:	**Basic Geology: Land system at site**
Assessed safe	Robe Pisolite mesa: Robe
Entrance type and dims – WxH (m):	**Entrance Orientation:**
A shallow shelter with an open entrance.	East
Cave Grouping:	**Insulation from surface above:**
Shelter is isolated in a gully.	Middle of local landscape
Cave Type:	**Internal domed chamber:**
Shallow shelter ~5 m deep.	No
Rear passages that may have roosts:	**Internal temp. and relative humidity:**
No	Ambient
Local foraging opportunities:	**Current distance to disturbance:**
Excellent, Mesa H central gully opens onto the Robe River riparian zone.	Mesa J mine is 3.5 km distant. Resource evaluation drilling nearby on mesa top.
Cave floorplan and entrance photo:	

Mesa H Shelter H27:

Assessed Ghost bat usage: Nocturnal Roost	**Coordinates:** 50K 416587 7596590
Entrance safe or unsafe to approach: Assessed safe	**Basic Geology: Land system at site** Robe Pisolite mesa: Robe
Entrance type and dims – WxH (m): Two entrances, one 8.6 x 3.8 m and another very small entrance to the north.	**Entrance Orientation:** North east
Cave Grouping: Shelter is a part of a complex of shelters and overhangs along the gully wall.	**Insulation from surface above:** Middle of local landscape
Cave Type: Shelter is 10.5 m deep with low roof and a low dome with a sinuous vertical pipe.	**Internal domed chamber:** Yes. 1.8 m high
Rear passages that may have roosts: A sinuous vertical pipe rises at least 5 m and continues out of sight.	**Internal temp. and relative humidity:** Ambient
Local foraging opportunities: Excellent, Mesa H central gully opens onto the Robe River riparian zone.	**Current distance to disturbance:** Mesa J mine is 3.5 km distant. Resource evaluation drilling nearby on mesa top.

Cave floorplan and entrance photo:



Mesa H Shelter H34:

Assessed Ghost bat usage: Shallow shelter/Overhang only. No GB guano present. Not regularly used	**Coordinates:** 50K 415315 7595811
Entrance safe or unsafe to approach: Assessed safe	**Basic Geology: Land system at site** Robe Pisolite mesa: Robe
Entrance type and dims – WxH (m): A shallow shelter among a group of overhangs.	**Entrance Orientation:** South
Cave Grouping: Shelter is a part of a complex of shelters and overhangs along the north side of the gully.	**Insulation from surface above:** Middle of local landscape
Cave Type: Shallow shelter ~5 m deep.	**Internal domed chamber:** No
Rear passages that may have roosts: No	**Internal temp. and relative humidity:** Ambient
Local foraging opportunities: Excellent, Mesa H is adjacent to Robe River riparian zone.	**Current distance to disturbance:** Mesa J mine is 5 km distant. Resource evaluation drilling nearby on mesa top.
Cave floorplan and entrance photo:	

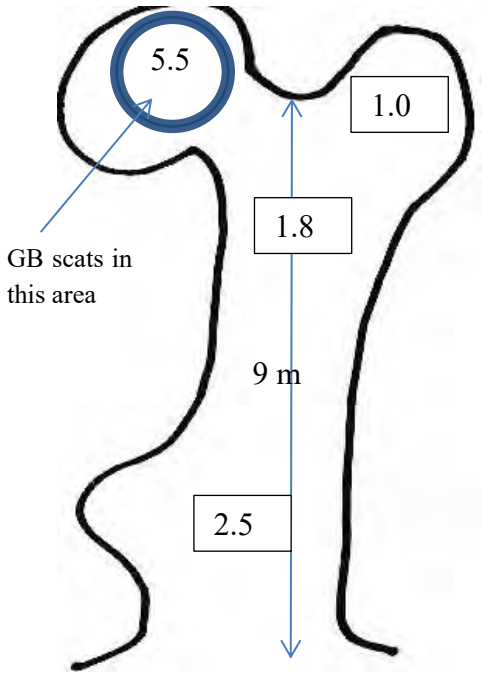
Mesa H Shelter H36:

Assessed Ghost bat usage:	**Coordinates:**
Shallow shelter. Unable to approach due to steep cliff. Assessed from opposite side of gully.	50K 415667 7595692
Entrance safe or unsafe to approach:	**Basic Geology: Land system at site**
Assessed safe if approached from gully floor.	Robe Pisolite mesa: Robe
Entrance type and dims – WxH (m):	**Entrance Orientation:**
A wide shallow shelter among a group of overhangs.	South
Cave Grouping:	**Insulation from surface above:**
Shelter is a part of a complex of shelters and overhangs along the north side of the gully.	Middle of local landscape
Cave Type:	**Internal domed chamber:**
Shallow shelter ~5 m deep.	No
Rear passages that may have roosts:	**Internal temp. and relative humidity:**
No	Ambient
Local foraging opportunities:	**Current distance to disturbance:**
Excellent, Mesa H is adjacent to Robe River riparian zone.	Mesa J mine is 5 km distant. Resource evaluation drilling nearby on mesa top.
Cave floorplan and entrance photo:	

Mesa H Shelter MH15-13 MH15-14:

Assessed Ghost bat usage: Nocturnal Roost. GB guano present under high pipe in roof.	**Coordinates:** 50K 417252 7594383
Entrance safe or unsafe to approach: Assessed safe	**Basic Geology: Land system at site** Robe Pisolite mesa: Robe
Entrance type and dims – WxH (m): Single entrance 2.7 x 2.5 m.	**Entrance Orientation:** West
Cave Grouping: Isolated shelter near top of central Mesa H gully.	**Insulation from surface above:** Middle of local landscape
Cave Type: Shelter is 9.0 m deep with low roof and a high pipe in the roof at the rear.	**Internal domed chamber:** Yes. 1.8 m dia pipe upwards at least 5.5 m high
Rear passages that may have roosts: No.	**Internal temp. and relative humidity:** Ambient
Local foraging opportunities: Excellent, Mesa H is adjacent to Robe River riparian zone.	**Current distance to disturbance:** Mesa J mine is 2.5 km distant. Resource evaluation drilling nearby on mesa top.

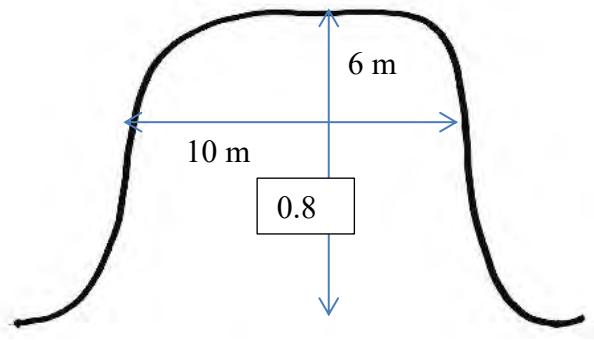
Cave floorplan and entrance photo:



Mesa H Shelter MH15-25 H29:

Assessed Ghost bat usage: Shallow shelter. No GB guano present. Not regularly used	**Coordinates:** 50K 416571 7597124
Entrance safe or unsafe to approach: Assessed safe.	**Basic Geology: Land system at site** Robe Pisolite mesa: Robe
Entrance type and dims – WxH (m): A wide shallow shelter among a group of overhangs. Entrance 10.0 x 2.0 m.	**Entrance Orientation:** South west
Cave Grouping: Shelter is amongst overhangs along the north side of the gully.	**Insulation from surface above:** Middle of local landscape
Cave Type: Shallow shelter 6 m deep.	**Internal domed chamber:** No
Rear passages that may have roosts: No	**Internal temp. and relative humidity:** Ambient
Local foraging opportunities: Excellent, Mesa H is adjacent to Robe River riparian zone.	**Current distance to disturbance:** Mesa J mine is 4 km distant. Resource evaluation drilling nearby on mesa top.

Cave floorplan and entrance photo:



Mesa H Shelter MH15-95:

Assessed Ghost bat usage:	**Coordinates:**
Shallow shelter. No GB guano present. Not regularly used.	50K 414938 7597150
Entrance safe or unsafe to approach:	**Basic Geology: Land system at site**
Assessed safe.	Robe Pisolite mesa: Robe
Entrance type and dims – WxH (m):	**Entrance Orientation:**
A wide shallow shelter among a group of overhangs. Roof ~0.5m high.	South east
Cave Grouping:	**Insulation from surface above:**
Shelter is a part of a complex of shelters and overhangs along the north-west side of the gully. Other overhangs are opposite on the south-east side of the gully.	Middle of local landscape
Cave Type:	**Internal domed chamber:**
Shallow shelter ~5 m deep.	No
Rear passages that may have roosts:	**Internal temp. and relative humidity:**
No	Ambient
Local foraging opportunities:	**Current distance to disturbance:**
Excellent, Mesa H is adjacent to Robe River riparian zone.	Mesa J mine is 6 km distant. Resource evaluation drilling nearby on mesa top.
Cave floorplan and entrance photo:	

Mesa H Shelter MH15-96:

Assessed Ghost bat usage: Shallow shelter. No GB guano present. Not used.	**Coordinates:** 50K 414925 7597127
Entrance safe or unsafe to approach: Assessed safe.	**Basic Geology: Land system at site** Robe Pisolite mesa: Robe
Entrance type and dims – WxH (m): A wide shallow shelter among a group of overhangs. Roof ~0.3 m high.	**Entrance Orientation:** South east
Cave Grouping: Shelter is a part of a complex of shelters and overhangs along the north-west side of the gully. Other overhangs are opposite on the south-east side of the gully.	**Insulation from surface above:** Middle of local landscape
Cave Type: Shallow shelter ~5 m deep.	**Internal domed chamber:** No
Rear passages that may have roosts: No	**Internal temp. and relative humidity:** Ambient
Local foraging opportunities: Excellent, Mesa H is adjacent to Robe River riparian zone.	**Current distance to disturbance:** Mesa J mine is 6 km distant. Resource evaluation drilling nearby on mesa top.

Cave floorplan and entrance photo:

MH15-96 is the right hand entrance

Mesa H Shelter MH15-97:

Assessed Ghost bat usage: Shallow shelter. No GB guano present. Not used.	**Coordinates:** 50K 414899 7597103
Entrance safe or unsafe to approach: Assessed safe.	**Basic Geology: Land system at site** Robe Pisolite mesa: Robe
Entrance type and dims – WxH (m): A wide shallow shelter among a group of overhangs. Roof ~0.3 m high.	**Entrance Orientation:** South east
Cave Grouping: Shelter is a part of a complex of shelters and overhangs along the north-west side of the gully. Other overhangs are opposite on the south-east side of the gully.	**Insulation from surface above:** Middle of local landscape
Cave Type: Shallow shelter ~5 m deep.	**Internal domed chamber:** No
Rear passages that may have roosts: No	**Internal temp. and relative humidity:** Ambient
Local foraging opportunities: Excellent, Mesa H is adjacent to Robe River riparian zone.	**Current distance to disturbance:** Mesa J mine is 6 km distant. Resource evaluation drilling nearby on mesa top.

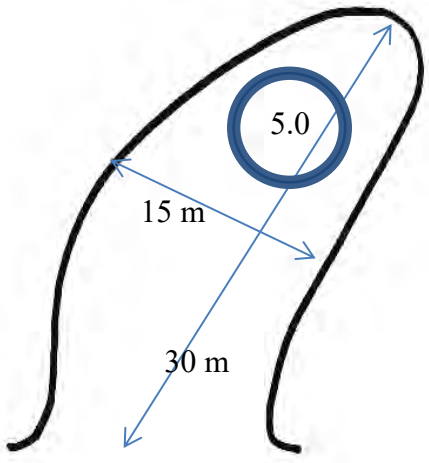
Cave floorplan and entrance photo:

MH15-97 is the left hand entrance

Mesa H Cave MH16-34:

Assessed Ghost bat usage: Diurnal roost. Potential maternity roost but no GB current evidence.	**Coordinates:** 50K 415815 7595655
Entrance safe or unsafe to approach: Assessed safe	**Basic Geology: Land system at site** Robe Pisolite mesa: Robe
Entrance type and dims – WxH (m): A wide entrance among a group of overhangs at top of deep gully. Entrance 8.0 x 3.0 m.	**Entrance Orientation:** South west
Cave Grouping: Cave is a part of a complex of shelters and overhangs along the north side of the gully.	**Insulation from surface above:** Bottom of landscape
Cave Type: Deep cave with a single large dome.	**Internal domed chamber:** Yes. 5.0 m high
Rear passages that may have roosts: No	**Internal temp. and relative humidity:** Ambient
Local foraging opportunities: Excellent, Mesa H is adjacent to Robe River riparian zone.	**Current distance to disturbance:** Mesa J mine is 4.5 km distant. Resource evaluation drilling nearby on mesa top.

Cave floorplan and entrance photo:



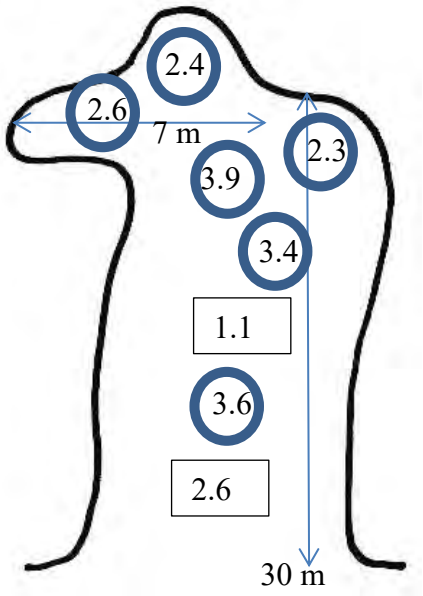
Mesa H Shelter MH16-35:

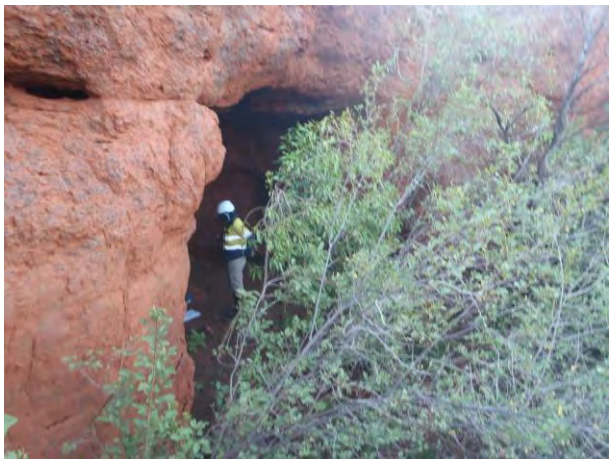
Assessed Ghost bat usage:	**Coordinates:**
Nocturnal roost. Shallow shelter. No GB guano present.	50K 415782 7595640
Entrance safe or unsafe to approach:	**Basic Geology: Land system at site**
Assessed safe.	Robe Pisolite mesa: Robe
Entrance type and dims – WxH (m):	**Entrance Orientation:**
A shallow shelter among a group of overhangs.	North west
Cave Grouping:	**Insulation from surface above:**
Shelter is a part of a complex of shelters and overhangs at the top of the gully, opposite cave MH16-34.	Middle of local landscape
Cave Type:	**Internal domed chamber:**
Shallow shelter ~5 m deep.	No
Rear passages that may have roosts:	**Internal temp. and relative humidity:**
No	Ambient
Local foraging opportunities:	**Current distance to disturbance:**
Excellent, Mesa H is adjacent to Robe River riparian zone.	Mesa J mine is 4.5 km distant. Resource evaluation drilling nearby on mesa top.
Cave floorplan and entrance photo:	

Mesa H Cave AC4:

Assessed Ghost bat usage: Diurnal roost. Potential maternal roost but no recent evidence. GB scats under domes at rear.	**Coordinates:** 50K 417586 7594895
Entrance safe or unsafe to approach: Assessed safe	**Basic Geology: Land system at site** Robe Pisolite mesa: Robe
Entrance type and dims – WxH (m): A large entrance 3.0 m x 2.8 m.	**Entrance Orientation:** North east
Cave Grouping: Cave is alone on the east side of the central Mesa H gully.	**Insulation from surface above:** Middle of local landscape
Cave Type: 30 m deep cave with multiple domes.	**Internal domed chamber:** Yes. Six domes between 2.5 and 3.9 m high
Rear passages that may have roosts: No	**Internal temp. and relative humidity:** Ambient
Local foraging opportunities: Excellent, Mesa H is adjacent to Robe River riparian zone.	**Current distance to disturbance:** Mesa J mine is 2 km distant. Resource evaluation drilling nearby on mesa top.

Cave floorplan and entrance photo:

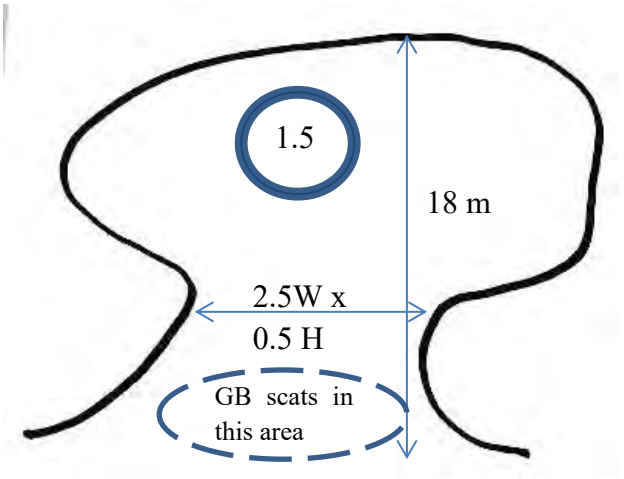




Mesa H Cave AC5:

Assessed Ghost bat usage: Nocturnal roost. GB guano present.	**Coordinates:** 50K 417109 7593285
Entrance safe or unsafe to approach: Assessed safe.	**Basic Geology: Land system at site** Brockman BIF: Newman
Entrance type and dims – WxH (m): A shallow cave with a wide low entrance 10.0 x 1.5 m.	**Entrance Orientation:** South east
Cave Grouping: Cave is in a gully on a ridge south west of mesa H..	**Insulation from surface above:** Middle of landscape
Cave Type: Shallow cave 18 m deep with a single low dome.	**Internal domed chamber:** Yes. 1.5 m high
Rear passages that may have roosts: No	**Internal temp. and relative humidity:** Ambient
Local foraging opportunities: Excellent, cave is 3.5 km from Robe River riparian zone.	**Current distance to disturbance:** Mesa J mine is 2.5 km distant.

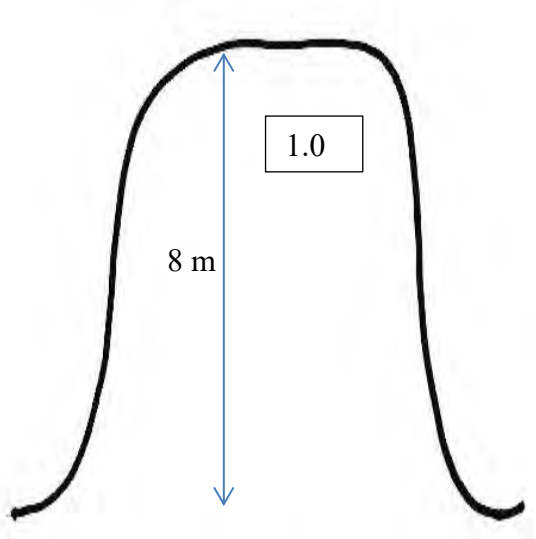
Cave floorplan and entrance photo:



Mesa H Cave AC6:

Assessed Ghost bat usage: Shallow shelter. No GB guano present. Not regularly used.	**Coordinates:** 50K 418068 7592683
Entrance safe or unsafe to approach: Assessed safe.	**Basic Geology: Land system at site** Brockman BIF: Newman
Entrance type and dims – WxH (m): A shelter with a low entrance 1.5 x 2.0 m.	**Entrance Orientation:** North east
Cave Grouping: Shelter is on a ridge south west of Mesa H.	**Insulation from surface above:** Middle of landscape
Cave Type: A low shelter 8 m deep.	**Internal domed chamber:** No
Rear passages that may have roosts: No	**Internal temp. and relative humidity:** Ambient
Local foraging opportunities: Excellent, cave is 4.5 km from Robe River riparian zone.	**Current distance to disturbance:** Mesa J mine is 1.5 km distant.

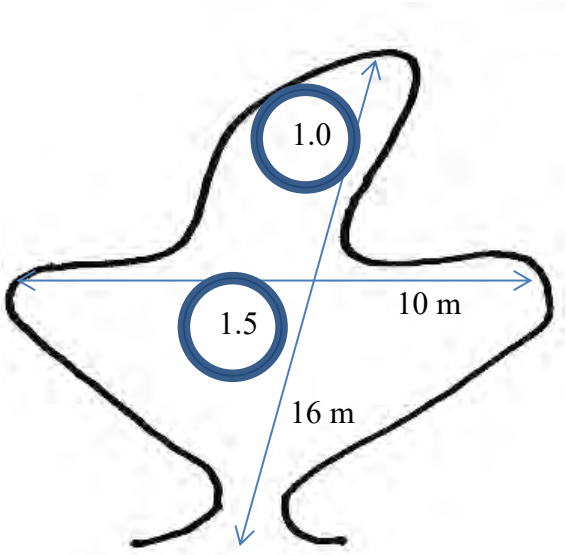
Cave floorplan and entrance photo:



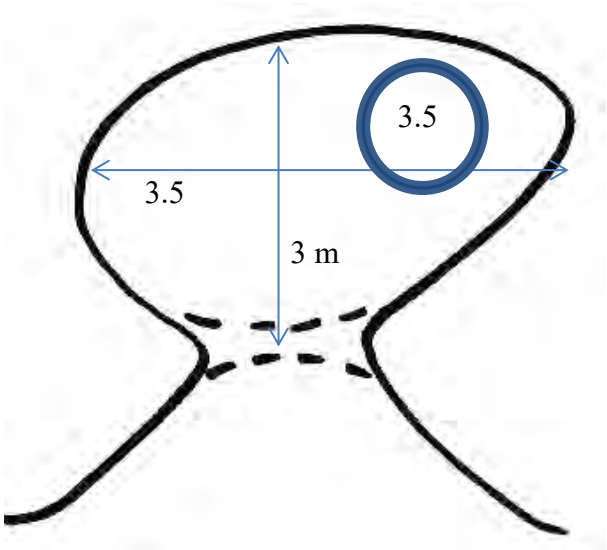
Mesa H Shelter Opp-1S:

Assessed Ghost bat usage: Nocturnal roost. Deep shelter. No GB guano present.	**Coordinates:** 50K 415625 7595659
Entrance safe or unsafe to approach: Assessed safe	**Basic Geology: Land system at site** Robe Pisolite mesa: Robe
Entrance type and dims – WxH (m): A small entrance among a group of overhangs. Entrance 1.5 x 1.5 m.	**Entrance Orientation:** North
Cave Grouping: Shelter is a part of a complex of overhangs along the south side of the gully opposite shelter H34.	**Insulation from surface above:** Middle of local landscape
Cave Type: Deep shelter with a two low domes.	**Internal domed chamber:** Yes. 1.5 and 1.0 m high
Rear passages that may have roosts: No	**Internal temp. and relative humidity:** Ambient
Local foraging opportunities: Excellent, Mesa H is adjacent to Robe River riparian zone.	**Current distance to disturbance:** Mesa J mine is 4.5 km distant. Resource evaluation drilling nearby on mesa top.

Cave floorplan and entrance photo:



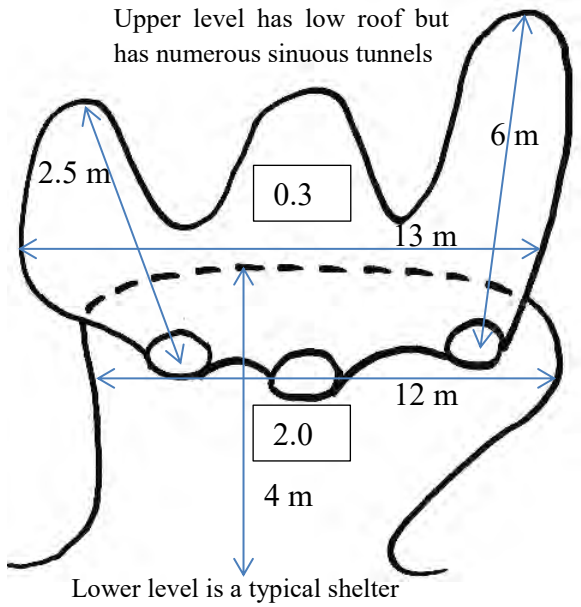
Mesa H Shelter Opp-2S:

Assessed Ghost bat usage: Nocturnal roost. Shallow shelter. No GB guano present.	**Coordinates:** 50K 416948 7596585
Entrance safe or unsafe to approach: Assessed safe	**Basic Geology: Land system at site** Robe Pisolite mesa: Robe
Entrance type and dims – WxH (m): A small constricted entrance 0.7 x 1.5 m.	**Entrance Orientation:** West
Cave Grouping: Shelter is a part of a complex of overhangs along the east side of the gully opposite shelter H27.	**Insulation from surface above:** Middle of local landscape
Cave Type: Shelter with small entrance and a low dome.	**Internal domed chamber:** Yes. 3.5 m high
Rear passages that may have roosts: No	**Internal temp. and relative humidity:** Ambient
Local foraging opportunities: Excellent, Mesa H is adjacent to Robe River riparian zone.	**Current distance to disturbance:** Mesa J mine is 3.5 km distant. Resource evaluation drilling nearby on mesa top.
Cave floorplan and entrance photo: 	

Mesa H Shelter Opp-3S:

Assessed Ghost bat usage: Nocturnal roost. No GB guano present.	**Coordinates:** 50K 417330 7595332
Entrance safe or unsafe to approach: Assessed safe	**Basic Geology: Land system at site** Robe Pisolite mesa: Robe
Entrance type and dims – WxH (m): A large entrance among a group of overhangs. Entrance 8.0 x 4.0 m.	**Entrance Orientation:** South east
Cave Grouping: Shelter is a part of a complex of overhangs along the west side of the central gully.	**Insulation from surface above:** Middle of local landscape
Cave Type: Deep shelter with a two levels. Upper level accessed by three pipes ~ 1.0 m diameter.	**Internal domed chamber:** No. Lower level has pipes in roof leading to upper level cavity that has numerous tunnels.
Rear passages that may have roosts: Yes in upper level	**Internal temp. and relative humidity:** Ambient
Local foraging opportunities: Excellent, Mesa H is adjacent to Robe River riparian zone.	**Current distance to disturbance:** Mesa J mine is 3.0 km distant. Resource evaluation drilling nearby on mesa top.

Cave floorplan and entrance photo:



Robe Valley Mesa A to Mesa 2405A, impact of mining on Ghost bat presence and activity, April 2017, including assessment of caves on Mesas F and G

Prepared for Rio Tinto

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Frontispiece: Yeera Bluff and the lower Robe River valley looking south west from the top of Mesa H by Tenielle Brown.

Images: Tenielle Brown or Bob Bullen unless otherwise noted.

Document Revision History

Issue	Date	Revision History
A	1 May 2017	Initial draft prepared for Rio Tinto review
B	28 May 2017	Second draft incorporating clients initial review
1	20 June 2017	First formal issue
2	28 June 2017	Second Issue
3	30 June 2017	Third Issue
Final	10 July 2017	Final Issue

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Attachment A Characteristics of caves examined during this survey.

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Attachment C. Data on supplementary sites within 10 km of Robe River including records of recent Ghost bat presence.

Executive Summary

Rio Tinto commissioned Bat Call WA (Bat Call) to undertake an assessment of the impact on Ghost bat populations of open cut iron ore mining on the Robe River valley's Deepdale, East Deepdale and Middle Robe deposits, east and west of Pannawonica, in the Pilbara region of Western Australia. This area includes the current and proposed Rio Tinto operations on Mesas A to J/K and the previously mined East Deepdale and Middle Robe areas.

Level one and two fauna surveys have been conducted in the area previously. Early surveys by Biota (Biota 2006, 2009, 2010) and more recently by Biologic in 2014, Astron Environmental Services in 2015/16, Rio Tinto internal ecologists in 2016 and 2017 and Bat Call in 2016 and 2017 have confirmed the ongoing presence of Ghost bats in the Robe River valley.

Data collected indicate that Ghost bats forage generally across the mesas and are roosting in a number of caves along the mesa perimeters. Multiple records including visual observations, cave middens and echolocation recordings, have been detected within and adjacent to the mesas confirming the presence of permanent or semi-permanent roosts supporting a number of maternity colonies.

This survey was designed to provide an assessment of the impact of mining practices since the Middle Robe operations began last century and to confirm whether the current mining practices under Rio Tinto management are effective in retaining the numbers of Ghost bats present in the Robe River valley.

There are twenty mesas of the thirty four (including Pannawonica Hill) on the Robe River system that have recent Ghost bat records. In addition there are five other sites within 10 km of the river where Ghost bat activity has been recently recorded.

There are eighteen mesas which have not been mined. The surveys from 2015 to 2017 show that the perimeters of the mesas that have not been mined including those that have had intense drilling programs on their caps remain as proven Ghost bat habitat and the caves and deep shelters continue to offer diurnal and maternity roost opportunities for the species.

There are two mesas where current large scale open cut resource extraction activities are underway, Mesas A and J. Neither of these currently has a known diurnal presence of Ghost bats although this is speculative due to a lack of survey data on the mesas from recent years. Scats collected in a shelter on Mesa A (Emma Carroll pers. comm.) and under a breakaway on Mesa J (Astron 2016) suggests that the species is using the mesa perimeters for foraging on an

occasional basis. Based on data from other Pilbara iron ore mine sites (e.g. West Angelas and others; author's unpublished data), the lack of diurnal presence is thought to be due to the disturbance from the sound, vibration and airborne dust generated by the blasting, crushing and hauling operations nearby.

There are thirteen mesas where mining of the cap has been completed. Of those, ten have a percentage of the original escarpment retained. The percentage ranges from 16% on Mesa 2402E to 93% on Mesa 2403D. This supplementary assessment of data previously collected (e.g. Astron 2016) demonstrates that the perimeters of the mesas that have been mined and retained in original condition in the Robe River valley remain as viable Ghost bat habitat and the protected caves and deep shelters continue to offer nocturnal and diurnal roosting opportunities for the species. It is also probable that the retained deepest caves and shelters are used as maternity sites although no evidence of this is available at this time.

An estimate of the combined impact of the iron ore mining on the Ghost bat species in the Robe River valley mesas has been made by assessing the lengths of the perimeters that are retained to a width that protects the deepest caves and shelters. The total perimeter length of the mesas between Mesas A and 2405A is approximately 275 km. Of this, approximately 227 km, or 83% has been retained or is in place on mesas not yet mined. Virtually all of these escarpments are in good condition although there have been some localised collapses and cut-outs for access roads. By applying a ratio of 2 deep caves (caves and shelters over 10 m deep) per km of escarpment, assessed from detailed surveys carried out in 2016 and 2017 by Rio Tinto and Bat Call on Mesas B, C, G and H, to the undisturbed remaining perimeter it is possible that there may be as many as 400 deep shelters and caves suitable for Ghost bat usage remaining on the mesas. While the height and definition of the escarpments varies from mesa to mesa, work done to date suggests that the ratio of 2 caves per km may be applied over the length of the Robe valley. The mesas therefore provide, in combination with the Robe River riparian zone, a continuous habitat for Ghost bats.

For the 48 km of perimeter that have been removed or destroyed, up to 100 caves and deep shelters may have been removed. The impact of removing these on the Ghost bats is unclear. In the Robe River valley, the numbers present may be limited by roosting opportunities or may be limited by the availability of prey. Firstly, based on the current understanding that availability of roosts is a limiting factor to Ghost bat presence (Woinarski *et al*. 2014), this removal may have had an impact on the total number of Ghost bats. It is also apparent, based on the evidence from the supplementary sites within 10 km of the river, that the areas surrounding the mesas have

retained all of their Ghost bat population. With a current estimate of 150 Ghost bats (author's unpublished data consistent with the population estimates in TSSC 2016) in the lower and mid Robe River valley, and recognising that the number will vary with the quality of the northern wet seasons, the loss of Ghost bats from mining in the early decades due to the loss of roosting habitat could be less than 20 individuals. However, this impact is offset by the presence of the very productive Robe River riparian and the major tributaries of Jimmawurrada, Bungaroo and Mungarathoona Creeks. In such a productive district, it is possible that the Ghost bat numbers are limited by seasonal and annual variations in prey numbers in the available high quality foraging opportunities in the river riparian and surrounding areas as has been shown to be the case in a number of predator/prey studies. If this is the case, the minimal impact on the Robe River riparian zone by mining would have left the original population levels virtually unchanged.

Currently in accordance with the statement, "The implication from all genetic studies is that losses of maternity sites containing breeding females have the potential to reduce the Area of Occupancy significantly" in Woinarski *et al*. (2014) it must be assumed that the presence of the caves and deep shelters is a limiting factor. Therefore retaining a minimum perimeter width of 20 m so as not to destroy the caves internal characteristics, together with providing specific protection for identified diurnal/maternal roosts and other candidate caves over 20 m deep, is unlikely to result in any significant loss of Ghost bats in the Robe River valley.

1.0 Introduction.

1.1 Project Background

Rio Tinto commissioned Bat Call to undertake an assessment of the impact of mining on the Ghost bat presence and activity along the Robe River valley. There are a series of mesas of Robe tertiary pisolitic limonite deposits (also known as Channel Iron Deposits, CIDs) that are in various stages of mining along approximately 90 km of the valley in the Pilbara region of Western Australia (WA). Pannawonica, in the Robe valley, lies roughly central in this district, figure 1. Mesa naming convention in this study follows the Rio Tinto names from Mesa A to Mesa N. Mesas further to the east mined by predecessors have been labelled Mesas 2400A to 2405A, figure 2.

Rio Tinto and its predecessors have been mining the mesa deposits for iron ore for five decades beginning at the eastern end of the line of mesas and progressively moving west. The mining operations involve the following main components and activities:

- Initial resource definition surveying involving track building and skeletal drilling patterns.
- Detailed resource evaluation drilling at various scales down to 50 m grids.
- Progressive open pit mining of ore and overburden from mesa deposits using open-cut pit mining techniques. These operations have generally removed the inner core of the mesa while leaving lengths of the rocky face of the perimeter intact to a width of at least 20 m at the mesa surface except where cuts are required for access. During the early years of mining, the larger mesas at the eastern end of the valley, Mesas L to 2405A, had their perimeters either removed entirely or the majority removed, and had overburden dumped over the side on top of the original talus. In recent decades facades facing the Robe River have been retained to varying widths to preserve caves and shelters that have been identified as significant to indigenous cultural heritage and/or the presence of conservation significant fauna-flora, e.g. Mesas A and J.
- Placement of overburden in out-of-pit waste dumps either adjacent to the mesas or on top of the original low mesa perimeters, and
- Construction and use of haul and access roads to the mine areas within the mesas.

Recent surveys have identified that two species of cave roosting bat of conservation significance are present in the area, the Ghost bat (*Macroderma gigas*) and the Pilbara leaf-nosed bat (*Rhinonicteris aurantia*) (PLNb). PLNb have been assessed as using the mesas for foraging while originating from a yet to be discovered roost further to the south or east (Bat Call 2016b, 2016d, 2017a). Multiple Ghost bat records including visual observations, echolocation recordings and cave middens have been detected within and adjacent to the study area (Biota 2006, 2009, 2010; Astron 2016, 2017; Bat Call 2015, 2016a, 2017a, 2017b, 2017c, 2017d).

The purpose of this survey was to assess the impact of open cut iron ore mining on the presence and activity of Ghost bats in the Robe valley, including bat colonies and/or nocturnal foraging. The study area is shown in figure 2. It includes all of the mesas between Mesa A and Mesa 2405A plus the areas immediately adjacent to the Robe River between these sites. In total, Ghost bats observations covering 33 mesas adjacent to the Robe River plus results from five sites within 10 km of the River are included in this assessment, figure 2.

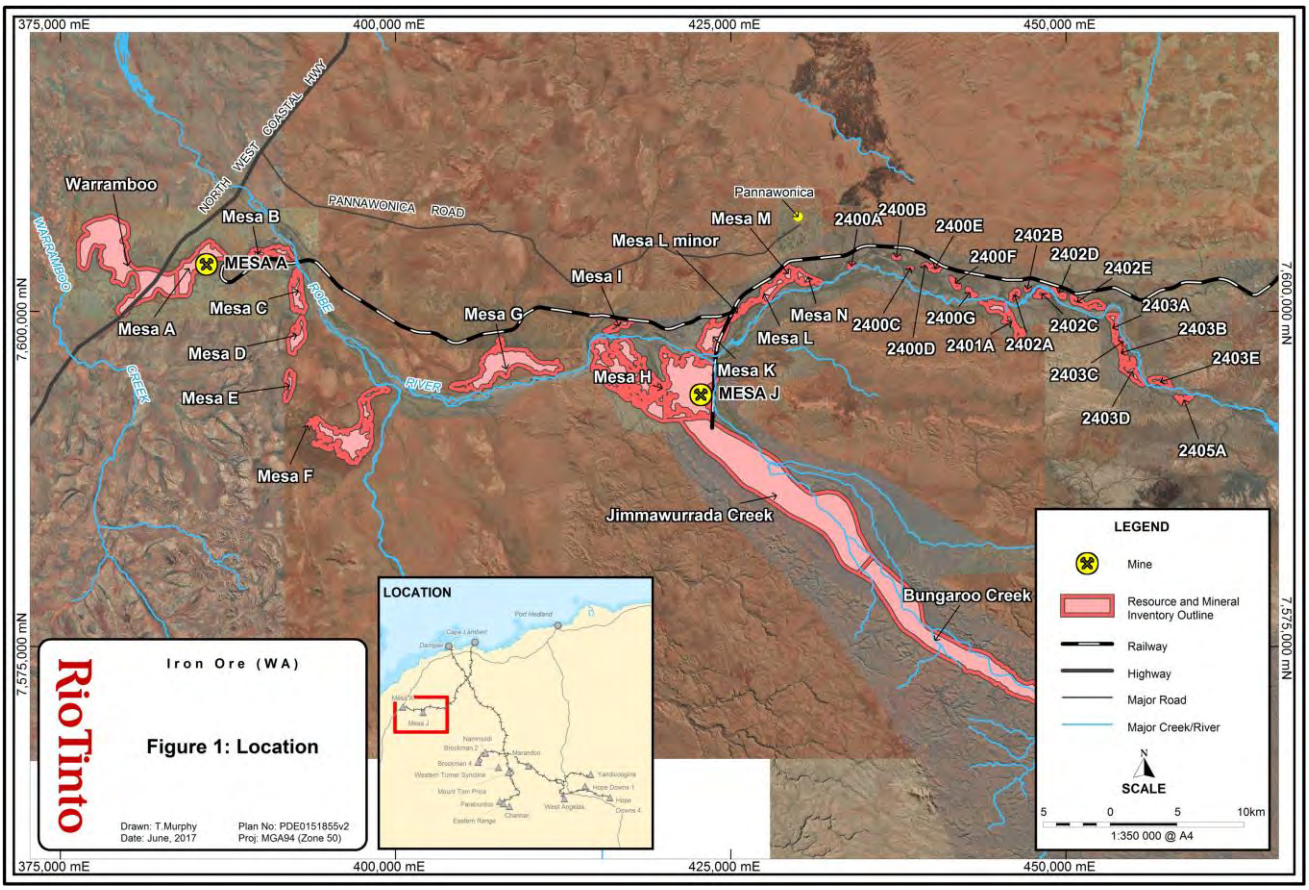


Figure 1. General Arrangement of Robe River valley mining area.

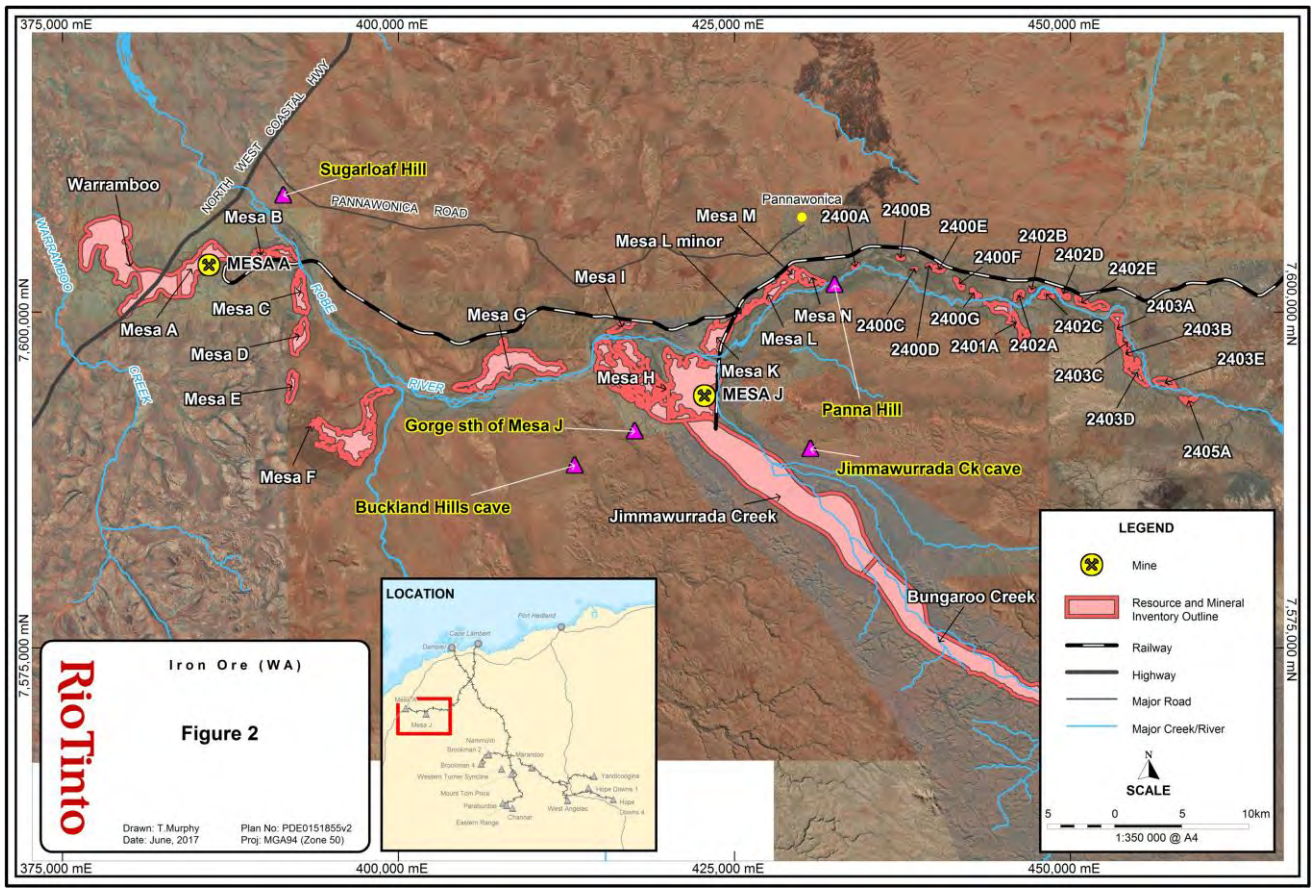


Figure 2. Mesas and supplementary sites (triangles) included in the assessment.

1.2 Existing Environment at Robe River valley Mesas and Surrounds

Topography

The Robe valley mesas cover an extensive area beginning at Mesa A in the west and running approximately 90 km eastward roughly paralleling the current orientation of the Robe River. They stand approximately 50 m higher than the flat plains that are crossed by the Robe River. Most of the mesas lie immediately adjacent to the river riparian zone with Mesas A, E and the majority of F being the most distant at 5 km. They vary in size from small unnamed pinnacles to very large mesas. The small unnamed pinnacles are not included further in this assessment. Pannawonica Hill is the smallest mesa with a cap of approximately 800 m^2 and perimeter of 0.11 km. Mesa F, with a cap of over 17 km^2 and a perimeter length over 39 km, is the largest. To the north and south the area is dominated by ironstone and basaltic uplands of the Hamersley Range, e.g. plate 1

Geology

In the Robe valley, the Robe Pisolite forms flat-topped mesa landforms (known as Channel Iron Deposits, CIDs) that are the remnants of the ancestral drainage channels of the Robe River formed during the Tertiary period. Erosion of the surrounding landscape has exposed the Pisolite formations creating an 'inverted topography' and subsequent erosion has created isolated mesa landforms. The larger mesas are incised with deep gullies around their perimeter. Pre mining, all mesas originally had overhangs, shelters and caves along extensive lengths of their perimeters and within major and minor gullies, e.g. plate 2.

Plate 1. Example of the three major land systems in the study area. This view is of the northern end of Yeera Bluff (Newman l.s., upper left), the Robe River riparian centre (River l.s., centre) and the north west rim of Mesa H (Robe l.s., right) showing the talus slope topped by the mesa cap.

Overhangs, shelters and caves are defined herein as:

- Overhangs are shallow hollows in a rock wall with a distinct roof structure. Their shape is such that they are fully lit by sunlight to their back wall. Their depth is typically 2 to 5 m.
- Shelters are deeper hollows or shallow caves in the rock wall that have ceiling structures from 1.0 to 5 m and higher and offer significant protection from predators and the weather. These are typically 5 to 15 m deep and have dark twilight conditions at their rear

extremities. Some have domed areas in their ceilings offering roosting and feeding opportunities to Ghost bats.

- Caves are defined as deep structures of various heights, widths and depths that are very dark in their deeper recesses. They often have one or more rear chambers separated from the entrance by constriction points. Those chambers that have ceiling heights of over 2.5m and an entrance constriction larger than 0.6 m square. They offer excellent roosting opportunities for Ghost bats.

- All three can have cracks or voids that continue back from their rear walls that may lead to additional internal cavities within the rock strata behind or above. Such cavities that are almost fully enclosed and can retain high levels of humidity are roosting opportunities for PLNb and Ghost bats if the entrance cracks are large enough.

Overhang and shelter density is high along the majority of the mesa perimeters with the rock strata forming numerous shallow shelters in mid and higher levels of the walls. There are a number of deeper caves formed in the Pisolite at mid and higher levels of the mesa walls but these rarely extend beyond 15 m in depth. Most shelters and caves were found on the mesa walls at or just above the top of the talus slope junction with the cliff wall.

Plate 2. Example of the presence of overhangs and shelters along the perimeters and within the incised gullies of mesas. This view is of a cave, shelter and overhang complex on Mesa H.

Land Systems (after Van Vreeswyk *et al.* 2004)

The mesas and their gullies and the surrounding talus slopes are elements of the Robe land system. They are low limonite mesas that support spinifex grasslands and thin Eucalypt (Snappy Gum) woodlands. The lower slopes and adjacent gravelly plains support spinifex grasslands and very scattered to moderately close Acacia and Eucalypt shrublands and woodlands, plate 2.

The adjacent Robe River flows westward from the distant Hamersley Range uplands. It is a very complex and productive linear river channel and flood plain with a Eucalyptus and Melaleuca woodland over tall Acacia and Petalostylis shrubland. It is an element of the Pilbara's River land system.

Yeera Bluff and the Buckland Hills to the south and west of Mesas H and J are rugged jaspilite ridges and hills of the Newman land system supporting Grevillia and Eucalypt shrublands and woodlands over hummock grasses.

The majority of the upland areas both north and south of the Robe to the east of Pannawonica are rounded and gently inclined basalt hills and plateau of the Rocklea land system. These support hummock grasslands with scattered Acacia and Senna shrublands.

The majority of the area to the north and south of the lower Robe mesas are stony plains of various land systems and low sedimentary hills of the Nanutarra land system. These support hummock grasslands with scattered Acacia and Senna shrublands.

Climate

The climate in the district is semi-desert tropical. Mean monthly minimum and maximum temperatures in the lower Robe valley range from 12 to 41 degrees Celsius (^{o}C). Annual rainfall is extremely variable and averages 400 mm, usually in cyclonic or thunderstorm events during the northern wet season. The northern dry season lasts from May to November and winter rainfall is uncommon.

Water Sources

Drainage systems in the district are associated with ephemeral gullies on the perimeters of the mesas that run into the Robe River drainage system. The Robe River riparian zone has a number of permanent and ephemeral pools along its length such as Gnieraoora Pool at the base of Yeera Bluff. Major tributary creeks include Jimmawurrada and Bungaroo Creeks to the south and east of Mesa J and Mungarathoona Creek to the south of Mesa F.

1.3 Bats of Conservation Significance

The Pilbara region contains 17 species of microbat, and of these, 13 have the potential to be found in the Robe valley (Van Dyke and Strahan 2008, McKenzie and Bullen 2009). A number of fauna surveys including targeted bat surveys have been previously conducted in the area, most recently by Astron in 2015 and 2016 and Bat Call in conjunction with internal Rio Tinto ecologists in 2016 and 2017, see table 1. Two Pilbara bat species of conservation significance have been recorded in the area, the Ghost bat (*Macroderma gigas*) and the PLNb (*Rhinonicteris aurantia*).

The Ghost bat is a large (130 g) carnivorous predator and the PLNb is a small (10 g) insectivore. Both are endemic to northern Australia and are obligate cave roosting species requiring specific cave environments for permanent roosting especially for supporting a successful maternity colony. The Ghost bat's foraging strategy and high trophic niche, as a top night-time carnivorous predator, is unique in Australian microbats. Both Ghost bat and PLNb populations are isolated from the main tropical populations that are extant across the mesic tropics by the uninhabitable arid zone of the Great Sandy Desert to the north and east. Both species are "conservation significant" as they are semi-desert adapted populations that have specific roosting requirements. The Ghost bat has suffered significant range loss in historical times. The reasons for the range contraction are open to speculation but it is known that the species is subject to disturbance (Richards *et al*. 2008, Woinarski *et al.* 2014). The Ghost bat has been detected within the study area and one or more caves are suspected as being maternity roost candidates.

The PLNb has been detected foraging across the mesas in the Robe valley. The PLNb is not discussed further in this report as a separate study is underway to determine the location of a PLNb roost thought to occur in the lower Robe valley.

Ghost bat (*Macroderma gigas*)

The Ghost bat has a conservation status of Vulnerable under the Commonwealth *Environment Protection and Biodiversity Act 1999* (EPBC Act), Vulnerable under the Western Australian *Wildlife Conservation Act* (1950) and Vulnerable C1 (a vulnerable species numbering less than 10,000 and in decline) under the IUCN Redlist (IUCN 2017). These listings are on the basis of the impact of loss of suitable roost opportunities. The Pilbara Ghost bat population is estimated at 1500-2000 based on recently published estimates (approximately 600, N.L. McKenzie pers. comm. in IUCN 2017; approximately 1200, Armstrong and Anstee 2000; "more common than previously supposed", McKenzie and Bullen 2009) and author's unpublished database

summarising data from a range of surveys carried out in recent years by Pilbara mining companies, including Rio Tinto and other organisations, supplemented by author's own data (summarised in Threatened Species Scientific Committee (TSSC) (2016)). These recent data (estimates less than 15 years old) cover the entire Pilbara bioregion. Current population estimates in the Hamersley and Chichester subregions are approximately 350 and 1500 respectively (author's unpublished database summarised in TSSC (2016)).

There is no information available regarding the population size upper limits in an undisturbed environment. For a mammal such as a Ghost bat with a restricted roosting habitat niche, there are two possibilities limiting species density. The numbers may be limited by the availability and size of roost caves offering suitable habitat or the number may be limited by the availability of prey, especially during the post breeding season when lactating mothers and juveniles are in an energetic bottleneck. If the former is the dominant limit, then the number of bats in a district would be proportional to the availability of the roosts. If the latter is the primary determinant, as is the case in a number of classical predator-prey studies (e.g. Peterson and Page, 1988; discussion on predator-victim ratios in Rosenzweig, 1995; but see Peterson *et al*., 1998) then the population of Ghost bats would rise, fall and be limited by the availability of prey of the favoured size on a seasonal or annual basis. We therefore cannot directly attribute a loss of population to a measured loss of roost sites. Current knowledge based on populations in the Northern Territory and Queensland summarised in Woinarski *et al.* (2014) and TSSC (2016) supports the statement, "The implication from all genetic studies is that losses of maternity sites containing breeding females have the potential to reduce the Area of Occupancy significantly". Future research may resolve this for the Pilbara Ghost bat. Currently we must assume that the loss of roosting opportunities will have a negative and permanent impact on numbers.

Ghost bats hunt their prey in two primary ways. They hunt birds and bats at cave entrances and elsewhere "air-to-air" by swooping from above or from a perch. They also hunt ground level prey in their target food size range by dropping onto the prey from a perch, either tree branch or rock outcrop. Their diet includes small mammals (including other bats), birds, reptiles, frogs and large insects. The proportion of food items in the diet varies with availability and reported foraging areas vary from a few to 10 km from the roost cave. In May 2016, a Ghost bat carcass was found entangled in a barbed wire fence (DPaW 2016) over 12 km from the nearest cave forming rocky strata suitable for roosting.

Ghost bat breeding populations are known from a small number of maternity roosts in the Pilbara and reproduce during the northern wet season. The largest of these colonies are in abandoned

mines in the Chichester subregion and number up to several hundred (Armstrong and Anstee 2000, author's unpublished observations)). Hamersley Range populations are typically between five and twenty five individuals in local groups (author's unpublished data). There is one known large, permanent maternity roost numbering over 70 bats in the lower Robe River valley on Mesa F (see Results below). For these groups to persist the bats need an "apartment block" of roosting opportunities, at least one deep cave with characteristics of a maternity roost, multiple caves/shelters and overhangs in close proximity offering nocturnal feeding and refuge opportunities, a local productive set of gullies and gorges, a productive foraging area within 5-10 km radius, usually including a good quality riparian line or ephemeral fresh water lake bed and appropriate protection from human interference (author's unpublished data). These groups are known to reproduce in good years using suitable natural roost caves. Examples are a group numbering 5 to 10 including reproducing females at West Angelas caves in 1980 (Dr Nic Dunlop pers. comm.), a small group including reproducing females at caves at Nammuldi/Silvergrass area (Hamersley Iron 1999), observation of a heavily pregnant female at a cave near Mt Robinson by the author in 2013 and a group numbering 14 including four juveniles at another cave near Mt Robinson in 2015 (Mr. Morgan O'Connell pers. comm.). The Ghost bat is also known to spread great distances on an annual cycle from these locations depending upon seasonal weather conditions and availability of suitable day roosts. Sporadic records of Pilbara Ghost bats have been identified in the Gascoyne (author's unpublished data) and the Little Sandy Desert (sightings by W.H. Butler at Durba Springs in 1971 and others since). Genetic work by Worthington Wilmer and Armstrong (summarised in Woinarski *et al.* 2014) suggests that the females remain or return to their birthplace and that the males can move between districts.

Ghost bats use three types of roost regularly, these being nocturnal roosts or feeding sites, diurnal or day roosts that may be permanent or semi-permanent sites and maternity roosts that are diurnal roosts with the range of characteristics allowing regular or permanent occupancy.

Nocturnal roosts or feeding sites are only used at night, either habitually or for transitory visits. They are typically shallow caves and shelters that are well lit during the day. They are often high in the strata and may be well or poorly insulated from the elements. They often contain guano scatters and/or midden(s) of various sizes containing guano and food scraps but these remains are sometimes removed by rainfall, disturbed by various larger mammals and marsupials such as macropods and goats and/or removed by varieties of "dung beetle" that are known to forage on the scats (author's unpublished observations).

Diurnal roosts are caves and mine adits that are deeper and more complex. They typically have one or more large chambers at or beyond the twilight area with additional fissures or chambers at the rear in the fully dark regions. They have a minimum roof height in the chambers of 2 to 3 m providing protection from attack by terrestrial predators. They are often at mid-levels or lower in the strata and are well insulated overhead providing a stable temperature environment. They typically contain multiple scat piles and middens of guano and food remains that include feathers and skeletal material.

Maternity roosts are diurnal roosts that provide additional features listed above that are able to support a reproducing population. These features usually include an interior chamber that is rising toward the rear thereby trapping warmer and more humid air at the top allowing suitably benign conditions to form during the period when reproductive females and pups are present.

Being carnivorous predators, during a nights foraging they may also hang for short periods in any deep overhang, shelter or cave with a high enough ceiling or tree branch overhead a cleared patch of ground for feeding or resting on an opportunistic basis. These sites are not routinely visited and show no evidence of Ghost bat presence.

1.4 Summary of Previous Bat Surveys

Prior to 2017 there have been a number of fauna surveys commissioned by Rio Tinto and predecessors in the lower Robe valley that have included bat species listings. These indicated the presence of both significant species foraging across the area. More recent surveys carried out in 2015 and 2016, summarised in table 1 below and including caves on Mesas F and G whose assessments are included in attachment B herein, indicated that the Ghost bats are roosting locally and include maternity colonies on Mesas B and F, plus other diurnal roost candidates at various other mesas.

Table 1. Summary of Fauna Surveys that Include Ghost Bat records in the Robe valley.

Date	Reference	Ghost bat activity detected.
2006	Biota (2006)	• Ghost bat sighted at cave on Mesa A prior to commencement of mining.
2009	Biota (2009)	• Ghost bats harp trapped at Mesa G
2010	Biota (2010)	• Group of Ghost bats sighted at Mesa F cave MF-01
2014	Biologic (2014)	• Visual sightings of Ghost bats at several caves within 10 km of the lower Robe River in the Yarraloola district.
2015	Astron (2015)	• Mid Robe survey where Ghost bats were detected at several locations between Mesas L and 2405A. Diurnal roost candidates identified at Mesas 2400E, 2402B and nearby 2403E
2015	Astron (2016)	• Ghost bat echolocation calls detected at Mesa H and surrounding area. A number of shelters/caves with scats recorded. Diurnal roost candidates identified on Mesas G and H and in hills south of Mesa H.
2015, 16 and 17	RTIO internal heritage staff	• Surveys of caves and shelters on various mesas. Several candidate diurnal roosts identified on Mesas B, C, G and H.
2016	Bat Call (2016a, b, d)	• Ghost bat visual sightings, cave assessments and echolocation calls detected at mesas between B and F. Maternity roost cave identified at Mesa B. Candidate diurnal roost identified on Mesa C.
2016	Astron (2017)	• Ghost bat echolocation calls detected at various mesas in East Deepdale and Middle Robe and a number of shelters/caves with scats recorded.
2017	RTIO internal ecologists	• Ghost bat seen at Mesa H at cave H27. Presence detected at Mesa F cave MF-01. Maternity roost candidate identified near Jimmawurrada Creek (Bat Call 2017b)

Date	Reference	Ghost bat activity detected.
2017	Bat Call (2017a, b, c, d)	• Visual sightings including bats, middens and scats and echolocation call detections at Mesas A, B, C, D, F, G, H. Maternity roost identified at Mesa F. Diurnal roosts identified at Mesas G and H.

2.0 Survey and Assessment Methods

2.1 Categorisation of status of mesas.

Mesas were measured for area and perimeter using aerial photography available on GOOGLE EARTH PRO. The complete perimeter of the upper cap of each mesa was outlined with a polygon and the area and perimeter length recorded. The length of the retained undamaged perimeter was then measured, e.g. figure 3.

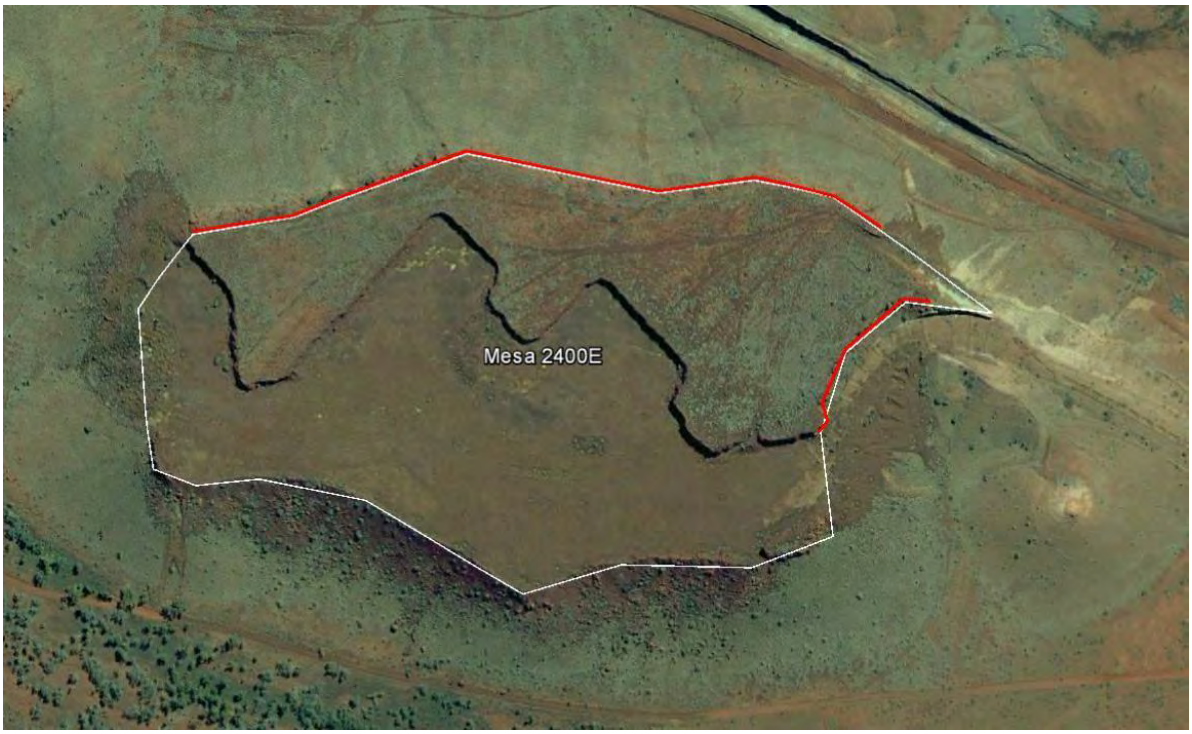


Figure 3. An example of the assessment of the size, perimeter length and state of preservation of the original mesa escarpment; Mesa 2400E in the Mid Robe valley. The white polygon surrounds the original mesa top cap. The red lines indicate the extent of the retained original perimeter containing caves, shelters and overhangs. The extent of the perimeter removed by mining is indicated by the visible overburden dumped along its length (dark brown scree outside polygon). The retained perimeter with original talus or abandoned haul track below is the light colour areas immediately outside the polygon.

Each mesa was then categorised for the extent of mining operations carried out. These operations covered:

- Mesa in original state.
- Initial resource evaluation including track building and skeletal drilling.
- Resource evaluation drilling on close grid patterns down to 50 m spacing.

- Overburden removal and resource mining operations including the building of access haul tracks through the perimeter.

- Post mining rehabilitation.

2.2 Density of caves and deep shelters on mesa rims

The locations of the deep caves and shelters around the complete perimeters were available from surveys completed on Mesas B, C, G and H (Rio Tinto data base). The number of sites was counted and the lengths of the facades including these were measured. Sites that included complexes or groups of caves/shelters/deep overhangs in close proximity, typically separated by less than 25 m, were counted as a single site.

2.3 Observation of current Ghost bat presence and usage.

Results from surveys included in this study were collected over a number of years using a variety of techniques. The majority of observations are recent dating from 2014 to 2017 and result from visual assessments of caves and shelters made on foot. These were supplemented by harp trap, mist net and echolocation detector records from the years since 2006.

The most recent fieldwork focussed on the assessment of habitat of Ghost bats at all mesas between A and 2403E by Astron, Bat Call and RTIO internal ecologists. In 2015 and 2016, Astron completed assessments of the mesas from the East Deepdale and Middle Robe areas. In July 2016 and April 2017 Bat Call and RTIO completed detailed assessments of all identified caves and shelters on Mesas B, C, F, G and H. Characterisation of significant caves on Mesas F and G are included in attachment A herein. In April 2017 a visual assessment was made of the state of preservation the mesas east of Mesa J to allow correlation with the Ghost bat presence records from the earlier surveys and to ground truth the aerial photography assessments.

2.4 Survey Team

The July 2016 and April 2017 survey teams consisted of two experienced ecologists on each survey. In 2016 and 2017, Ms Emma Carroll (Rio Tinto) and Ms Tenielle Brown (Rio Tinto) were team leaders respectively. Mr Robert Bullen (Bat Call) acted as principal ecologist for both surveys. In April 2017, Ms Melinda Brand (Rio Tinto) accompanied the assessments of Mesa H and those further to the east.

2.5 Inclusion of sites nearby Robe River in study

Ghost bat presence records from five sites within 10 km of the river but not on the named CID mesas were included in the study for context. These sites are all locations were Ghost bats have been sighted during daytime survey activities and are therefore possible diurnal roost candidates.

2.6 Survey Limitations

Detailed interior searches of caves were carried out under the guidelines of the Rio Tinto safety procedures. Prior to July 2016 entry by fauna surveyors into caves and shelters was prohibited. Post July 2016, entry into any cave that was deemed to have an unstable ceiling as characterised by loose rocks overhead or around the entrance, heavy cracking or the presence of fresh slab like roof material fallen to the floor continued to be prohibited. These procedures also prohibited entry into any chamber that required sliding on stomach or back or that required climbing or descending 2 m using rock-climbing techniques. The rear areas of some caves could therefore not be searched completely and the possible presence and number of Ghost bats in such caves was therefore not confirmed absolutely.

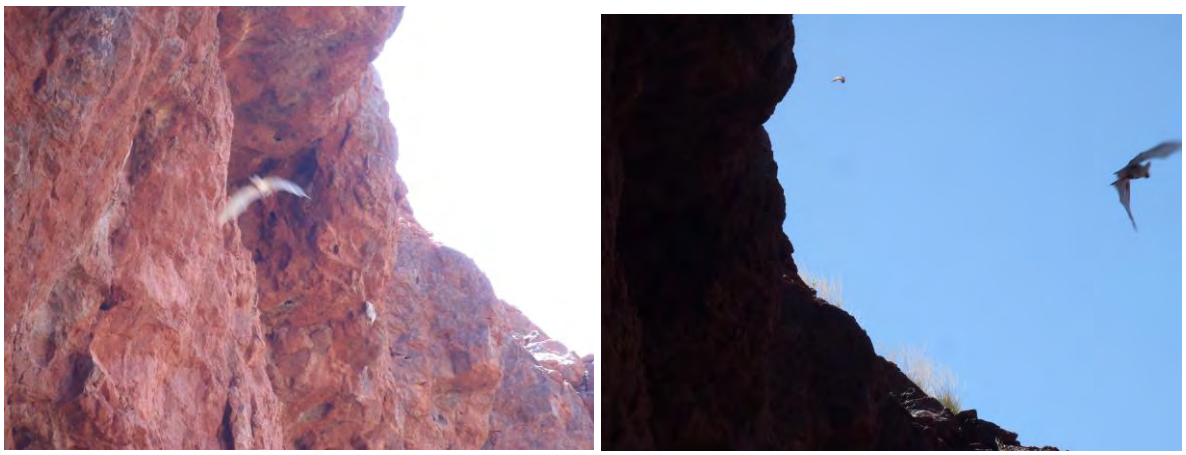
Complete perimeter searches for caves and deep shelters greater than 10 m depth have only been completed on mesas A, B, C, G and H. Incomplete searches that identified only the most visible caves and shelters have been completed on the rest of the mesas.

3.0 Results

3.1 Cave Characterisations at Mesas F and G

Mesa F

During this study an ongoing Ghost bat presence at cave MF-01 on Mesa F was confirmed. Ghost bats had been reported at this site by a number of earlier visits (e.g. Biota 2010 and Rio Tinto internal ecologists 2017). On entering the first chamber of the cave, audible social calls were heard originating at the rear of the cave. Almost immediately over 70 Ghost bats emerged at high speed along the rear tunnel, flew past the author and observer, and departed the main entrance, plates 3 and 4. A number roosted under overhangs beside the cave, plates 5 and 6, and then re-entered once the observers had departed. Additionally, as the main group was exiting the cave the observer at the entrance saw a number flying above the entrance that appeared to be originating from a secondary entrance higher up the cliff directly above. Following the departure of the main group, the rear tunnel was found to have a very large and high second chamber where the bats had been roosting, attachment A. During the assessment, the floor of the cave was found to have Ghost bats scats along its full length. The characteristics of this cave supported by the multiple observations of roosting bats, the extensive scat carpet and the presence of a large number of "dung beetles" are consistent with its use as a permanent diurnal/maternity cave.



Plates 3 and 4. Ghost bats departing cave MF-01.

Plates 5 and 6. Ghost bats roosting temporarily under overhangs outside the entrance of cave MF-01.

Due to the speed of their departure from the cave, no observations regarding their gender or apparent age could be made.

Mesa G

During this study a group of caves on the southern face of Mesa G was assessed. In conjunction with the earlier data, a Ghost bat presence at Mesa G was confirmed, figure 4.

Figure 4. Mesa G caves and shelters where Ghost bat observations were made. The red dot denotes the diurnal cave G02 at the eastern end of the mesa. The yellow dot denotes a nocturnal feeding shelter at G03. The white dot denotes one location where Ghost bats have been reported (Biota 2009) but no other indication of a roost cave or activity was observed during this survey.

Two sites in one deeply incised gully were assessed as being in possible current use by Ghost bats including one diurnal roost cave and one nocturnal roost shelter. Assessments of each cave and observations of Ghost bat activity are provided below, attachment A, with detailed characteristics of the caves including floorplans and dimensions. Cave G02 was found to be over 20 m deep and to have the characteristics of a diurnal roost although no evidence of current habitation was found.

The eastern gully on the south face containing caves G02 and G03 was assessed as the most significant areas on Mesa G. Cave G02 (50K 411740 7595774) being a part of a complex of caves, shelters and overhangs, and the gully containing it, has all of the characteristics required by Ghost bats for this to be considered a possible maternity roost. These characteristics include an internal shape adequately deep and dark along with a high domed chamber at the rear shaped to trap warm humid air, multiple nocturnal roost opportunities, multiple daytime refuge opportunities, multiple early evening observation sites and a major productive riparian zone within 5 km. No evidence of Ghost bat presence was found within this complex during this survey although a small midden containing scats and *Taphozous* sp. wing bones, the age which could not be determined, was found in cave G03 (50K 411727 7595625) nearby.

3.2 Unmined mesas, density of caves and shelters.

There are nine mesas with no mining activity evident, attachment B. These are Mesas D, E, I, L2, 2400A, 2400B, 2400C, 2400D and 2402B. A view representative of the rim of an unmined mesa is presented in plate 7.

The density of caves and shelters greater than 10 m deep on unmined mesas was assessed from the data available from Mesas B, C, G and H that have 100% of their original perimeters intact, are presented in table 2. A density of up to 2 caves/shelters per km of unmined facade was found to be typical of the mesas west of Pannawonica. The visual review of the mesas east of Pannawonica undertaken suggests that this figure is also applicable in the East Deepdale and Middle Robe areas. Ghost bats have been found to be present on Mesas B, C, G and H for both roosting and foraging. The current Ghost bats presence records for Mesas B, C and H are presented in detail in Bat Call (2016a, 2017c, 2017d). These data are supplemented with Mesa G data herein. Diurnal roosts classified as maternal have been identified at caves on Mesas B (MBC-05) and F (MF-01). Five diurnal roosts candidates have been identified on Mesas C, G, H and 2402B. A summary of the results and the available data from the other unmined mesas is

given in attachment B. A summary of the available data from the unmined supplementary sites within 10 km of the river is in attachment C.

Plate 7. A view of the unmined central gully and eastern face of Mesa H showing the upper rim, the cliff face with caves and shelters present and the lower talus slope. This view is representative of the condition of the unmined mesas along the valley.

Table 2. Density of caves and deep shelters on unmined Robe River mesas.

Mesa	Number of sites with caves and/or deep shelters	Perimeter of mesa facade containing the sites	Density of caves and shelters deeper than 10m
B	16	9.6	~1.7 / km
C	21	10.5	~2 / km
G	12	6.0	~2 / km
H	46	25	~1.9 / km

3.3 Mesas with initial resource evaluation activities or resource evaluation drilling.

An assessment of the impact of resource evaluation drilling on the caves and shelters potentially in use by Ghost bats has shown that skeletal resource assessment drilling programs do not impact the mesa facades and therefore do not impact the caves and shelters, figure 5. A minor length of facade is lost when access tracks are cut through the face but these lengths are typically very short, i.e. 25 to 50 m. An example is given in figure 6. There are three mesas that have an initial, drilling (or equivalent) program with only skeletal tracks and pads present, Mesas F, L1 and 2405A.

Figure 5. View of the top of an unnamed mesa west of the Buckland Hills showing a recent skeletal drilling pattern retaining an unaffected perimeter at least 50 m wide.

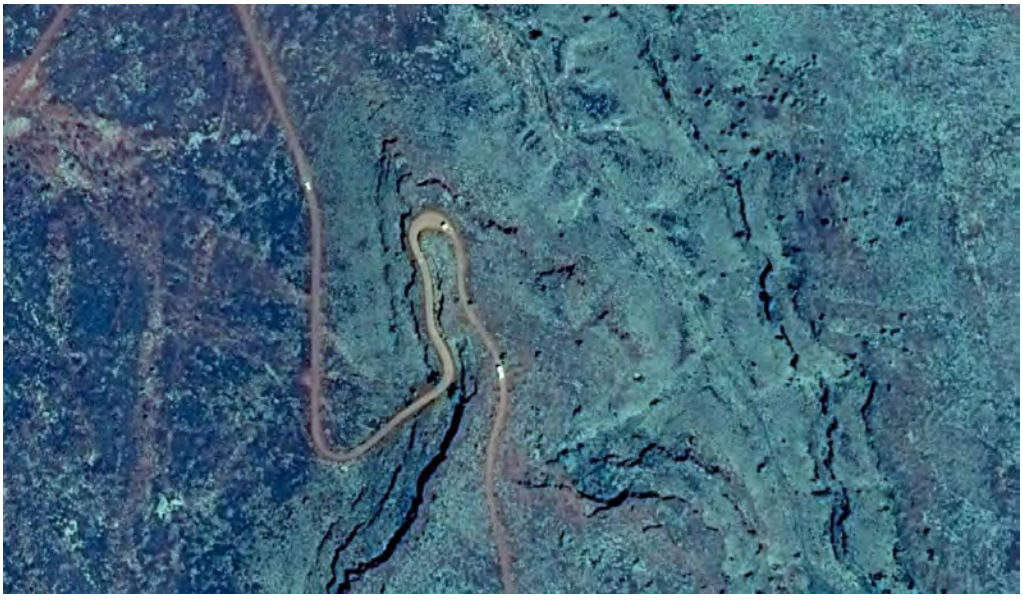


Figure 6. View of the top of the northern end of Mesa C access track to the top of the mesa that has removed approximately 25 m of the lower cliff and 20 m of the upper cliff.

In early decades facade retention was not prioritised and the pattern of resource evaluation disturbance continued to within 10m of the rim edge, figure 7. This is evident on Mesa 2403E. This suggests that some limited loss of habitat due to localised rim collapse was possible on these mesas prior to mining operations beginning. More detailed resource evaluation drilling patterns in recent years have maintained an approximately 50 m standoff from the rim of the mesa cap, figure 8. There are four mesas with this type of pattern, Mesas B, C, G and H. This has ensured that all but the very deepest caves have remained unaffected by drilling programs on mesas between B and H.

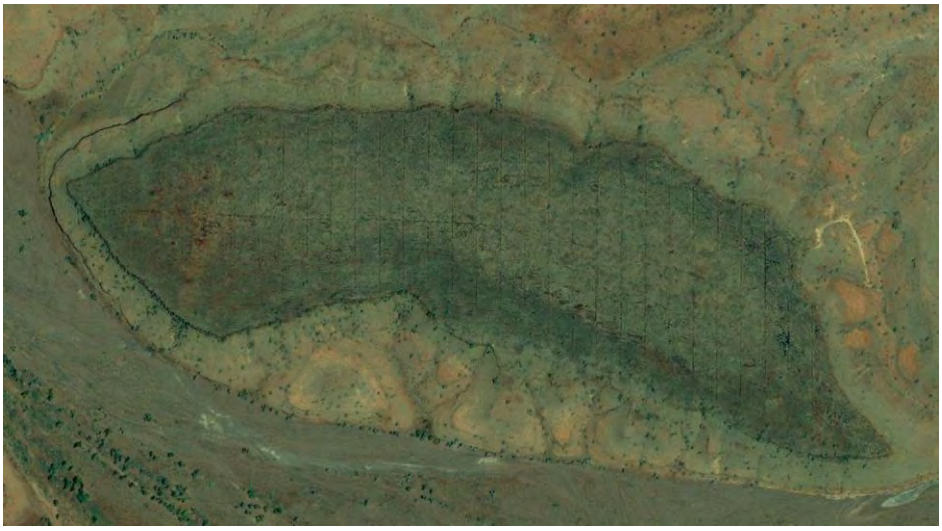


Figure 7. View of the top of Mesa 2403E showing a resource evaluation work pattern dating from several decades ago that extends to the mesa perimeter (facade) potentially impacting sites on the cliff below.

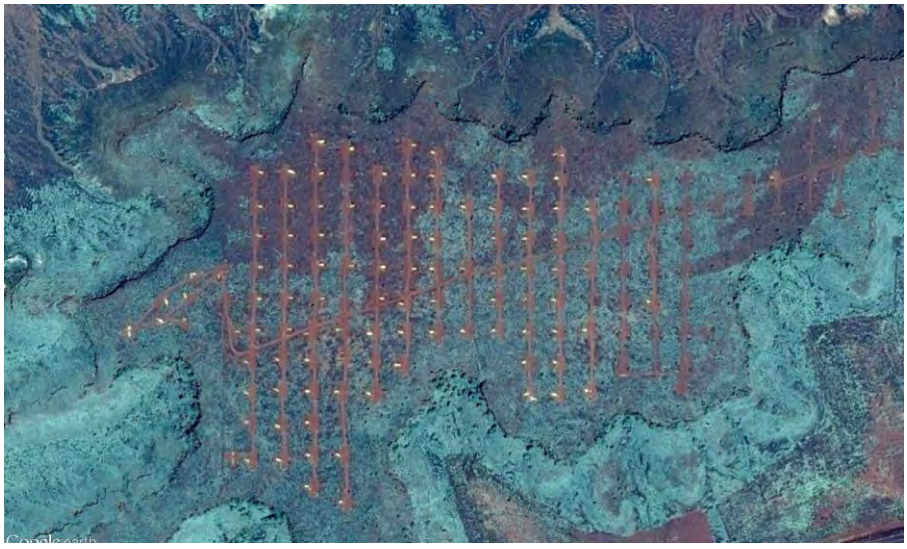


Figure 8. View of the top of the western end of Mesa B showing a recent drilling pattern retaining an unaffected facade at least 50 m wide.

3.4 Mesas with current overburden and/or open-cut resource extraction operations.

There are two mesas with current mining operations. These are A and J, attachment B. Mining at Mesa A has been in progress since 2010 and the operations now cover the majority of the original mesa. Mesa A does not have an escarpment on its southwestern side. Almost 100% of the original escarpment of the northern half of the mesa has been retained to a width of 50 to over 100 m, figure 9. This retained length includes an area in the north-eastern corner that surrounds a deeply incised gully to a width of 150 m. Cave MAI06-SH17 was assessed in September 2016 as a nocturnal roost and a single scat was found by an internal Rio Tinto ecologist (Emma Carroll pers. comm.). Cave A5 was assessed in April 2017 to be a nocturnal roost candidate with no current evidence of Ghost bat presence. No other current evidence indicating Ghost bat presence has been recorded on the mesa in recent years however minimal surveying has been completed in this period.

Figure 9. View of the top of Mesa A showing the extent of the mining operations and the retained perimeter. Caves MA-05 and MA-06 are shown in the retained north-eastern gully.

Mining at Mesa J began in 1994 and the operations also cover the majority of the original mesa. The majority, 88%, of the original perimeter that was an escarpment, i.e. the northern half of the mesa, (see attachment B) has been retained to a width of 50 to over 100 m, figure 10. Similar to Mesa A, minimal surveying has been completed in recent years at this mesa, the only current Ghost bat record at Mesa J is a single site with scats on the north-western bluff opposite the Robe River. This site is behind a retained facade of over 500 m width locally.

Figure 10. View of the top of Mesa J showing the mining operations and the retained perimeter (red line). Ghost bat scats have been recorded at the bluff on the retained north-western corner (circled).

While limited, the available evidence suggests that while there are caves and shelters available on the retained perimeter of a mesa with active mining, Ghost bats are generally not roosting in numbers where blasting, crushing and hauling operations are underway behind a facade of 20 to 50 m. This is likely to be the result of disturbance by sound, vibration and/or airborne dust. The evidence also suggests that with perimeters of such width, Ghost bats are foraging occasionally on the facades.

3.5 Mesas with historical mining operations.

There are thirteen mesas with historical mining operations. These are Mesas K, L, M, N, 2400E, 2400F, 2400G, 2401A, 2402A, 2402C, 2402E, 2403ABC and 2403D, attachment B, all of which were mined in the early decades of the Robe valley operations. The extent of the retained perimeters is 0% on N, 2402A and 2402C and is generally less than 50% on the others. Only Mesa 2403D has retained the majority of its original facade at 93%. Examples of the extent of perimeter removal are given in figures 3 and 11. Figure 3 shows Mesa 2400E that has 50% of its perimeter retained. The disturbance to the other 50% where overburden has been dumped is evident. Figure 11 shows Mesa 2402C which has no original perimeter retained. A side view of a mesa with its perimeter destroyed by dumped overburden is given in plate 8. There is no retention of any of the original cliff line or its cave/shelter features. On mesas where parts of the original perimeter have been retained, the original caves and shelters are in general in good

condition, plate 9. The available evidence detailed in attachment A, and summarised below, shows that Ghost bats have recolonised these undamaged perimeters following the completion of mining and are roosting in appropriate caves.

Figure 11. Aerial view of Mesa 2402C that was mined in the early decades and has had all of its original facade removed. The extent of dumping overburden over the side and covering the talus is clearly visible as darker brown scree flowing over the lighter original material.

Plate 8. Image of the side of a mesa that has had overburden dumped on the original façade. This is typical of the condition of the current state of the majority of the perimeters of the mesas mined in the 1970s.

Plate 9. Image of the side of a mesa that has had a portion of its original façade retained. This indicates that caves and shelters on those portions of facade remain as viable Ghost bat habitat.

3.6 Summary of Ghost bat records on the Robe River mesas.

There are twenty mesas of the thirty four, including Pannawonica Hill, on the Robe River system that have recent Ghost bat records. In addition there are five other sites within 10 km of the river where Ghost bat activity has been recently recorded. These are detailed in attachments B and C.

There are eighteen mesas that have not been mined. Of these, three have had skeletal drilling on their caps (Mesas F, L1 and 2405A) and four (Mesas B, C, G and H) have had extensive resource evaluation drilling programs, all of which have a retained facade of 50 m. Of the unmined eighteen, twelve mesas that have been surveyed for Ghost bat activity in recent years have evidence of activity. Of these, there are maternity roosts identified on Mesas B and F plus diurnal roosts, some of which may be utilised as maternity sites, on Mesas C, G, H and 2402B, plus three of the supplementary sites, attachments B and C. Of the supplementary sites, three have current evidence in the form of sites with scats or with recorded calls. Of the six unmined mesas without current evidence (Mesas E, L1, 2400B, 2400C, 2403E and 2405A) insufficient survey activity has been carried out and evidence of Ghost bat usage may be present.

This result shows unequivocally that the escarpments of the mesas that have not been mined including those that have had intense drilling programs on their caps remain as confirmed Ghost

bat habitat and the caves and deep shelters continue to offer diurnal and maternity roost opportunities for the species.

There are two mesas where current large scale open cut resource extraction activities are underway, A and J. Neither of these currently has a known diurnal presence of Ghost bats although this is speculative due to a lack of survey data on the mesas from recent years. The available data suggests that it is possible that the species does use the perimeters for foraging on an occasional basis as a single scat has been identified on Mesa A (cave MA06) and scats have been recorded on the facade of Mesa J (cave Opp02). Based on data from other Pilbara iron ore mine sites (e.g. West Angelas and others; author's unpublished data), the lack of diurnal presence is thought to be due to the disturbance from the sound, vibration and airborne dust generated by the blasting, crushing and hauling operations nearby.

There are thirteen mesas where mining has been completed. Of these, three have had their caps completely removed and none of their perimeters retained. There is no current evidence of Ghost bat usage on these three although it is possible that occasional foraging visits are made. Of the remaining ten, the percentage of retained perimeter varies from 16% on Mesa 2402E to 93% on 2403D. The six that have been recently surveyed all have current evidence of Ghost bat usage, one of which, Mesa 2400E, has a site that has been identified as a possible diurnal roost, attachment A. This result shows unequivocally that the perimeters that have been retained on the mesas that have been mined remain as Ghost bat habitat and the protected caves and deep shelters continue to offer nocturnal and diurnal roost opportunities for the species. It is also possible that the retained deepest caves and shelters are used as maternity sites although no evidence of this is available at this time.

An assessment of impact of iron ore mining on the Ghost bat species in the Robe valley mesas therefore was made by reviewing the lengths of the perimeters that are retained to a width that protects the deepest caves and shelters that are available for nocturnal and diurnal roosting. The total original escarpment length of the mesas between Mesa A and Mesa 2405A is approximately 275 km. Of this, approximately 227 km, or 83% has been retained or is in place on mesas not yet mined. Virtually all is in good condition although there have been some localised collapses such as one noted at Mesa A adjacent to cave MAI06-SH17 (note that this collapse occurred prior to 2001 before mining began nearby). By applying the 2 caves/km ratio from above to the undisturbed perimeter it is possible that there are up to 400 deep shelters and caves suitable for Ghost bat usage remaining on the mesas.

For the 48 km of perimeter that have been removed or destroyed, potentially up to 100 caves and shelters may have been removed. This quantity may have had an impact on the total number of Ghost bats present although this is speculative as the numbers may be limited by availability of prey, see section 1.3 above. Based on the observations since 2014 of Ghost bats and/or their scats and middens at the supplementary sites that are in the upland areas nearby the Robe River and its mesas stretching from Sugarloaf Hill in the west to the bluff opposite Mesa 2403D in the east, Attachment C, it is also apparent that the areas surrounding the mesas have retained all of their Ghost bat population. With a current estimate of 150 Ghost bats in the Robe valley, from above, and recognising that the number will vary with the quality of the seasons, the loss of bats due to the loss of roosting habitat that has already occurred is estimated to be less than 20 individuals. For current and future mining operations, retaining a facade of greater than 20 m around the mesa perimeters and providing particular protection to significant diurnal/maternal roost caves will result in no further loss of Ghost bats in the valley due to roost destruction.

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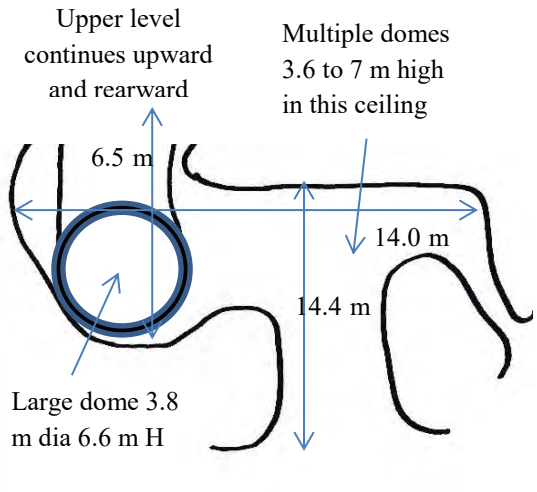
Attachment A: Characteristics of caves examined during this study.

Unboxed dimensions indicate cave/shelter width and depth and boxed or "dome height" (solid circles) dimensions indicate ceiling heights.

Mesa F Cave MF01:

Assessed Ghost bat usage: Permanent maternity roost. 70 present.	**Coordinates:** 50K 398218 7591036
Entrance safe or unsafe to approach: Assessed safe	**Basic Geology: Land system at site** Robe Pisolite mesa: Robe
Entrance type and dims – WxH (m): Cave has two entrances opening into a mid-size chamber. Left 6 x 7 m. Right 0.8 x 0.5 m.	**Entrance Orientation:** East
Cave Grouping: Other overhangs along gully sides outside entrance.	**Insulation from surface above:** Middle of local landscape
Cave Type: First chamber 15 m deep with four high domes. Second chamber is 5.0 x 6.5 m with a 6.6 m high dome and a higher level.	**Internal domed chamber:** Yes. Multiple between 2.5 and 7.0 m high.
Rear passages that may have roosts: Second chamber has an upper level going back an unknown distance.	**Internal temp. and relative humidity:** Ambient to second chamber then hot and humid behind.
Local foraging opportunities: Excellent, Mesa F is adjacent to Robe River riparian zone.	**Current distance to disturbance:** Mesa A mine is >17 km distant. Resource evaluation drilling nearby on mesa top.



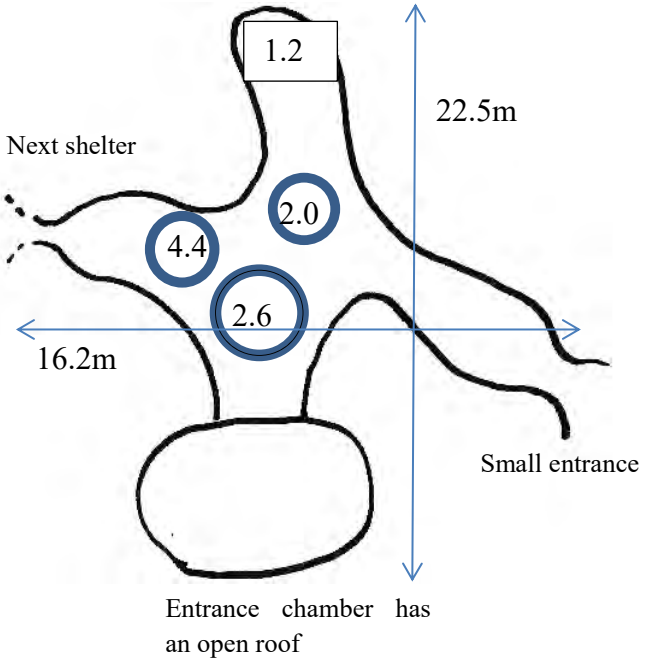
Mesa G Site G01:

Assessed Ghost bat usage: Shallow overhangs and semipermanent pool nearby coordinates. Ghost bats trapped in 2009. No deep cave found in April 2017. Probable foraging site.	**Coordinates:** 50K 410531 7595661
Entrance safe or unsafe to approach: Assessed safe	**Basic Geology: Land system at site** Robe Pisolite mesa: Robe
Entrance type and dims – WxH (m): N/A	**Entrance Orientation:** N/A
Cave Grouping: Group of overhangs and shallow shelters along a gully.	**Insulation from surface above:** Middle to Top of local landscape
Cave Type: N/A.	**Internal domed chamber:** N/A
Rear passages that may have roosts: N/A.	**Internal temp. and relative humidity:** Ambient
Local foraging opportunities: Excellent, Mesa G is adjacent to Robe River riparian zone.	**Current distance to disturbance:** Mesa J mine is >10 km distant. Resource evaluation drilling nearby on mesa top.
Cave floorplan and entrance photo:	

Mesa G Cave G02:

Assessed Ghost bat usage: Diurnal Roost although no Ghost bats present in April 2017	**Coordinates:** 50K 411740 7595774
Entrance safe or unsafe to approach: Assessed safe	**Basic Geology: Land system at site** Robe Pisolite mesa: Robe
Entrance type and dims – WxH (m): Entrance chamber has a large open roof.	**Entrance Orientation:** South
Cave Grouping: Cave is a part of a complex of shelters and overhangs with some internal connection.	**Insulation from surface above:** Middle of local landscape
Cave Type: Cave 22.5 m deep with low roof and three domes.	**Internal domed chamber:** Yes. 2.0 m to 4.4 m high
Rear passages that may have roosts: Side chambers interconnect to other shelters along the gully.	**Internal temp. and relative humidity:** Ambient
Local foraging opportunities: Excellent, Mesa G is adjacent to Robe River riparian zone.	**Current distance to disturbance:** Mesa J mine is >10 km distant. Resource evaluation drilling nearby on mesa top.

Cave floorplan and entrance photo:

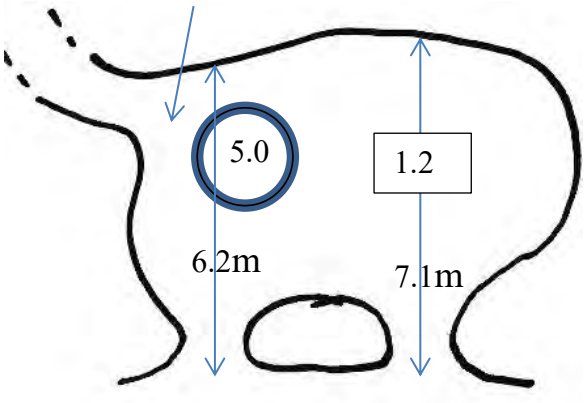


Mesa G Shelter G03:

Assessed Ghost bat usage: Nocturnal shelter with a Ghost bat midden.	**Coordinates:** 50K 411727 7595625
Entrance safe or unsafe to approach: Assessed safe	**Basic Geology: Land system at site** Robe Pisolite mesa: Robe
Entrance type and dims – WxH (m): Cave has two entrances opening into a mid-size shelter. Left 1.2 x 2.5m. Right 2.8 x 2.6m.	**Entrance Orientation:** West
Cave Grouping: Other overhangs along gully side to the north.	**Insulation from surface above:** Middle of local landscape
Cave Type: Cave 7.0 m deep with low roof, a dome and a tight rear tunnel.	**Internal domed chamber:** Yes. 5.0 m high
Rear passages that may have roosts: One rear sinuous tunnel continues on the left side. It has as small Ghost bat midden under its entrance.	**Internal temp. and relative humidity:** Ambient
Local foraging opportunities: Excellent, Mesa G is adjacent to Robe River riparian zone.	**Current distance to disturbance:** Mesa J mine is >10 km distant. Resource evaluation drilling nearby on mesa top.

Cave floorplan and entrance photo:

Small PGb midden with *Taphozous* sp. wing bones



Attachment B. Data on Robe River mesas including records of recent Ghost bat presence.

Note 1: Perimeter lengths of Mesas A and J indicate the original escarpment lengths that only partially encircled the mesas.

Mesa	Approx. Area km^2	Perimeter length km	Land System	Drilled for resource evaluation?	Mining status	Retained perimeter length km	Retained perimeter %	Recent survey including Ghost bats?	Ghost bat usage - Summary of current evidence	Reference
A	8.6	10.1 Note 1	Robe	N/A	Underway	10.0	99%	Yes - Incomplete	Yes Minimal current activity, one scat found (MAI06-SH17) 200 m from pit.	Bat Call 2017c
B	1.9	9.6	Robe	Yes	Not begun	9.6	100%	Yes	Yes Maternity roost (MBC-03 with 16 PGb present) plus >10 nocturnal "caves" with scats and middens	Bat Call 2016a
C	2.3	11	Robe	Yes	Not begun	11	100%	Yes	Yes Potential diurnal roost (MCC-02) plus 8 “caves” with scats and middens	Bat Call 2016a
D	1.3	9.7	Robe	No	Not begun	9.7	100%	Yes - Incomplete	Yes One site (cave Opp) with calls on southern facade	Biota 2010 Bat Call 2010
E	1.1	11	Robe	No	Not begun	11	100%	No		

Mesa	Approx. Area km^2	Perimeter length km	Land System	Drilled for resource evaluation?	Mining status	Retained perimeter length km	Retained perimeter %	Recent survey including Ghost bats?	Ghost bat usage - Summary of current evidence	Reference
F	17.2	39	Robe	Initial assessment only	Not begun	39	100%	Yes - Incomplete	Yes Maternity roost (MF01 with over 70 PGb present) plus multi shelters and overhangs present nearby.	This study
G	11.6	32	Robe	Yes	Not begun	32	100%	Yes	Yes Diurnal roost (Cave G02) plus >10 nocturnal "caves" with scats and middens	Biota 2009, Astron 2017, This study
H	10.3	35	Robe	Yes	Not begun	35	100%	Yes	Yes Two diurnal roosts (Caves MH16-34, AC-04) plus >9 nocturnal "caves" with scats and middens	Bat Call 2017d
I	1.4	8.7	Robe	No	No	8.7	100%	Yes	Yes One breakaway site with echolocation calls recorded	Astron 2016
J	15.3	14.0 Note 1	Robe	N/A	Underway	12.3	88%	Yes - Incomplete	Yes One breakaway site with scats on retained facade, 500 m from pit	Astron 2016
K	3.3	9.5	Robe	N/A	Finished	4.3	45%	Yes	Yes One site (SM12) with calls on retained facade	Astron2015, Bat Call 2015

Mesa	Approx. Area km^2	Perimeter length km	Land System	Drilled for resource evaluation?	Mining status	Retained perimeter length km	Retained perimeter %	Recent survey including Ghost bats?	Ghost bat usage - Summary of current evidence	Reference
L	2.1	11.4	Robe	N/A	Finished	2.5	22%	Yes	Yes One site (Opp-01) with scats on retained facade	Astron 2015
L1	0.3	4.3	Robe	Initial assessment only	No	4.3	100%	No		
L2	0.1	2.6	Robe	No	No	2.6	100%	Yes	Yes One site (Opp-07) with scats on retained facade	Astron 2015
M	0.7	3.9	Robe	N/A	Finished	1.8	46%	No		
N	0.1	0.1	Robe	N/A	Finished	0	0%	Yes - Incomplete		
2400A	0.04	1	Robe	No	No	1	100%	Yes	Yes One site (HA06) with scats on retained facade	Astron 2015
2400B	0.1	1.2	Robe	No	No	1.2	100%	Yes - Incomplete		
2400C	0.02	0.8	Robe	No	No	0.8	100%	Yes - Incomplete		

Mesa	Approx. Area km^2	Perimeter length km	Land System	Drilled for resource evaluation?	Mining status	Retained perimeter length km	Retained perimeter %	Recent survey including Ghost bats?	Ghost bat usage - Summary of current evidence	Reference
2400D	0.02	0.8	Robe	No	No	0.8	100%	Yes	Yes One site (HA07) with scats on retained facade	Astron 2015
2400E	0.3	2.4	Robe	N/A	Finished	1.0	42%	Yes	Yes One site (SM10) with calls on retained facade, assessed by Astron as possible diurnal roost	Astron2015 Bat Call 2015
2400F	0.2	2.3	Robe	N/A	Finished	0.65	28%	Yes	Yes One site (Opp06) with scats on retained facade	Astron 2015
2400G	0.2	2.2	Robe	N/A	Finished	0.65	30%	Yes - Incomplete		
2401A	2	13	Robe	N/A	Finished	5.7	44%	Yes	Yes One site (SM14) with calls and four with scats on retained facade	Astron2015 Bat Call 2015
2402A	0.3	2.5	Robe	N/A	Finished	0	0%	No		
2402B	0.05	1	Robe	No	No	1	100%	Yes	Yes One possible diurnal roost (Opp04 - PGb present) plus two sites (HA12, Opp05) with scats on retained facade	Astron 2015

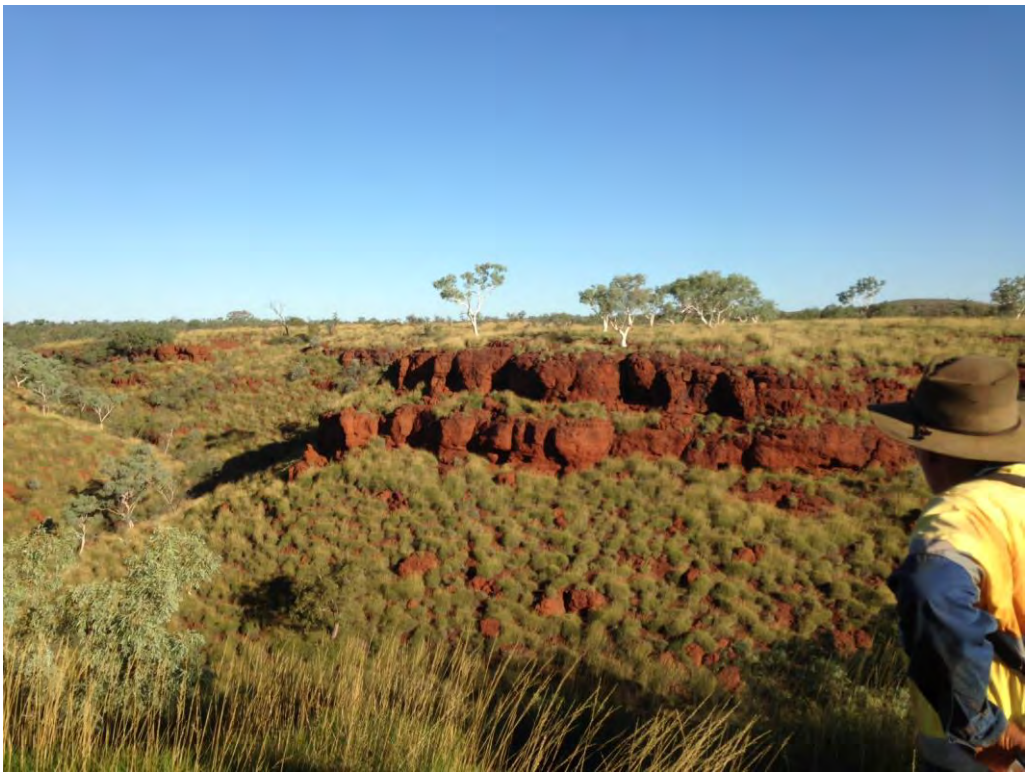
Mesa	Approx. Area km^2	Perimeter length km	Land System	Drilled for resource evaluation?	Mining status	Retained perimeter length km	Retained perimeter %	Recent survey including Ghost bats?	Ghost bat usage - Summary of current evidence	Reference
2402C	0.3	2.8	Robe	N/A	Finished	0	0%	No		
2402D	0.3	2.7	Robe	No	No	2.7	100%	Yes	Yes One site (Opp03) with scats on retained facade	Astron 2015
2402E	0.8	6.8	Robe	N/A	Finished	1.1	16%	Yes - Incomplete		
2403ABC	1.3	9.3	Robe	N/A	Finished	2	22%	Yes - Incomplete		
2403D	1.2	6.9	Robe	N/A	Finished	6.4	93%	Yes	Yes One site (HA13) with scats on retained facade	Astron 2015
2403E	0.7	4.1	Robe	Yes but old	No	4.1	100%	No		
2405A	0.3	3.4	Robe	Initial assessment only	No	3.4	100%	No		

Attachment C. Data on Supplementary sites within 10 km of Robe River including records of recent Ghost bat presence.

Mesa	Approx. Area km^2	Perimeter length km	Land System	Drilled for resource evaluation?	Mining status	Retained perimeter length km	Retained perimeter %	Recent survey including Ghost bats?	Ghost bat usage - Summary of current evidence	Reference
Pannawonica Hill	0.001	0.1	Robe	No	No	0.1	100%	No		
Unnamed Bluff facing Robe River near Mesa 2403E	N/A	N/A	McKay	No	No	N/A	100%	Yes	Yes One site with two nearby caves. Multi PGb seen (SF13, SF14) and calls recorded, assessed as diurnal/maternal roost due to high number of calls detected	Astron 2015 Bat Call 2015
Unnamed bluff near Jimmawurrada Creek (1.25 km from Ck, 9 km from Robe)	N/A	N/A	Newman	No	No	N/A	100%	Yes	Yes One diurnal roost (MJmar17-09 >20 PGb present 2017). Maternity roost candidate	RTIO internal survey March 2017
Major unnamed gorge system SW of Mesa J (6km from Robe)	N/A	N/A	Newman	No	No	N/A	100%	Yes	Yes One probable maternity roost (Bat04) plus two diurnal roosts (DRML01/02 - both with PGb present 2016). Additional sites with scats and calls nearby	Astron 2016 Bat Call 2016c

Mesa	Approx. Area km^2	Perimeter length km	Land System	Drilled for resource evaluation?	Mining status	Retained perimeter length km	Retained perimeter %	Recent survey including Ghost bats?	Ghost bat usage - Summary of current evidence	Reference
Cave system in gully on unnamed mesa on west side of Buckland Hills (7 km from Robe)	0.7	4.9	Robe	Initial assessment only	No	4.9	100%	Yes	Yes One possible diurnal roost (PGb present 2014)	Biologic 2014
Cave system on Sugarloaf Hill on North side of Robe River, north of Mesa B (1.5 km from Robe)	0.15	1.9	Robe	No	No	1.9	100%	Yes	Yes One site (Bat07) with calls detected on facade and scats present.	Astron 2016 Bat Call 2016c

Robe Valley Mesa H,
Ghost bat roost cave assessment,
April 2017



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Peer review: Mr Norman L McKenzie, Senior Principal Research Scientist (ret)

Document Revision History

Issue	Date	Revision History
A	21 April 2017	Initial draft prepared for Rio Tinto review
B	29 April 2017	Second draft incorporating initial review comments.
C	22 May 2017	Third draft incorporating client's comments
1	20 June 2017	First formal issue
Final	7 July 2017	Final issue

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Executive Summary

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2.0 Survey and Assessment Methods

3.0 Results

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Attachment A. Characteristics of caves examined during this survey

Executive Summary

Rio Tinto commissioned Bat Call WA (Bat Call) to undertake a targeted assessment of bat conservation values of caves at Mesa H. This resource is located in the Robe River valley 17 km south west of Pannawonica, in the Pilbara region of Western Australia. This assessment was completed in parallel with a broader assessment of bat conservation values across the entire Robe River that is the subject of a separate report.

Level one and two fauna surveys have been conducted in the area previously, most recently by Astron Environmental Services in 2015/16. Two bat species of conservation significance have been recorded within the area, namely Pilbara leaf-nosed bat (*Rhinonicteris aurantia*) (Pilbara form of the Orange leaf-nosed bat) (PLNb) and Ghost bat (*Macroderma gigas*), both listed as Vulnerable under Federal and State legislation. PLNb have been assessed as using Mesa H for foraging while originating from a yet to be discovered roost further to the south or east (e.g. Bat Call 2016, 2017). Multiple Ghost bat records including echolocation recordings, visual observations and cave middens have been detected within and adjacent to the study area (e.g. Biota 2009; Astron 2016; Astron 2017).

This survey was designed to provide an assessment of the conservation value of caves associated with the presence of Ghost bats at Mesa H. A visual assessment of cave environments and an extensive search for Ghost bat presence, including roosting bats, was carried out. Ghost bat presence on Mesa H was determined to be irregular with the mesa being used for nocturnal foraging and occasional diurnal roosting. Ghost bat presence, in the form of guano and middens, was recorded across all of the different areas inspected. Eleven of twenty four sites were found to be used or suitable for use by the species. No colonies of diurnally roosting Ghost bats were found. Two caves on Mesa H (MH16-34 and AC04) were found to have the characteristics of diurnal roosts for the species with the possibility of occasional use as maternity roosts. Eight sites on Mesa H were assessed to be nocturnal feeding sites. One site south of Mesa H in the nearby Buckland Hills was also assessed to be a nocturnal feeding site. Thirteen sites on Mesa H were determined to be not currently used by Ghost bats and not suitable for regular occupancy. A number of additional overhangs nearby the caves and shelters were also assessed for signs of Ghost bat use but none were found.

The caves and surrounding environments at Mesa H were found to be supporting foraging Ghost bats originating from either the Buckland Hills to the south, Yeera Bluff between mesas G and H or the Three Peak Hills to the north-west. Two diurnal roost caves with maternity cave potential

have been confirmed. These are located in productive gullies and are associated with a number of near-by caves and shelters providing a series of escape and nocturnal foraging opportunities, including the presence of the Robe River riparian zone, required by the species for successful reproduction.

1.0 Introduction.

1.1 Project Background

Rio Tinto commissioned Bat Call to undertake a targeted assessment of bat conservation values at the Mesa H deposit located approximately 17 kilometres (km) south-west of Pannawonica in the Robe River valley, in the Pilbara region of Western Australia (WA), figure 1. Rio Tinto is considering sustaining its Robe Valley operations by including additional deposits to replace ore supply from the Mesa J operations as it nears the end of its mine life. In summary, the planned mining operation would involve the following main components and activities in addition to the existing approved operations:

- progressive open pit mining of ore and overburden from Mesa H using similar open pit mining techniques to those currently used at Mesa J. These operations are planned to remove the inner core of the mesa while leaving the rocky face of the perimeter intact to a width of at least 20m at the mesa surface,
- placement of overburden in out-of-pit waste dumps adjacent to the mesa, and
- construction and use of haul and access roads to the mine areas within the mesa.

Recent surveys have identified that two species of cave roosting bat of conservation significance are present in the area, the Ghost bat (*Macroderma gigas*) and the Pilbara leaf-nosed bat (*Rhinonicteris aurantia*) (PLNb). PLNb have been assessed as using the Mesas for foraging while originating from a yet to be discovered roost further to the south or east (Bat Call 2016, 2017). Multiple Ghost bat records including echolocation recordings, visual observations and cave middens have been detected within and adjacent to the study area (Biota 2009; Astron 2016; Astron 2017).

The purpose of this survey was to assess the conservation values of caves potentially associated with Ghost bats at Mesa H that had been previously identified by both external and internal resources. This involved a visual assessment of cave geometry and environments and an extensive search for Ghost bat presence, including bat colonies and/or middens. The study area is shown in figure 1. It includes the perimeter of Mesa H including its major central gully.

1.2 Existing Environment at Robe Valley Mesas and Surrounds

Topography

The Robe River Valley mesas cover an extensive area beginning at Mesa A and running approximately 100 km upstream. Mesa H lies immediately adjacent to that river riparian zone. It is roughly circular and is 3.5 km in diameter and stands approximately 50 m higher than a flat plain that is crossed by the river. It is bisected by a major gully running south to north toward the Robe River riparian zone.

Geology

Mesa H is a tertiary Robe Pisolite iron ore deposit, also known as a Channel Iron Deposit (CID), incised with deep gullies around the perimeter. It has overhangs, shelters and caves along extensive lengths of the perimeter and the central gully, e.g. plate 1.

Overhangs, shelters and caves are defined herein as:

- Overhangs are shallow hollows in a rock wall with a distinct roof structure. Their shape is such that they are fully lit by sunlight to their back wall. Their depth is typically 2 to 5 m.
- Shelters are deeper hollows or shallow caves in the rock wall that have ceiling structures from 1.0 to >5 m. They offer significant protection from predators and the weather, are typically 5 to 15 m deep and have dark twilight conditions at their rear extremities. Some have domed areas in their ceilings offering nocturnal roosting and feeding opportunities to Ghost bats. Some are occasionally used diurnally.
- Caves are defined as deep structures of various heights, widths and depths that are very dark in their deeper recesses. They often have additional rear chamber(s) separated from the entrance by a constriction point(s). Those chambers that have ceiling heights of over 2.5m offer excellent roosting opportunities for Ghost bats.
- All three can have cracks or voids that continue back from their rear walls that may lead to additional internal cavities within the rock strata behind or above. If these cavities are almost fully enclosed, have entrance cracks large enough, and can retain high levels of humidity, they provide roosting opportunities for PLNb and Ghost bats.

Overhang and shelter density is high along the majority of the mesa perimeters with the rock strata forming numerous shallow shelters in mid and higher levels of the walls. There are a

number of deeper caves formed in the Pisolite at mid and higher levels of the mesa walls but these rarely extend beyond 15 m in depth. Most shelters and caves were found on the mesa's cliff walls at or just above the top of the talus slope.

Land Systems (after Van Vreeswyk *et al.* 2004)

Mesas H including the gullies and the surrounding gravelly plains are elements of the Robe Land System. It is a low limonite mesa that support spinifex grasslands and scattered Snappy Gums. The lower slopes and adjacent gravelly plains support spinifex grasslands with sparse Acacia and Eucalypt shrubs with low trees that sometimes form thickets.

The adjacent Robe River is a very complex and productive linear river channel and flood plain with a Eucalyptus and Melaleuca woodland over tall Acacia and Petalostylis shrubland. It is an element of the Pilbara's River Land System

The Buckland Hills to the south of Mesa H and Yeera Bluff to the west are rugged jaspilite ridges and mountains of the Newman Land System supporting open shrublands and open low woodlands of Grevillia and Eucalypt over hummock grasses.

Climate

The climate in the district is semi-desert tropical. Mean monthly minimum and maximum temperatures in the lower Robe Valley range from 12 to 41 degrees Celsius (^{o}C). Annual rainfall is extremely variable and averages 400 mm, usually in cyclonic or thunderstorm events during the northern wet season. The northern dry season lasts from May to November and winter rainfall is uncommon.

Water Sources

Drainage systems in the immediate area are associated with ephemeral gullies on the perimeters of the mesas that run into the Robe River drainage system. That riparian zone has a number of permanent and ephemeral pools along its length such as Gnieraoora Pool at the base of Yeera Bluff.

Plate 1. Example of the presence of overhangs and shelters along the perimeters and within the incised gullies on Mesa H. This view is of the Cave H18, H19 complex.

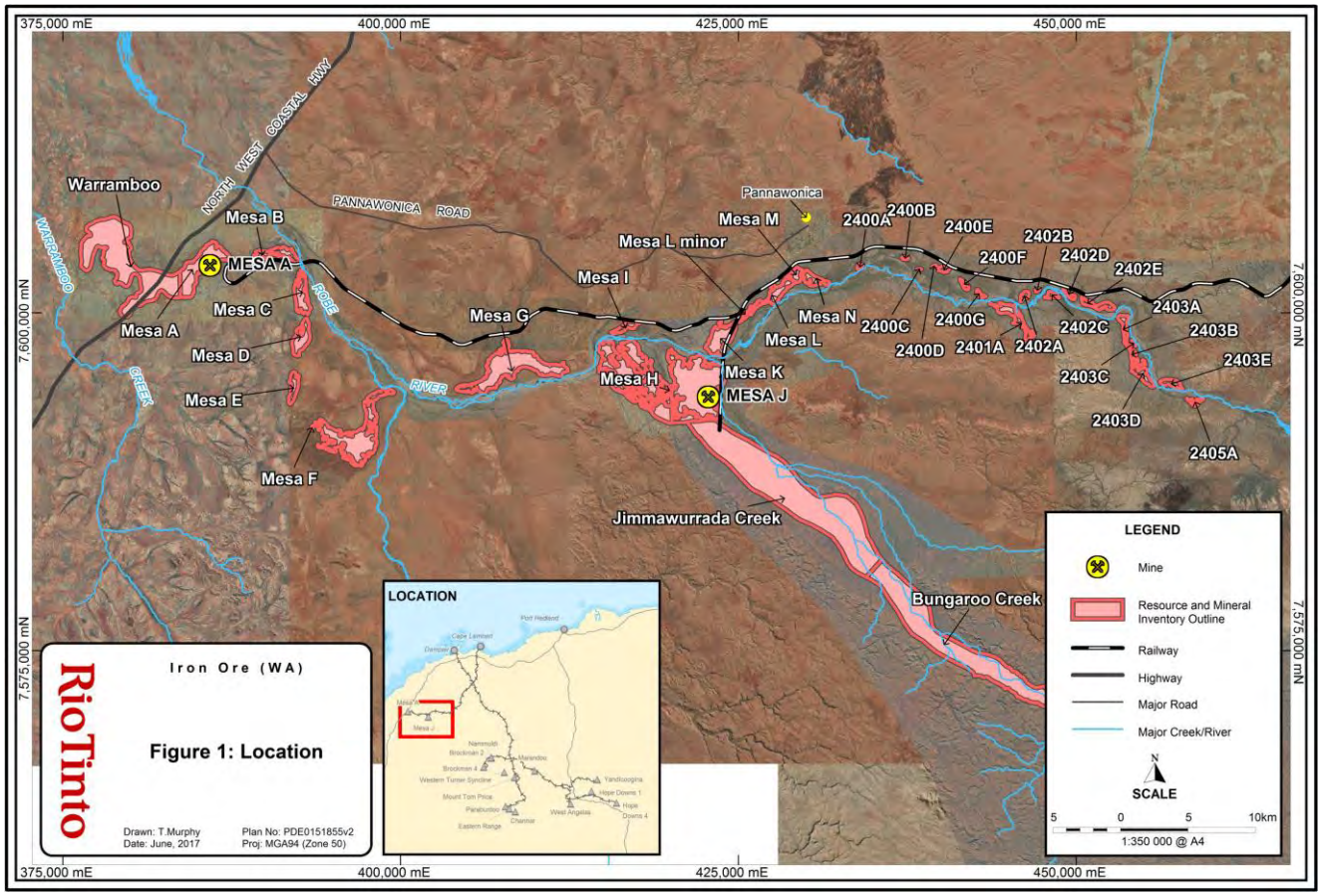

Figure 1. General Arrangement of Robe River valley mining area.

1.3 Bats of Conservation Significance

The Pilbara region contains 17 species of microbat, and of these, 13 have the potential to be found in the Mesa G-H vicinity (Van Dyke and Strahan 2008, McKenzie and Bullen 2009). A number of fauna surveys including targeted bat surveys have been previously conducted in the area, most recently by Astron in 2015 and 2016 and internal Rio Tinto ecologists in 2016-17, see table 1. Two Pilbara bat species of conservation significance have been recorded in the area, the Ghost bat (*Macroderma gigas*) and the PLNb (*Rhinonicteris aurantia*).

The Ghost bat is a large (130 g) carnivorous predator and the PLNb is a small (10 g) insectivore. Both are endemic to northern Australia and are obligate cave roosting species requiring specific cave environments for permanent roosting especially for their maternity colonies. The Ghost bat's foraging strategy and high trophic niche, as a top night-time carnivorous predator, is unique in Australian microbats. The Pilbara's Ghost bat and PLNb populations are isolated from Australia's other populations that are extant across the mesic tropics by the uninhabitable arid zone of the Great Sandy Desert to the north and east. Both species are "conservation significant" as they are semi-desert adapted populations that have specific roosting requirements. The Ghost bat has suffered significant range loss in historical times. The reasons for the range contraction are open to speculation but it is known that the species is sensitive to disturbance (e.g. Richards *et al*. 2008, Woinarski *et al.* 2014)).

The PLNb has been detected foraging across the mesas in the Middle Robe valley. A roost has not been identified on Mesa H and echolocation records indicate that it lies to the south or east of Mesa H or J.

The Ghost bat has also been detected within the study area.

1.3.1 Ghost bat (*Macroderma gigas*)

The Ghost bat is listed as Vulnerable under the commonwealth *Environment Protection and Biodiversity Act 1999* (EPBC Act), Vulnerable under the Western Australian *Wildlife Conservation Act* (1950) and Vulnerable C1 (a vulnerable species numbering less than 10,000 and in decline) under the IUCN Redlist (IUCN 2017). The listing is on the basis of the impact of loss of suitable roost opportunities. The Pilbara Ghost bat population is estimated at 1500-2000 based on recently published estimates (approximately 600, N.L. McKenzie pers. comm. in IUCN 2016; approximately 1200, Armstrong and Anstee 2000; "more common than previously supposed", McKenzie and Bullen 2009) and author's unpublished database summarising data from a range of surveys carried out in recent years by Pilbara mining companies, including Rio

Tinto and other organisations, supplemented by author's own data (summarised in Threatened Species Scientific Committee (TSSC 2016). These recent data (estimates less than 15 years old) cover the entire Pilbara bioregion. Current population estimates in the Hamersley and Chichester subregions are approximately 350 and 1500 respectively (author's unpublished database summarised in TSSC (2016)).

Ghost bats hunt their prey in two primary ways. They hunt birds and bats "air-to-air" at cave entrances and elsewhere by swooping from above or from a perch. They also hunt ground level prey in their target food size range by dropping onto the prey from a perch, either tree branch or rock outcrop. Their diet includes small mammals including other bats, birds, reptiles, frogs and large insects. The proportion of food items in the diet varies with availability and reported foraging areas vary from a few to 10 km from the roost cave. One Ghost bat carcass was found recently entangled in a barbed wire fence in the Fortescue Marsh over 12 km from the nearest cave forming rocky strata suitable for roosting (Stephen Van Leeuwen pers. comm.).

Along the lower Robe River valley multiple Ghost bat records including visual observations and the presence of cave middens have been detected on the various mesas within and adjacent to the study area (table 1).

Ghost bat breeding colonies are known from a small number of maternity roosts in the Pilbara and reproduce during the northern wet season. The largest of these colonies are in abandoned mines in the Chichester subregion and number up to several hundred (Armstrong and Anstee 2000). Hamersley Range populations are typically between 5 and 25 individuals in local groups (author's unpublished database). There is one known large, permanent maternity roost (unpublished assessment by the author) numbering over 70 bats in the lower Robe River valley of the Hamersley subregion. For these groups to persist the bats need an "apartment block" of roosting opportunities, at least one deep cave with characteristics of a maternity roost, multiple caves/shelters and overhangs in close proximity offering nocturnal feeding and refuge opportunities, a productive set of gullies and gorges locally, a productive foraging area within 5 to 10 km radius, usually including a good quality riparian corridor or ephemeral fresh water lake bed and appropriate protection from human interference (author's unpublished data base). These groups are known to reproduce in good years using suitable natural roost caves. Examples are a group numbering 5 to 10 including reproducing females at West Angeles caves in 1980 (Dr Nic Dunlop pers. comm.), a small group including reproducing females at caves at Nammuldi/Silvergrass area (Hamersley Iron 1999), observation of a heavily pregnant female at a cave near Mt Robinson by the author in 2013 and a group numbering 14 including four juveniles

at another cave near Mt Robinson in 2015 (Mr. Morgan O'Connell pers. comm.). The Ghost bat is also known to spread great distances on an annual cycle from these locations depending upon seasonal weather conditions and availability of suitable day roosts. Sporadic records of Pilbara Ghost bats have been identified in the Gascoyne (author's unpublished data) and the Little Sandy Desert (sightings by W.H. Butler at Durba Spring in 1971 and others since). Genetic work by Worthington Wilmer and Armstrong (summarised in Woinarski *et al.* 2014) suggests that the females remain or return to their birthplace and that the males can move between districts.

Ghost bats use three types of roost regularly, these being nocturnal roosts or feeding sites, diurnal or day roosts that may be permanent or semi-permanent sites and maternity roosts that are diurnal roosts with the range of characteristics allowing regular or permanent occupancy.

Nocturnal roosts or feeding sites are only used at night, either habitually or for transitory visits. They are typically shallow caves and shelters that are well lit during the day. They are often high in the strata and may be well or poorly insulated from the elements. They often contain guano scatters and/or midden(s) of various sizes containing guano and food scraps but these remains are sometimes removed by rainfall and/or varieties of "dung beetle" that are known to forage on the scats (author's unpublished observations).

Diurnal roosts are caves and mine adits that are deeper and more complex. They typically have one or more large chambers at or beyond the twilight area with additional fissures or chambers at the rear in the fully dark regions. They have a minimum roof height in the chambers of 2 to 3 m providing protection from attack by terrestrial predators. They are often at mid-levels or lower in the strata and are well insulated overhead providing a stable temperature environment. They typically contain multiple scat piles and middens of guano and food remains that include feathers and skeletal material.

Maternity roosts are diurnal roosts that provide additional features to those listed above that are able to support a reproducing population. These features usually include an interior chamber that is rising toward the rear thereby trapping warmer and more humid air at the top allowing suitable conditions to form during the period when reproductive females and pups are present.

Being predators, during a night's foraging they may also hang for short periods in any deep overhang, shelter or cave with a high enough ceiling or tree branch above a cleared patch of ground for feeding or resting on an opportunistic basis. These sites are not routinely visited and usually show no evidence of Ghost bat presence.

1.3.2 Pilbara leaf-nosed bat (*Rhinonicteris aurantia*)

The PLNb is listed as 'Vulnerable' under the federal *Environment Protection and Biodiversity Act 1999* (EPBC Act) and by the Western Australian *Wildlife Conservation Act* (1950). This listing is on the basis of the impact on its population of the loss of suitable roosts with the correct microclimate.

The PLNb requires roosts with very specific requirements of high temperature and humidity for survival in the Pilbara. These are warm deep and humid caves and historical underground mines. The humidity required is higher than the Ghost bat, approaching 100%. The species is subject to rapid dehydration and death within a day if removed from its roost. It is known to have a usual foraging range up to 20 km from its primary roost caves (Bullen 2013). It also appears to spread from these roosts to satellite roosts when wet season conditions allow and to consolidate back to permanent sites during dry periods.

1.4 Summary of Previous Bat Surveys

Prior to 2017, a number of the fauna surveys commissioned by Rio Tinto in the lower Robe River valley have included microbat species listings. These indicated the presence of both significant species foraging across the area (e.g. Bat Call 2010). More recent surveys carried out since 2015, summarised in table 1 below, indicated that the Ghost bat may be roosting locally and may include a maternity colony at Mesa H and that the PLNb was foraging generally across all Robe valley mesas but not roosting on Mesa H.

Table 1. Summary of Fauna Surveys that Include Ghost Bat records in the Mesa H District

Date	Reference	Ghost bat activity detected.
2009	Biota (2009)	• Ghost bats harp trapped at Mesa G
2015	Astron (2016)	• Ghost bat echolocation calls detected at Mesa H and a number of shelters/caves with scats recorded
2016	Astron (2017)	• Ghost bat echolocation calls detected at Mesa G and a number of shelters/caves with scats recorded
2017	RTIO internal ecologists	• Ghost bat seen at cave H27on Mesa H.

2.0 Survey and Assessment Methods

A survey consisting of three days field work was completed in April 2017 (9th to 11th April) on Mesa H. Twenty four sites were assessed plus nearby overhangs and shallow shelters.

The fieldwork focussed on the assessment of potential roosting habitat of Ghost bat that previous surveys had indicated were important for this species. Eight sites listed as Ghost bat habitat were assessed. In addition, 13 caves/shelters on Mesa H that the Rio Tinto heritage surveys had recorded with depths greater than 10m were also included in the survey. Three previously unrecorded deep shelters suitable for Ghost bat use were also found and assessed.

On an opportunistic basis, a secondary set of overhangs and shelters recorded by the heritage surveys (often within 100m of the primary caves) were also searched.

2.1 Survey Team, Timing and Weather

The survey team consisted of two experienced ecologists. Ms Tenielle Brown (Rio Tinto) was team leader and Mr Robert Bullen (Bat Call) acted as principal ecologist.

The northern wet season of 2016-17 was wetter than average in the Pilbara region. Heavy rain fell in the district in the three months prior to the survey with 535 mm being recorded at the Bureau of Meteorology station at Pannawonica (Bureau of Meteorology station No 5069) between January and March. This rain continued until a week prior to the survey. The weather during the assessment was typical late wet season conditions being hot and dry with temperatures between 20 and 40^{O}C.

Sunset and sunrise were at 18:09 and 06:26 during the survey while dusk and dawn civil twilight were at 18:31 and 06:04 respectively. The moon phase was full.

2.2 Survey Techniques

The survey was designed to assess all Ghost bat (and any PLNb) roost cave candidates, to review cave morphology, geology and cave conditions, and to narrow down the list of potential Ghost bat maternity and/or PLNb roost caves. These visits were completed during daylight hours. Caves and shelters were entered after a rigorous safety inspection that assessed potential hazardous rock structures. Each was then measured for height, width and depth using a hand held laser (Bosch model PLR-50). Some caves and gorges had been surveyed earlier by Astron, for evidence of Ghost bat activity including the presence of middens and scats. Along the perimeter of Mesa H, twenty four sites were visited and were assessed by their attributes as probable night

feeding locations, seasonal day roost candidates or permanent day/maternity roost candidates. Numerous overhangs and shallow shelters identified by the Rio Tinto heritage surveyors near these sites were also assessed. These combined totals constituted all potential Ghost bat roost caves and shelters previously known or identified during the survey on the two mesas.

The presence of Ghost bat was confirmed by either of the following observations:

- Visual observation of a large pale bat entering or departing the cave. Note that the Ghost bat is distinctive in being much larger than any other cave dwelling bat in the region; or
- Detection of Ghost bat scats or middens on the floor of the caves or shelters entered, plate 2.

Plate 2. Typical Ghost bat midden containing scats and feathers on the floor of a cave

Caves and Shelters were then classified as maternal, diurnal, nocturnal or "not used" based on the cave characteristics and evidence found. The "not used" classification was applied when there is unsuitable characteristics such as low ceilings (typically <1.5m) and/or shallow depth (typically < 5m) with no physical evidence or other record such as a sighting or echolocation recording.

Observations of bat species other than the two conservation significant species were not recorded during this assessment.

2.3 Survey Effort

Sites previously identified were approached from either the top rim or from the plain below and scanned visually for the presence of caves. Caves were assessed for safe entry and sections of the perimeter that showed cave forming strata were then walked at the height of the top of the talus slope where the caves were most common. Twenty four caves and shelters were visited, see figure 2, and assessed for Ghost bat presence. One ecologist entered each cave following agreed Rio Tinto health and safety guidelines covering personal protective equipment (PPE), access limitations and communication strategies. The cave interior was searched for evidence of Ghost bat roosting including the presence of middens and adult Ghost bats. The team's second member remained at the entrance to observe any Ghost bat that might depart the cave behind the observer inside, a common behaviour of this species. Any Ghost bats that departed and/or entered the caves or were seen flying close to the entrance were thereby recorded visually. Any that departed could be tracked visually to record the alternative cave or shelter that they re-entered.

Figure 2 Mesa H with locations of caves and shelters assessed during the survey.

2.4 Survey Limitations

The primary objective of the survey was the characterisation of Ghost bat activity on Mesa H. All aspects of the survey including site access using 4WD, team make-up and experience levels, equipment used, logistics and safety support provided by Rio Tinto were suitable for the task.

No activities were undertaken that could cause harm to the bats present.

Detailed internal dimensions of a cave and its daytime use by bats cannot be reliably determined from the entrance or by the size of the entrance. Entry of candidate caves was therefore necessary to confirm internal characteristics including the bat species present. (Note that distinctive Ghost bat social calls heard from the entrance, or Ghost bats seen departing caves in daylight following the approach of survey parties, serve to confirm the presence of Ghost bats but do not provide information on their numbers or maternity status).

Detailed interior searches of caves were carried out under the guidelines of the Rio Tinto safety procedures. These prohibited entry into any cave that was deemed to have an unstable ceiling as characterised by loose rocks overhead or around the entrance, heavy cracking or the presence of fresh slab like roof material fallen to the floor. These procedures also prohibited entry into any chamber that required sliding on stomach or back or that required climbing or descending 2 m using rock-climbing techniques. The rear areas of some caves could therefore not be searched completely and the possible presence and number of Ghost bats in such caves was therefore not confirmed absolutely.

Due to the porous nature of the Robe Pisolite and the very high number of cracks and sinuous tubes and pipes throughout the strata, the floors of a number of caves had been washed clean of any evidence of Ghost bat occupation by the preceding heavy rain. In addition most caves were inhabited by a species of beetle that is known to act as a scat cleaner thereby removing Ghost bat scats. This combination resulted in fewer caves being identified with scats than expected from the previous surveys.

3.0 Results

A number of observations of Ghost bats middens and scat piles were made during this assessment with Ghost bat presence and foraging activity confirmed generally around the perimeter. In addition two diurnal roost caves with the characteristics of occasional maternity roosts have been located on Mesa H, figure 3.

Assessments of each cave and observations of Ghost bat activity are provided below, table 2, with detailed characteristics of the caves examined including floorplans and dimensions in Attachment A. Most caves were found to be less than 20 m deep and therefore not expected to be impacted by the mining behind the facade. Caves MH16-34 and AC4 were found to be over 30 m deep, depths that are significant when planning the facade to be retained.

Eleven sites were assessed as being suitable for roosting by Ghost bats including two diurnal roost caves and nine nocturnal roost shelters. Note that this total includes shelter AC05 that is in the Buckland Hills BIF strata (Newman land system) adjacent to Mesa H. The two assessed as diurnal roost caves are MH16-34 (50K 415815 7595655), a simple linear chamber 30 m deep with a single high dome at the distal end, and cave AC04 (50K 417586 7594895), a more complex cave with six ceiling domes between 2.5 and 3.9 m high along its length. Both were assessed as being maternity cave candidates although no evidence of significant Ghost bat use of this type was found during the survey. Cave AC04 had a number of scats present.

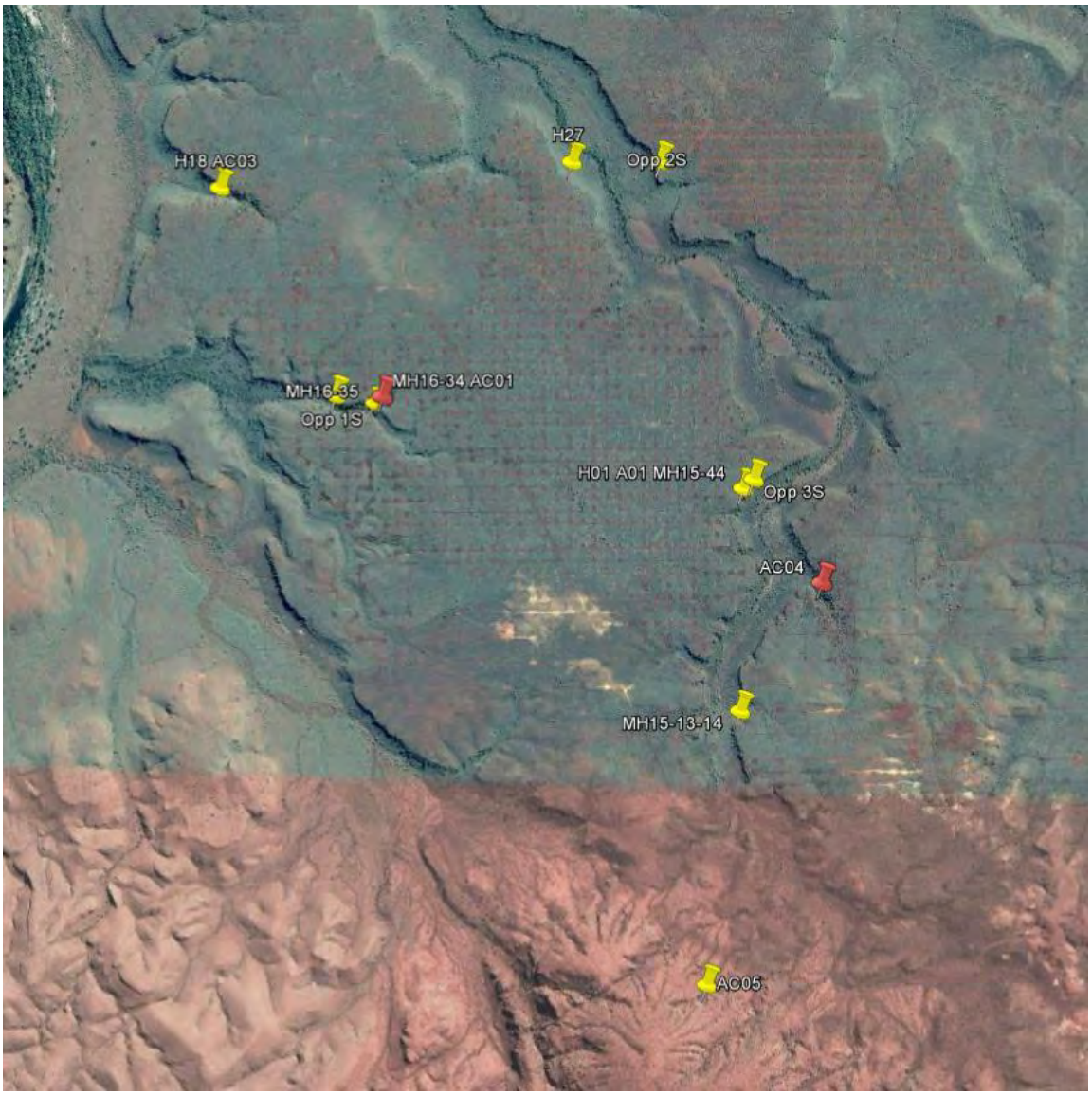

Figure 3. Mesa H caves and shelters where positive Ghost bat assessments were made. The red dots denote the diurnal caves MH16-34 and AC04. Yellow dots denote caves/shelters assessed as nocturnal feeding roosts.

Table 2. Summary of caves visited on Mesa H and assessed for Ghost bat usage.

Cave	Easting	Northing	Observations	Assessed Ghost Bat roost type
H01-A01 MH15- 44	417270	7595276	Shelter with a low internal dome. Several overhangs to the north and south. Ghost bat guano present	Nocturnal feeding roost
H2	414628	7597699	Overhang. No Ghost bat guano present	Overhang only. Not used
H3,H4,H5,H6,H7	414730	7597728	A series of overhangs along cliff face. No Ghost bat guano present	Overhang only. Not used
H16	415266	7596488	Shelter with low roof. No Ghost bat guano present. Additional overhangs nearby and on opposite side of gully with no Ghost bat evidence.	Shelter only. Not used
H18	415164	7596495	Shallow cave with two low domes. No Ghost bat guano present	Nocturnal feeding roost
H19	415126	7596488	Shelter with low roof. No Ghost bat guano present	Shelter only. Not used
H24	416776	7596072	Overhang. No Ghost bat guano present	Overhang only. Not used
H27	416587	7596590	Deep shelter with two low internal domes. Several overhangs to the north and south. No Ghost bat guano present	Nocturnal feeding roost
H34	415315	7595811	Shelter with several overhangs to the east and west. No Ghost bat guano present	Shelter only. Not regularly used
H36	415667	7595692	Unable to approach due to steep cliff. Assessed from opposite side of gully.	Shallow shelter only. Not used
MH15-13 MH15-14	417252	7594383.	Shelter with a high pipe in roof. Ghost bat guano present	Nocturnal feeding roost
MH15-25 H29	416571	7597124	Shelter with overhangs to west and east. No Ghost bat guano present	Shelter only. Not regularly used
MH15-47	417248	7595912	Shelter with low roof. No Ghost bat guano present	Not used
MH15-95	414938	7597150	Shelter with low roof. No Ghost bat guano present. Has additional overhangs nearby and on opposite face with no Ghost bat evidence.	Not regularly used
MH15-96	414925	7597127	Shelter with low roof. No Ghost bat guano present	Not used

Cave	Easting	Northing	Observations	Assessed Ghost Bat roost type
MH15-97	414899	7597103	Shelter with low roof. No Ghost bat guano present	Not used
MH16-34	415815	7595655	Deep cave with a single internal dome. No Ghost bats present	Diurnal roost. Possible maternal roost
MH16-35	415782	7595640	Shelter with overhangs to west and opposite. No Ghost bat guano present	Nocturnal feeding roost
AC04	417586	7594895	Cave with a multiple internal domes. Ghost bat scats present	Diurnal roost. Occasional use as a maternal roost possible but no current evidence of use this year
AC05	417109	7593285	Cave with a single internal dome. Ghost bat scats present	Nocturnal feeding roost
AC06	418068	7592683	Shelter with overhangs at creek level to the east. No Ghost bat guano present	Shelter only. Not regularly used
MH-Opp 1S	415625	7595659	Deep shelter with several overhangs to the east and west. No Ghost bat guano present	Nocturnal feeding roost
MH-Opp 2S	416948	7596585	Deep shelter with several overhangs to the north. No Ghost bat guano present	Nocturnal feeding roost
MH-Opp 3S	417330	7595332	Deep shelter with several overhangs to the south. No Ghost bat guano present	Nocturnal feeding roost

Note: All coordinates are zone 50K.

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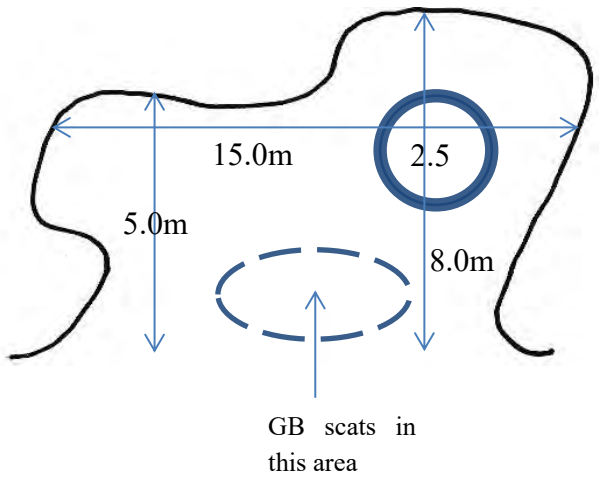
Attachment A: Characteristics of caves examined during this study.

Note that unboxed dimensions indicate cave/shelter width and depth and boxed or "dome height" (solid circles) dimensions indicate ceiling heights. Dotted ellipses indicate the locations of Ghost bat middens or scat piles.

Mesa H Shelter H01-A01 MH15-44:

Assessed Ghost bat usage: Nocturnal shelter with Ghost bat scats.	**Coordinates:** 50K 417270 7595276
Entrance safe or unsafe to approach: Assessed safe	**Basic Geology: Land system at site** Robe Pisolite mesa: Robe
Entrance type and dims – WxH (m): Single wide entrance 9.0 x 1.5 m.	**Entrance Orientation:** South
Cave Grouping: Shelter has additional shallow overhangs along gully wall to the north and south.	**Insulation from surface above:** Middle of local landscape
Cave Type: Shelter is 8 m deep with low roof and one low dome.	**Internal domed chamber:** Yes. 2.5 m high
Rear passages that may have roosts: No.	**Internal temp. and relative humidity:** Ambient
Local foraging opportunities: Excellent, In central Mesa H gully that opens onto the Robe River riparian zone.	**Current distance to disturbance:** Mesa J mine is 2.5 km distant. Resource evaluation drilling nearby on mesa top.

Cave floorplan and entrance photo:



Mesa H Shelter H2:

Assessed Ghost bat usage: Shallow shelter/Overhang only. No Gb guano present. Not used.	**Coordinates:** 50K 414628 7597699
Entrance safe or unsafe to approach: Assessed safe	**Basic Geology: Land system at site** Robe Pisolite mesa: Robe
Entrance type and dims – WxH (m): Wide shallow shelter.	**Entrance Orientation:** North
Cave Grouping: Shelter is a part of a complex of shelters and overhangs overlooking the Robe River.	**Insulation from surface above:** Middle of local landscape
Cave Type: Shallow shelter ~5 m deep.	**Internal domed chamber:** No
Rear passages that may have roosts: No.	**Internal temp. and relative humidity:** Ambient
Local foraging opportunities: Excellent, Mesa H is adjacent to Robe River riparian zone.	**Current distance to disturbance:** Mesa J mine is 6 km distant. Resource evaluation drilling nearby on mesa top.
Cave floorplan and entrance photo:	

Mesa H Shelters H3, H4, H5, H6, H7:

Assessed Ghost bat usage: Shallow shelter/Overhang only. No GB guano present. Not used	**Coordinates:** 50K 414730 7597728
Entrance safe or unsafe to approach: Assessed safe	**Basic Geology: Land system at site** Robe Pisolite mesa: Robe
Entrance type and dims – WxH (m): A series of wide shallow overhangs.	**Entrance Orientation:** North
Cave Grouping: A complex of shelters and overhangs along cliff face.	**Insulation from surface above:** Middle of local landscape
Cave Type: Shallow shelter ~5 m deep.	**Internal domed chamber:** No
Rear passages that may have roosts: No	**Internal temp. and relative humidity:** Ambient
Local foraging opportunities: Excellent, Mesa H is adjacent to Robe River riparian zone.	**Current distance to disturbance:** Mesa J mine is 6 km distant. Resource evaluation drilling nearby on mesa top.

Cave floorplan and entrance photo:

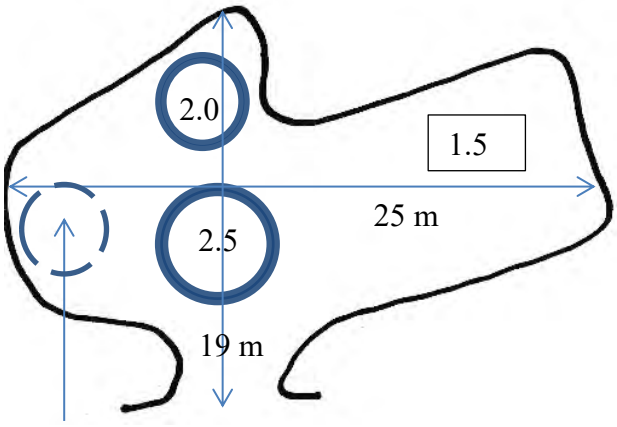
Mesa H Shelter H16:

Assessed Ghost bat usage:	**Coordinates:**
Shallow shelter/Overhang only. No GB guano present. Not used	50K 415266 7596488
Entrance safe or unsafe to approach:	**Basic Geology: Land system at site**
Assessed safe	Robe Pisolite mesa: Robe
Entrance type and dims – WxH (m):	**Entrance Orientation:**
A wide shallow shelter among a group of caves, shelters and overhangs.	North
Cave Grouping:	**Insulation from surface above:**
Shelter is a part of a complex of shelters and overhangs along both sides of gully.	Middle of local landscape
Cave Type:	**Internal domed chamber:**
Shallow shelter ~5 m deep.	No
Rear passages that may have roosts:	**Internal temp. and relative humidity:**
No	Ambient
Local foraging opportunities:	**Current distance to disturbance:**
Excellent, Mesa H is adjacent to Robe River riparian zone.	Mesa J mine is 6 km distant. Resource evaluation drilling nearby on mesa top.
Cave floorplan and entrance photo:	

Mesa H Cave H18:

Assessed Ghost bat usage: Nocturnal Roost. No GB guano present but cave was recently washed through by heavy rainfall.	**Coordinates:** 50K 415164 7596495
Entrance safe or unsafe to approach: Assessed safe	**Basic Geology: Land system at site** Robe Pisolite mesa: Robe
Entrance type and dims – WxH (m): Single small entrance 2.6 x 1.7 m.	**Entrance Orientation:** North
Cave Grouping: Cave is a part of a complex of shelters and overhangs along both sides of gully.	**Insulation from surface above:** Middle of local landscape
Cave Type: Cave 19.0 m deep with low roof and two low domes.	**Internal domed chamber:** Yes. 2.5 m and 2.0 m high
Rear passages that may have roosts: Has multiple pipes through to the surface above.	**Internal temp. and relative humidity:** Ambient
Local foraging opportunities: Excellent, Mesa H is adjacent to Robe River riparian zone.	**Current distance to disturbance:** Mesa J mine is 6 km distant. Resource evaluation drilling nearby on mesa top.

Cave floorplan and entrance photo:



Multiple pipes through to surface in this area

Mesa H Shelter H19:

Assessed Ghost bat usage: Shallow shelter/Overhang only. No GB guano present. Not used	**Coordinates:** 50K 415126 7596488
Entrance safe or unsafe to approach: Assessed safe	**Basic Geology: Land system at site** Robe Pisolite mesa: Robe
Entrance type and dims – WxH (m): A wide shallow shelter among a group of caves, shelters and overhangs.	**Entrance Orientation:** North
Cave Grouping: Shelter is a part of a complex of shelters and overhangs along both sides of gully.	**Insulation from surface above:** Middle of local landscape
Cave Type: Shallow shelter ~5 m deep.	**Internal domed chamber:** No
Rear passages that may have roosts: No	**Internal temp. and relative humidity:** Ambient
Local foraging opportunities: Excellent, Mesa H is adjacent to Robe River riparian zone.	**Current distance to disturbance:** Mesa J mine is 6 km distant. Resource evaluation drilling nearby on mesa top.

Cave floorplan and entrance photo:

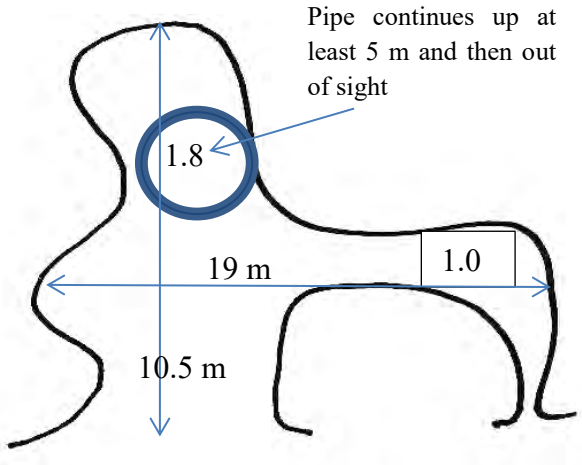
Mesa H Shelter H24:

Assessed Ghost bat usage:	**Coordinates:**
Shallow shelter/Overhang only. No GB guano present. Not used	50K 416776 7596072
Entrance safe or unsafe to approach:	**Basic Geology: Land system at site**
Assessed safe	Robe Pisolite mesa: Robe
Entrance type and dims – WxH (m):	**Entrance Orientation:**
A shallow shelter with an open entrance.	East
Cave Grouping:	**Insulation from surface above:**
Shelter is isolated in a gully.	Middle of local landscape
Cave Type:	**Internal domed chamber:**
Shallow shelter ~5 m deep.	No
Rear passages that may have roosts:	**Internal temp. and relative humidity:**
No	Ambient
Local foraging opportunities:	**Current distance to disturbance:**
Excellent, Mesa H central gully opens onto the Robe River riparian zone.	Mesa J mine is 3.5 km distant. Resource evaluation drilling nearby on mesa top.
Cave floorplan and entrance photo:	

Mesa H Shelter H27:

Assessed Ghost bat usage: Nocturnal Roost	**Coordinates:** 50K 416587 7596590
Entrance safe or unsafe to approach: Assessed safe	**Basic Geology: Land system at site** Robe Pisolite mesa: Robe
Entrance type and dims – WxH (m): Two entrances, one 8.6 x 3.8 m and another very small entrance to the north.	**Entrance Orientation:** North east
Cave Grouping: Shelter is a part of a complex of shelters and overhangs along the gully wall.	**Insulation from surface above:** Middle of local landscape
Cave Type: Shelter is 10.5 m deep with low roof and a low dome with a sinuous vertical pipe.	**Internal domed chamber:** Yes. 1.8 m high
Rear passages that may have roosts: A sinuous vertical pipe rises at least 5 m and continues out of sight.	**Internal temp. and relative humidity:** Ambient
Local foraging opportunities: Excellent, Mesa H central gully opens onto the Robe River riparian zone.	**Current distance to disturbance:** Mesa J mine is 3.5 km distant. Resource evaluation drilling nearby on mesa top.

Cave floorplan and entrance photo:



Mesa H Shelter H34:

Assessed Ghost bat usage: Shallow shelter/Overhang only. No GB guano present. Not regularly used	**Coordinates:** 50K 415315 7595811
Entrance safe or unsafe to approach: Assessed safe	**Basic Geology: Land system at site** Robe Pisolite mesa: Robe
Entrance type and dims – WxH (m): A shallow shelter among a group of overhangs.	**Entrance Orientation:** South
Cave Grouping: Shelter is a part of a complex of shelters and overhangs along the north side of the gully.	**Insulation from surface above:** Middle of local landscape
Cave Type: Shallow shelter ~5 m deep.	**Internal domed chamber:** No
Rear passages that may have roosts: No	**Internal temp. and relative humidity:** Ambient
Local foraging opportunities: Excellent, Mesa H is adjacent to Robe River riparian zone.	**Current distance to disturbance:** Mesa J mine is 5 km distant. Resource evaluation drilling nearby on mesa top.
Cave floorplan and entrance photo:	

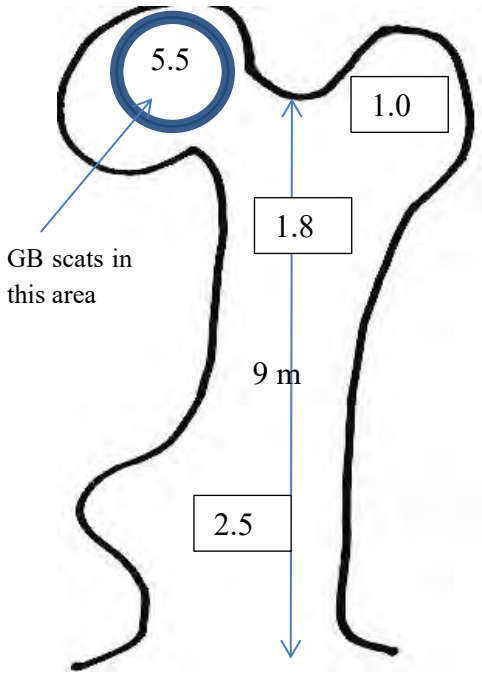
Mesa H Shelter H36:

Assessed Ghost bat usage:	**Coordinates:**
Shallow shelter. Unable to approach due to steep cliff. Assessed from opposite side of gully.	50K 415667 7595692
Entrance safe or unsafe to approach:	**Basic Geology: Land system at site**
Assessed safe if approached from gully floor.	Robe Pisolite mesa: Robe
Entrance type and dims – WxH (m):	**Entrance Orientation:**
A wide shallow shelter among a group of overhangs.	South
Cave Grouping:	**Insulation from surface above:**
Shelter is a part of a complex of shelters and overhangs along the north side of the gully.	Middle of local landscape
Cave Type:	**Internal domed chamber:**
Shallow shelter ~5 m deep.	No
Rear passages that may have roosts:	**Internal temp. and relative humidity:**
No	Ambient
Local foraging opportunities:	**Current distance to disturbance:**
Excellent, Mesa H is adjacent to Robe River riparian zone.	Mesa J mine is 5 km distant. Resource evaluation drilling nearby on mesa top.
Cave floorplan and entrance photo:	

Mesa H Shelter MH15-13 MH15-14:

Assessed Ghost bat usage: Nocturnal Roost. GB guano present under high pipe in roof.	**Coordinates:** 50K 417252 7594383
Entrance safe or unsafe to approach: Assessed safe	**Basic Geology: Land system at site** Robe Pisolite mesa: Robe
Entrance type and dims – WxH (m): Single entrance 2.7 x 2.5 m.	**Entrance Orientation:** West
Cave Grouping: Isolated shelter near top of central Mesa H gully.	**Insulation from surface above:** Middle of local landscape
Cave Type: Shelter is 9.0 m deep with low roof and a high pipe in the roof at the rear.	**Internal domed chamber:** Yes. 1.8 m dia pipe upwards at least 5.5 m high
Rear passages that may have roosts: No.	**Internal temp. and relative humidity:** Ambient
Local foraging opportunities: Excellent, Mesa H is adjacent to Robe River riparian zone.	**Current distance to disturbance:** Mesa J mine is 2.5 km distant. Resource evaluation drilling nearby on mesa top.

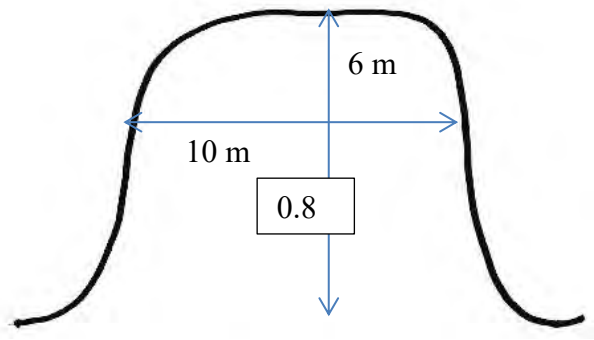
Cave floorplan and entrance photo:



Mesa H Shelter MH15-25 H29:

Assessed Ghost bat usage: Shallow shelter. No GB guano present. Not regularly used	**Coordinates:** 50K 416571 7597124
Entrance safe or unsafe to approach: Assessed safe.	**Basic Geology: Land system at site** Robe Pisolite mesa: Robe
Entrance type and dims – WxH (m): A wide shallow shelter among a group of overhangs. Entrance 10.0 x 2.0 m.	**Entrance Orientation:** South west
Cave Grouping: Shelter is amongst overhangs along the north side of the gully.	**Insulation from surface above:** Middle of local landscape
Cave Type: Shallow shelter 6 m deep.	**Internal domed chamber:** No
Rear passages that may have roosts: No	**Internal temp. and relative humidity:** Ambient
Local foraging opportunities: Excellent, Mesa H is adjacent to Robe River riparian zone.	**Current distance to disturbance:** Mesa J mine is 4 km distant. Resource evaluation drilling nearby on mesa top.

Cave floorplan and entrance photo:



Mesa H Shelter MH15-95:

Assessed Ghost bat usage:	**Coordinates:**
Shallow shelter. No GB guano present. Not regularly used.	50K 414938 7597150
Entrance safe or unsafe to approach:	**Basic Geology: Land system at site**
Assessed safe.	Robe Pisolite mesa: Robe
Entrance type and dims – WxH (m):	**Entrance Orientation:**
A wide shallow shelter among a group of overhangs. Roof ~0.5m high.	South east
Cave Grouping:	**Insulation from surface above:**
Shelter is a part of a complex of shelters and overhangs along the north-west side of the gully. Other overhangs are opposite on the south-east side of the gully.	Middle of local landscape
Cave Type:	**Internal domed chamber:**
Shallow shelter ~5 m deep.	No
Rear passages that may have roosts:	**Internal temp. and relative humidity:**
No	Ambient
Local foraging opportunities:	**Current distance to disturbance:**
Excellent, Mesa H is adjacent to Robe River riparian zone.	Mesa J mine is 6 km distant. Resource evaluation drilling nearby on mesa top.
Cave floorplan and entrance photo:	

Mesa H Shelter MH15-96:

Assessed Ghost bat usage: Shallow shelter. No GB guano present. Not used.	**Coordinates:** 50K 414925 7597127
Entrance safe or unsafe to approach: Assessed safe.	**Basic Geology: Land system at site** Robe Pisolite mesa: Robe
Entrance type and dims – WxH (m): A wide shallow shelter among a group of overhangs. Roof ~0.3 m high.	**Entrance Orientation:** South east
Cave Grouping: Shelter is a part of a complex of shelters and overhangs along the north-west side of the gully. Other overhangs are opposite on the south-east side of the gully.	**Insulation from surface above:** Middle of local landscape
Cave Type: Shallow shelter ~5 m deep.	**Internal domed chamber:** No
Rear passages that may have roosts: No	**Internal temp. and relative humidity:** Ambient
Local foraging opportunities: Excellent, Mesa H is adjacent to Robe River riparian zone.	**Current distance to disturbance:** Mesa J mine is 6 km distant. Resource evaluation drilling nearby on mesa top.

Cave floorplan and entrance photo:

MH15-96 is the right hand entrance

Mesa H Shelter MH15-97:

Assessed Ghost bat usage: Shallow shelter. No GB guano present. Not used.	**Coordinates:** 50K 414899 7597103
Entrance safe or unsafe to approach: Assessed safe.	**Basic Geology: Land system at site** Robe Pisolite mesa: Robe
Entrance type and dims – WxH (m): A wide shallow shelter among a group of overhangs. Roof ~0.3 m high.	**Entrance Orientation:** South east
Cave Grouping: Shelter is a part of a complex of shelters and overhangs along the north-west side of the gully. Other overhangs are opposite on the south-east side of the gully.	**Insulation from surface above:** Middle of local landscape
Cave Type: Shallow shelter ~5 m deep.	**Internal domed chamber:** No
Rear passages that may have roosts: No	**Internal temp. and relative humidity:** Ambient
Local foraging opportunities: Excellent, Mesa H is adjacent to Robe River riparian zone.	**Current distance to disturbance:** Mesa J mine is 6 km distant. Resource evaluation drilling nearby on mesa top.

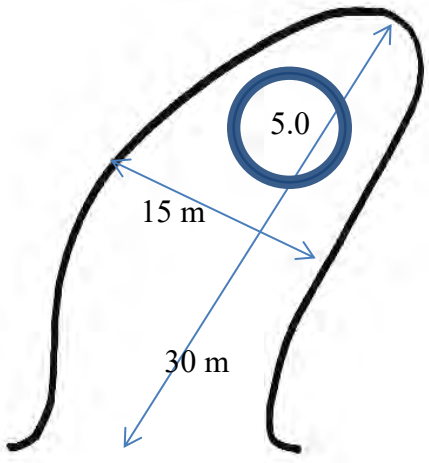
Cave floorplan and entrance photo:

MH15-97 is the left hand entrance

Mesa H Cave MH16-34:

Assessed Ghost bat usage: Diurnal roost. Potential maternity roost but no GB current evidence.	**Coordinates:** 50K 415815 7595655
Entrance safe or unsafe to approach: Assessed safe	**Basic Geology: Land system at site** Robe Pisolite mesa: Robe
Entrance type and dims – WxH (m): A wide entrance among a group of overhangs at top of deep gully. Entrance 8.0 x 3.0 m.	**Entrance Orientation:** South west
Cave Grouping: Cave is a part of a complex of shelters and overhangs along the north side of the gully.	**Insulation from surface above:** Bottom of landscape
Cave Type: Deep cave with a single large dome.	**Internal domed chamber:** Yes. 5.0 m high
Rear passages that may have roosts: No	**Internal temp. and relative humidity:** Ambient
Local foraging opportunities: Excellent, Mesa H is adjacent to Robe River riparian zone.	**Current distance to disturbance:** Mesa J mine is 4.5 km distant. Resource evaluation drilling nearby on mesa top.

Cave floorplan and entrance photo:



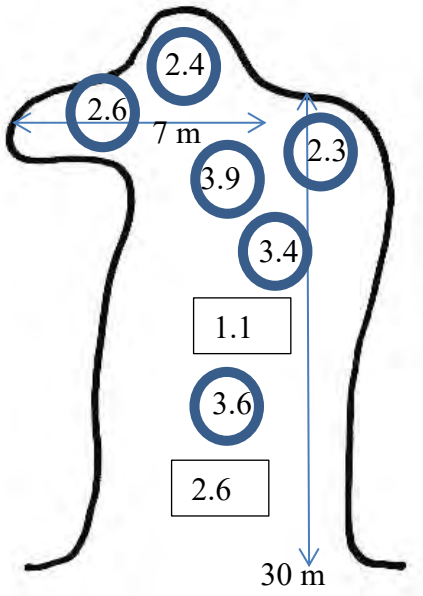
Mesa H Shelter MH16-35:

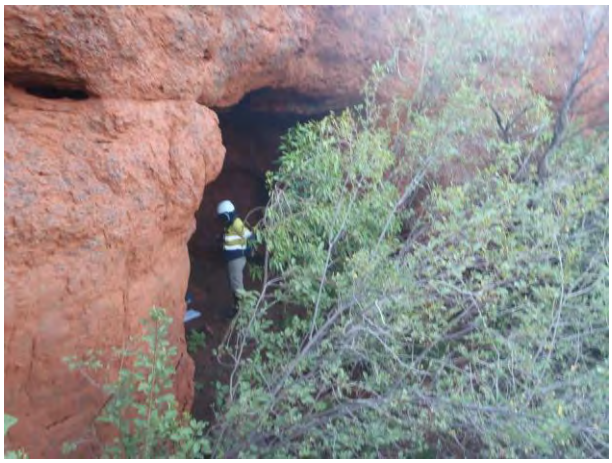
Assessed Ghost bat usage:	**Coordinates:**
Nocturnal roost. Shallow shelter. No GB guano present.	50K 415782 7595640
Entrance safe or unsafe to approach:	**Basic Geology: Land system at site**
Assessed safe.	Robe Pisolite mesa: Robe
Entrance type and dims – WxH (m):	**Entrance Orientation:**
A shallow shelter among a group of overhangs.	North west
Cave Grouping:	**Insulation from surface above:**
Shelter is a part of a complex of shelters and overhangs at the top of the gully, opposite cave MH16-34.	Middle of local landscape
Cave Type:	**Internal domed chamber:**
Shallow shelter ~5 m deep.	No
Rear passages that may have roosts:	**Internal temp. and relative humidity:**
No	Ambient
Local foraging opportunities:	**Current distance to disturbance:**
Excellent, Mesa H is adjacent to Robe River riparian zone.	Mesa J mine is 4.5 km distant. Resource evaluation drilling nearby on mesa top.
Cave floorplan and entrance photo:	

Mesa H Cave AC4:

Assessed Ghost bat usage: Diurnal roost. Potential maternal roost but no recent evidence. GB scats under domes at rear.	**Coordinates:** 50K 417586 7594895
Entrance safe or unsafe to approach: Assessed safe	**Basic Geology: Land system at site** Robe Pisolite mesa: Robe
Entrance type and dims – WxH (m): A large entrance 3.0 m x 2.8 m.	**Entrance Orientation:** North east
Cave Grouping: Cave is alone on the east side of the central Mesa H gully.	**Insulation from surface above:** Middle of local landscape
Cave Type: 30 m deep cave with multiple domes.	**Internal domed chamber:** Yes. Six domes between 2.5 and 3.9 m high
Rear passages that may have roosts: No	**Internal temp. and relative humidity:** Ambient
Local foraging opportunities: Excellent, Mesa H is adjacent to Robe River riparian zone.	**Current distance to disturbance:** Mesa J mine is 2 km distant. Resource evaluation drilling nearby on mesa top.

Cave floorplan and entrance photo:

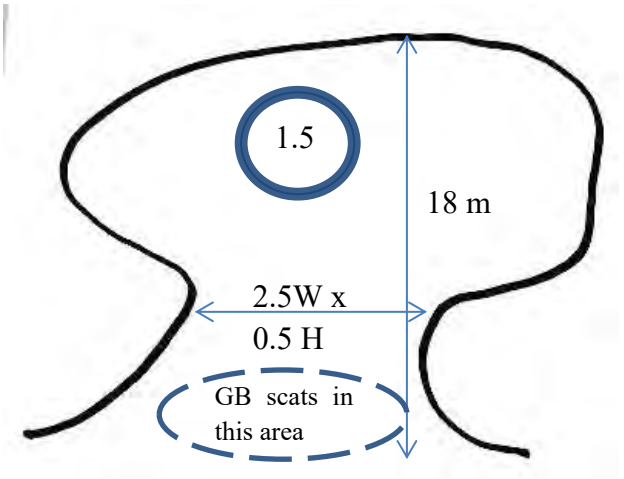




Mesa H Cave AC5:

Assessed Ghost bat usage: Nocturnal roost. GB guano present.	**Coordinates:** 50K 417109 7593285
Entrance safe or unsafe to approach: Assessed safe.	**Basic Geology: Land system at site** Brockman BIF: Newman
Entrance type and dims – WxH (m): A shallow cave with a wide low entrance 10.0 x 1.5 m.	**Entrance Orientation:** South east
Cave Grouping: Cave is in a gully on a ridge south west of mesa H..	**Insulation from surface above:** Middle of landscape
Cave Type: Shallow cave 18 m deep with a single low dome.	**Internal domed chamber:** Yes. 1.5 m high
Rear passages that may have roosts: No	**Internal temp. and relative humidity:** Ambient
Local foraging opportunities: Excellent, cave is 3.5 km from Robe River riparian zone.	**Current distance to disturbance:** Mesa J mine is 2.5 km distant.

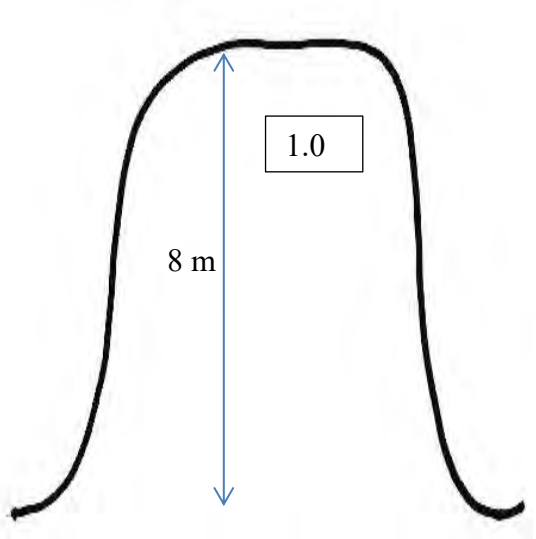
Cave floorplan and entrance photo:



Mesa H Cave AC6:

Assessed Ghost bat usage: Shallow shelter. No GB guano present. Not regularly used.	**Coordinates:** 50K 418068 7592683
Entrance safe or unsafe to approach: Assessed safe.	**Basic Geology: Land system at site** Brockman BIF: Newman
Entrance type and dims – WxH (m): A shelter with a low entrance 1.5 x 2.0 m.	**Entrance Orientation:** North east
Cave Grouping: Shelter is on a ridge south west of Mesa H.	**Insulation from surface above:** Middle of landscape
Cave Type: A low shelter 8 m deep.	**Internal domed chamber:** No
Rear passages that may have roosts: No	**Internal temp. and relative humidity:** Ambient
Local foraging opportunities: Excellent, cave is 4.5 km from Robe River riparian zone.	**Current distance to disturbance:** Mesa J mine is 1.5 km distant.

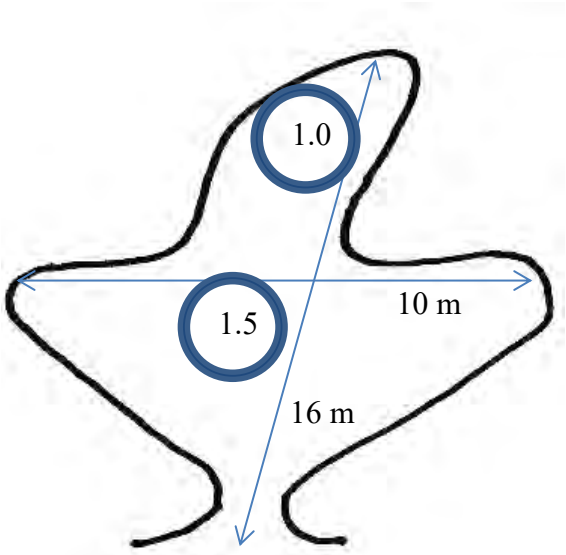
Cave floorplan and entrance photo:



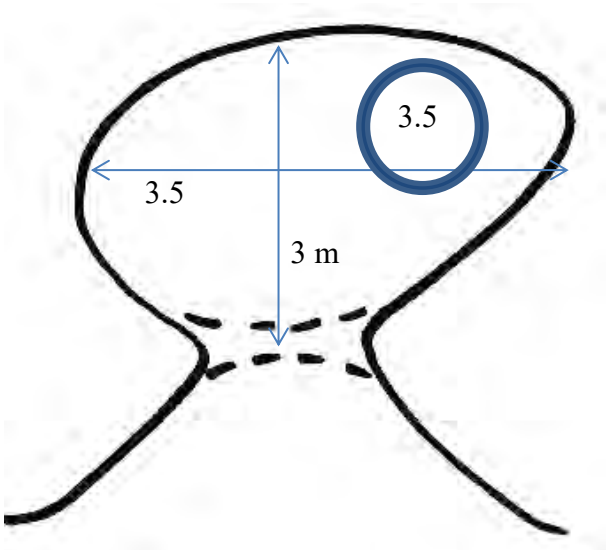
Mesa H Shelter Opp-1S:

Assessed Ghost bat usage: Nocturnal roost. Deep shelter. No GB guano present.	**Coordinates:** 50K 415625 7595659
Entrance safe or unsafe to approach: Assessed safe	**Basic Geology: Land system at site** Robe Pisolite mesa: Robe
Entrance type and dims – WxH (m): A small entrance among a group of overhangs. Entrance 1.5 x 1.5 m.	**Entrance Orientation:** North
Cave Grouping: Shelter is a part of a complex of overhangs along the south side of the gully opposite shelter H34.	**Insulation from surface above:** Middle of local landscape
Cave Type: Deep shelter with a two low domes.	**Internal domed chamber:** Yes. 1.5 and 1.0 m high
Rear passages that may have roosts: No	**Internal temp. and relative humidity:** Ambient
Local foraging opportunities: Excellent, Mesa H is adjacent to Robe River riparian zone.	**Current distance to disturbance:** Mesa J mine is 4.5 km distant. Resource evaluation drilling nearby on mesa top.

Cave floorplan and entrance photo:



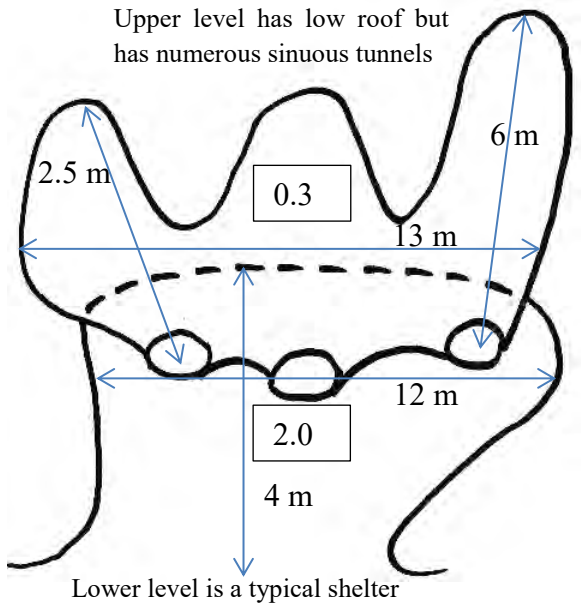
Mesa H Shelter Opp-2S:

Assessed Ghost bat usage: Nocturnal roost. Shallow shelter. No GB guano present.	**Coordinates:** 50K 416948 7596585
Entrance safe or unsafe to approach: Assessed safe	**Basic Geology: Land system at site** Robe Pisolite mesa: Robe
Entrance type and dims – WxH (m): A small constricted entrance 0.7 x 1.5 m.	**Entrance Orientation:** West
Cave Grouping: Shelter is a part of a complex of overhangs along the east side of the gully opposite shelter H27.	**Insulation from surface above:** Middle of local landscape
Cave Type: Shelter with small entrance and a low dome.	**Internal domed chamber:** Yes. 3.5 m high
Rear passages that may have roosts: No	**Internal temp. and relative humidity:** Ambient
Local foraging opportunities: Excellent, Mesa H is adjacent to Robe River riparian zone.	**Current distance to disturbance:** Mesa J mine is 3.5 km distant. Resource evaluation drilling nearby on mesa top.
Cave floorplan and entrance photo: 	

Mesa H Shelter Opp-3S:

Assessed Ghost bat usage: Nocturnal roost. No GB guano present.	**Coordinates:** 50K 417330 7595332
Entrance safe or unsafe to approach: Assessed safe	**Basic Geology: Land system at site** Robe Pisolite mesa: Robe
Entrance type and dims – WxH (m): A large entrance among a group of overhangs. Entrance 8.0 x 4.0 m.	**Entrance Orientation:** South east
Cave Grouping: Shelter is a part of a complex of overhangs along the west side of the central gully.	**Insulation from surface above:** Middle of local landscape
Cave Type: Deep shelter with a two levels. Upper level accessed by three pipes ~ 1.0 m diameter.	**Internal domed chamber:** No. Lower level has pipes in roof leading to upper level cavity that has numerous tunnels.
Rear passages that may have roosts: Yes in upper level	**Internal temp. and relative humidity:** Ambient
Local foraging opportunities: Excellent, Mesa H is adjacent to Robe River riparian zone.	**Current distance to disturbance:** Mesa J mine is 3.0 km distant. Resource evaluation drilling nearby on mesa top.

Cave floorplan and entrance photo:



Technical Services – Assurance Geotechnical
Level 11 Central Park,
152-158 St Georges Terrace
Perth
6000
Western Australia

Site visit report

From	Fanie Wessels
Department	D3 Assurance and Systems
To	Melinda Brand; Fiona Bell
CC	Ed Clarke, Alex Walter, Iain Daggers
Reviewed By	Iain Daggers
Reference	SVR_RVO_Mesa H Environmental sites Assessments
Date	19 October 2017

Geotechnical assessments – Potential diurnal Ghost Bat roost complexes at Robe Valley

1 Summary

The D3 Assurance and Systems team was requested to geotechnically assess the potential diurnal Ghost Bat roost complexes located at Robe Valley (Mesa H). The purpose of the assessments is to determine the level of blast control needed to be put in place to mitigate large scale damaged induced by mining, and to highlight any other possible geotechnical hazards within the sites that may present a risk for future access.

The geotechnical sensitivity (robustness) of the site was assessed in conjunction with the assessed environmental significance to determine the tolerable blast vibration range required to protect the integrity of the structure. Blast vibration thresholds were based on guidance that were developed for protection of heritage sites, specifically caves and shelters, based on discussions with the Explosive and Dangerous Goods team and referring to the Australian Standard AS2187.2 – Ground Vibration and Air blast Overexposure (Reference 1) as a guideline. The objective is to define vibration levels where routine mining activities (excavation and blasting) do not negatively impact on the integrity of the identified cave. However, natural weathering processes will continue to physically act on the cave and might eventually affect the integrity of the cave.

The tolerable vibration level for the sites has been assessed and are summarised in Figure 6. All the sites that were reviewed have recommended threshold Peak Particle Velocity (PPV) values of 50mm/s. The scaled distance method, as outlined in the AS2187.2:2006, should be used to determine the expected vibration levels at the sites. If the predicted PPV levels exceed the thresholds, more detailed blast management plans must be developed for the relevant sites.

2 Introduction

A list of sites to be assessed was provided by the Rio Tinto Environmental team. Some of the sites listed were previously also assessed for heritage purposes. The Geotechnical assessment of stability from a heritage perspective considers the possibility of any disturbance to the site, from a relative small rockfall to total collapse of the site. For the environmental assessment, smaller rockfalls were not evaluated. The main consideration is the permanent, large scale collapse of the site, preventing future Ghost Bat useof the site.

Development of a blast vibration threshold is based on a combination of the geotechnical sensitivity and the heritage / environmental value. All of the bat roost sites that are reported in this document are considered to have a high sensitivity. Where the environmental thresholds differed from the heritage thresholds, the more conservative threshold, i.e. the lower PPV number, was applied.

The sites that are reported in this document are listed in Table 1.

Cave/shelter ID	mE	mN
Mesa H		
Astron Cave 1	415815	7595655
MH16_35	415782	7595640
Astron Cave 4	417586	7594895

Table 1 List of sites that were assessed and reported in this document

3 Methodology

The level of required blast control depends on a combination of environmental significance and geotechnical sensitivity. These assessments are recorded on a matrix and the vibration thresholds, and other possible controls, determined depending on where it plots on the risk matrix (Figure 17). The Peak Particle Velocity (PPV) thresholds are based the Australian Standard AS2187.2 – Ground Vibration and Air blast Overexposure and discussions with the Explosive and Dangerous Goods team.

Some of the terminology used to describe the different areas of the caves or overhangs are explained in Figure 1.

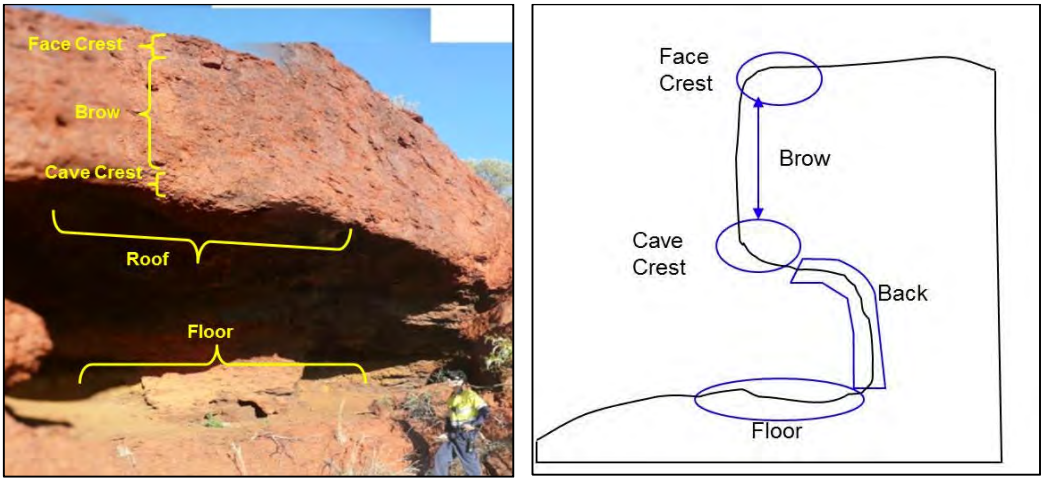


Figure 1 Explanation of terminology used in this report.

The size descriptions for the caves are based on the hydraulic radius measured in the field. In general cave sizes that are:

- Small caves – 1-50 m^2
- Medium caves – 51-100 m^2
- Large caves – 101 – 150 m^2
- Very Large caves >150 m^2

The size descriptions of historical rock-falls are based on size of particles in the rock-fall. In general the sizes are as follows:

- Very small rock-fall – very small size gravels and cobbles/slabs (< 0.1m)
- Small rock-fall – small size boulders/slabs (0.1 - 0.3m)
- Medium rock-fall – medium size boulders/slabs (0.3 – 0.6m)
- Large rock-fall – large size boulders/slabs (0.6 – 1.0m)
- Very large rock-fall – very large size boulders/slabs (> 1.0m)

4 Mesa H Assessments

The sites that were assessed for Mesa H are shown in Figure 2.

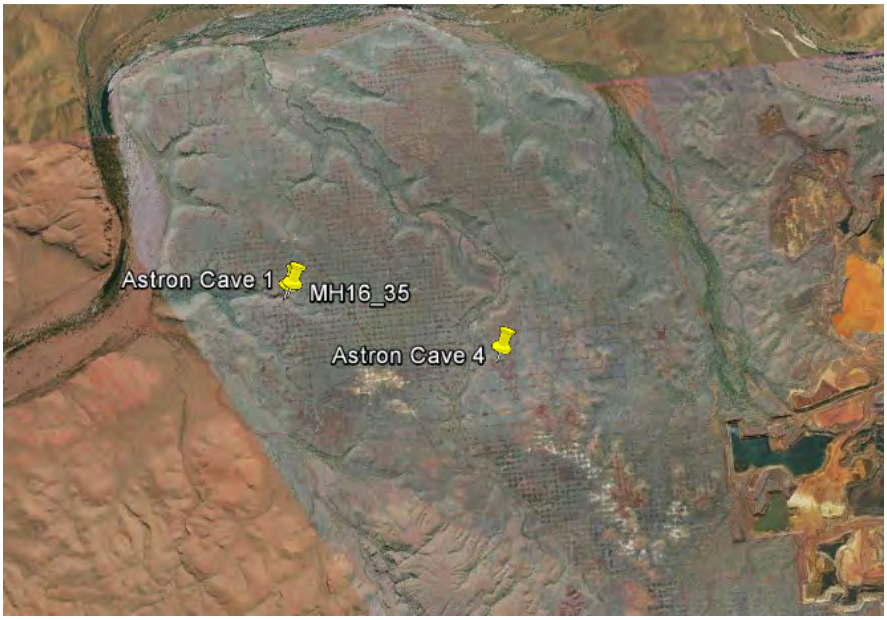


Figure 2 Location of environmental sites in Mesa H.

4.1 Astron Cave 1

Astron Cave 1 is a large (20 W x 3.5 H x 12 m D) cave developed in hydrated hardcap. There are three different entrances and two pillars. The roof is dome shaped. The floor is sloped towards the entrances and is covered in sediment and some historical rock falls. There is relic bedding which is tight, short, undulating and rough. There are no major joint sets in the cave. There are smaller random discontinuities throughout which are short and tight. Some roof slabs have developed along bedding planes and there are signs of spalling on the roof and walls of the cave. The pillar to the north appears sound with no defects. The south pillar has bedding and some random defects throughout with cracks opening up. The brow appears stable, with some minor spalling. There is a moderate rock fall potential at this site. The likelihood of a structural instability of the cave is rated as low.

Based on the absence of large continuous structures that could lead to collapse of the cave the geotechnical sensitivity of this site is rated as low.

The recommended PPV threshold is 50mm/s.

Figure 3: General view of Astron Cave 1

4.2 MH16_35

The site is a large (8 W x 4 H x 8 m D), wide cave developed in hydrated hardcap pisolite. It has a dome shaped roof, with a floor that inclines towards the rear with a large hump in the middle from historical rock falls, varying in size from medium to very large. These historical rock falls also partially obstruct the cave entrance. There is a secondary cavern at the western side of the cave and widely spaced relic bedding that disappears towards the rear of the cave where the structure becomes more massive. There is minor discontinuities near the entrance, however these are short and are not visible towards the rear of the cave. There is minor spalling around the centre pillar of the entrance, with potential for some smaller slabs to fail. These failures would not block the cave entrance. The roof and walls are stable inside the cave. The brow is stable with no signs of spalling or loose rocks above the brow. However the roof is a long unsupported span which increases the risk of failure. There is a moderate potential of rock fall in this cave but the likelihood of overall instability is rated as low.

The absence of large scale structures and low likelihood of overall instability results in a low geotechnical sensitivity rating of overall instability. The geotechnical sensitivity to rockfalls is also rated as low..

The recommended PPV threshold is 50mm/s.

Figure 4: General view (MH16_31) Blue arrow indicates central pillar; red oval is historical rock falls.

4.3 Astron Cave 4

Astron 4 is a large (7 W x 3.5 H x 25 m D), deep cave developed in hydrated hardcap pisolite. The cave is square shaped, with a flat roof controlled by relic bedding. There are large historical rock falls on the floor. The main structures in the cave are relic bedding planes spaced ±1 m, tight, cemented and persistent through the whole cave. The floor rises towards the rear of the cave where the internal height is around 1.5 m. There are a number of additional random joint sets all widely spaced which are vertical to sub-vertical dipping which define side walls of the cave. The main structural concerns are the well-defined large blocks in the roof, similar to the historical rock falls on the floor of the cave. There is a moderate potential for rockfall in this cave. Due to the tabular shape and size of these rocks, it is not expected to impact on cave entrance, in the event of a rock fall. No large scale instabilities are expected.

The sensitivity for overall structural collapse is rated as low. Due to the large blocks in the roof which have potential to fall as well as historical rock fall evidence, the geotechnical rock fall sensitivity of the site is rated as medium.

The environmental PPV threshold of 50mm/s.should apply to this location.

Figure 5 Entrance to Astron Cave 4.

5 Recommendations

The recommended blast vibration thresholds are based on a combination of the environmental significance and the geotechnical sensitivity. The results are summarised in Table 2 and Figure 6. All the sites assessed have a recommended PPV threshold of 50mm/s.

The scaled distance method as outlined in the Australian Standard AS2187.2:2006 should be used to determine the expected vibration levels at the sites. In the absence of site specific data, use of proxy constants K = 1140 and b = -1.6 can be used as a starting point. Should the calculated vibration levels exceed the recommended thresholds, the Drill and Blast team can:

- develop site specific K and b values, or
- modify the blast design to reduce the maximum charge weight.

Cave/shelter ID	Environmental Rating	Geotechnical Rating	Recommended PPV
Mesa H			
Astron Cave 1	High	Low	50
MH16_35	High	Low	50
Astron Cave 4	High	Low	50

Table 2 Summary of recommended blast vibration thresholds

Should the predicted estimated thresholds levels still be exceeded following these modifications, a more detailed blast management plan should be developed.

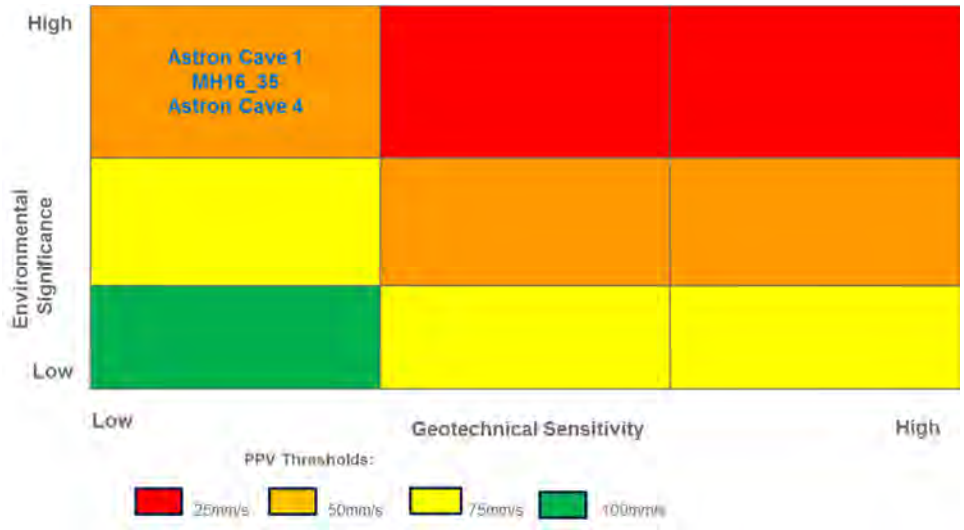


Figure 6 PPV recommendations based on environmental geotechnical assessments. All the environmental thresholds are 50mm/s.

Should you have any queries, don't hesitate to contact me at any time.

Regards

Fanie Wessels
Geotechnical Superintendent – Orebody Knowledge and Risk Management

References

1. Australian Standard AS 2187.2. 2006. Appendix J. ***Ground Vibration and Air blast overexposure.***

Rio Tinto

Technical Services – Explosives & Dangerous Goods

Recent Examples of Blast Vibration Control in Pilbara Iron Ore Mines

October 2013

Production blast at Hope Downs 1 mine

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1. Introduction

Explosives are charged into drilled holes and fired to break and loosen intact rock, so that ore and other material can be excavated and delivered to the processing plant, a stockpile, or a waste dump. Rio Tinto Iron Ore utilises around 200,000 tonnes of explosives each year in blasting across its Pilbara mines.

Uncontrolled ground vibrations from blasting can lead to damage or adverse effects to sensitive sites, so the blast planning process includes risks assessment and, where required, implementation of specific management plans to control blast vibrations.

This document highlights some recent examples of programs implemented by Rio Tinto's Pilbara mines to control blast vibrations and achieve a required risk level.

2. Blast vibration overview

Ground vibrations are generated from blasting buried explosives, and these travel through the ground in much the same way that sound travels through air. There are several types of waves generated (e.g. compressive, shear and surface waves), and the sum of these waves can be detected and measured using geophones, accelerometers or other sensors with appropriate data acquisition equipment.

A geophone glued to rock mass, ready to capture blast vibration data

Blast vibration is often expressed as a 'peak particle velocity', measured in millimetres per second. The vibration may be expressed in terms of the three orthogonal components (e.g. longitudinal, transverse and vertical), or the vector sum of these components. Key measures are defined in Appendix J of AS2187.2–2006.

The magnitude of measured blast vibrations depends on the size of the explosives charge fired, the blast timing (i.e. the layout and delays between firing successive holes), the distance from the blast to the monitoring location, the topography and the geological properties of the ground.

Table 1 shows the typical vibration levels associated with potential negative impacts to sensitive sites, and limits typically applied by Rio Tinto to prevent vibration-induced damage.

Table 1. Potential adverse effects from blast vibration

	Typical vibration levels (PCPV) associated with adverse effects	**Typical vibration control levels applied by Rio Tinto in Pilbara mines**
Human discomfort (residential areas)	> 5 mm/s	N/A (no residential areas directly impacted)
Human discomfort (industrial areas)	> 25 mm/s	< 25 mm/s
Minor damage to sensitive heritage sites (e.g. rock shelters with recognised heritage importance)	> 50 mm/s	< 25 mm/s (95% confidence)
Damage to buried gas pipeline	> 50 to 100 mm/s	< 10 mm/s (95% confidence)
Cosmetic damage to reinforced or framed structures (Industrial and heavy commercial buildings)	> 50 mm/s (as per Table J4.4.2.1 of AS2187.2)	< 25 mm/s (95% confidence)
Structural damage to buildings of reinforced concrete or steel construction	> 100 mm/s (as per Table J4.5(b) of AS2187.2)	< 50 mm/s (95% confidence)
Damage to communications or other key infrastructure	> 50 to 100 mm/s	< 25 to 50 mm/s (95% confidence)
Fracturing of intact rock	Typ. 250 - 1000 mm/s	

Notes: These values are examples only; in practice the vibration limits will be based on specific risk assessment, with due consideration of structural design, potential mechanical resonance and other factors. PCPV is the peak component particle velocity, defined in Appendix J of AS2187.2–2006.

2.1 Blast vibration modelling

Models can be developed to predict vibration, and refined over time as new data comes to hand and as pit conditions change. Figure 1 shows an example of a ‘scaled distance’ plot from a recent Rio Tinto vibration control project.

3. Recent examples of blast control in Pilbara operations

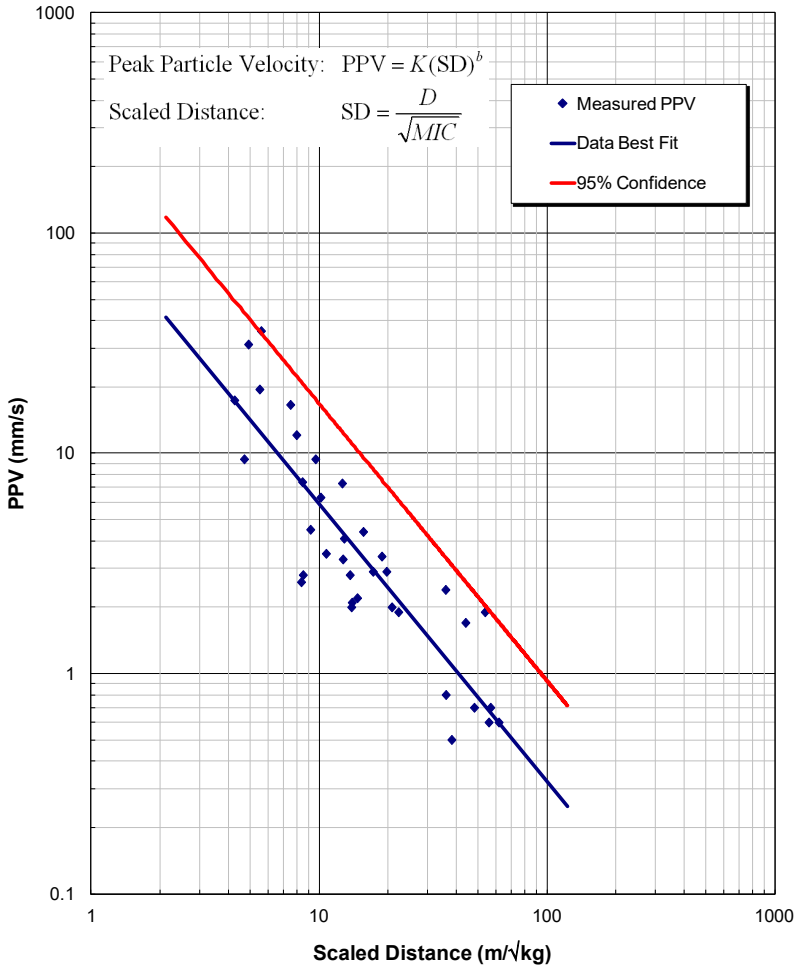
Vibration control and management projects are regularly established to protect sensitive sites. The projects may apply to a small number of blasts, or through a large mining area and last a number of years. The level of rigour applied is commensurate with the risk.

In a number of specific cases, Blast Vibration Management Plans have been put into effect to ensure that accountabilities and responsibilities are clear, appropriate test work is conducted, blast vibration is monitored and controlled through the blast design and execution phases, and review and reporting is completed to share insights.

3.1 Culturally sensitive sites

A number of rock shelters in the Pilbara are designated as having high cultural significance to the traditional owners. The proximity of some of these sites to mine pit limits means that tight vibration control is required to ensure the integrity of the sites. Current examples include sites on the Hope Downs 1, West Angelas and Tom Price mining leases.

Figure 1. Example of a Scaled Distance plot for monitoring & predicting blast vibration



Best Fit: PPV = 107 (SD)$^{-1.26}$ 95% Confidence: PPV = 305 (SD)$^{-1.26}$

$R^2 = 0.78$

Measured Data					Measured Data			
Distance (m)	Charge (8ms)	PPV (mm/s)	SD		Distance (m)	Charge (8ms)	PPV (mm/s)	SD
51	46.5	16.6	7.5		160	158.4	3.3	12.7
95	46.5	2.1	13.9		453	158.4	0.8	36.0
152	46.5	1.9	22.3		62	160.8	31.2	4.9
419	46.5	0.6	61.4		107	160.8	7.4	8.4
48	76.8	19.5	5.5		160	160.8	7.3	12.6
94	76.8	3.5	10.7		455	160.8	2.4	35.9
151	76.8	2.9	17.2		68	73.1	12.1	8.0
420	76.8	0.7	47.9		110	73.1	4.1	12.9
47	122.4	17.4	4.2		161	73.1	3.4	18.8
94	122.4	2.8	8.5		457	73.1	1.9	53.5
151	122.4	2.8	13.6		76	68.9	4.5	9.2
422	122.4	0.5	38.1		115	68.9	2.0	13.9
57	105.0	35.9	5.6		164	68.9	2.9	19.8
104	105.0	6.3	10.1		461	68.9	0.6	55.5
160	105.0	4.4	15.6		80	68.9	9.4	9.6
450	105.0	1.7	43.9		122	68.9	2.2	14.7
59	158.4	9.4	4.7		173	68.9	2.0	20.8
105	158.4	2.6	8.3		469	68.9	0.7	56.5

A recent example is a rock shelter at West Angelas Deposit E. A management plan has been developed that defines limits on explosives charge per hole and per delay interval; quality assurance and control requirements; site access control; and monitoring and reporting expectations. The drill and blast engineers, blast crew and other personnel involved are all trained in the vibration control process.

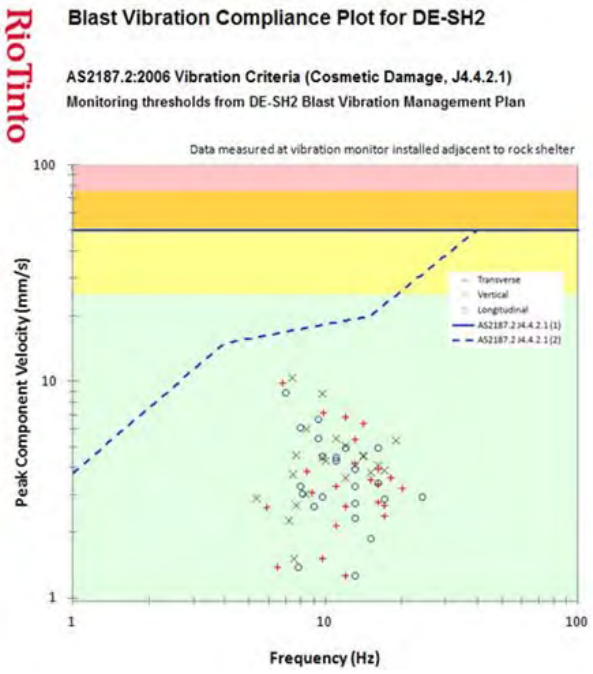
To establish the vibration criteria, a geotechnical survey was conducted to assess stability of the rock shelter and specific structures. In line with current best practice, a set of trial blast holes were individually fired to set a baseline for a vibration model.

To the end of October 2013, almost forty blasts have been conducted under the management plan, with no vibration readings outside of the target range. Figure 2 shows peak vibration through many blasts as measured adjacent to the rock shelter (blasts less than 1 mm/s are not visible).

The blast vibration model is regularly reviewed and adjusted to account for changing pit topography (e.g. the vibration response varies depending on the direction from a blast to the monitoring location).

Following the management plan will enable mining to within 60 metres of the rock shelter.

Figure 2. Example of Blast vibration data from West Angelas Deposit E rock shelter



3.2 High pressure gas pipeline at Eastern Range

A 10 MPa gas pipeline runs close to the Eastern Range mining area near Paraburdoo. Damage to the pipeline could lead to a rupture of the pipeline resulting in a loss of gas and the potential for an explosion.

A vibration control program was established in 2010 following test work in 2009. The test work involved development of a scaled distance vibration model, plus use of advanced vibration analysis tools to assess the 'worst case' vibration potential. The blast vibration management plan placed a vibration limit of 10 mm/s at the surface above the buried

pipeline. With blasts as close as 120 metres from the pipeline, a number of controls had to be established, including strict limits on the explosives charge per hole and per delay, reduced blast sizes, a custom quality assurance program and a strict reporting regime.

3.3 Protecting Troglobitic fauna at Mesa A

'Troglofauna' species and populations have been identified at the Mesa A mine. Blasting activities during mining have the potential to cause collapses of strata and other features such as mesocaverns in the retained portion of the mesa formation. There is also the possibility of direct impacts on fauna close to blasting activity through direct physical effects.

A blast management program was established at Mesa A to ensure that blast vibrations are controlled and potential for damage beyond the defined 'mining exclusion zone' is limited. This program is ongoing to ensure that the troglofauna are protected.

3.4 Communications tower at Yandicoogina

At the Yandicoogina central pit, a key communications tower is located less than 30 metres from the pit crest. Due to the resonant nature of the tall structure, a blast vibration control program was put in place whilst blasting within 100 metres of the tower, to ensure that blasts were engineered to avoid undesirable vibration frequencies that could induce significant mechanical stress.

Small scale test blasts were conducted to identify the dispersion and attenuation characteristics of the rock mass, and to characterise the frequency response of the tower. Blasts were simulated to assess the dominant frequencies that the blast would produce, and the blast timing adjusted until requirements were met.

The subsequent production blasts were conducted without any damage to the tower.

3.5 Cape Lambert Port B Construction Blasting

The construction of Cape Lambert Port B necessitated blasting within close proximity of critical port and infrastructure and ongoing construction works. These included blasting:

- within 10m of live rail;
- within 2m of concrete;
- immediately under live water mains;
- within 30m of a gas pipeline;
- within 30m of a diesel line;
- within 50m of office buildings;
- for shallow trenches whilst managing fly rock; and
- for presplit rock faces to minimise construction footprint.

A variety of techniques including varying drill hole diameters, drill angles, uncharged holes, deck loading and air decking were combined with careful initiation sequencing to ensure all blasting met required rock fragmentation without exceeding blast vibration limits, fly rock occurrences, whilst controlling shear force acting on the existing infrastructure from blast muckpile displacement.

Blast design parameters to predict PPV limits were calibrated through a heavily observed blasting monitoring program. The monitoring included video surveillance and ground vibration monitors for every blast on site.

A stringent blast management plan was also put in place to ensure all personnel involved in the blast were safely evacuated behind blast radiuses. Blast wardens were elected and trained for every contractor and RTIO department affected by the blasting.

3.6 Pit walls

The underlying intent of blasting is to break rock for subsequent excavation; this is in direct opposition to the need to maintain structural integrity of pit walls for safe and economic mining. Vibration monitoring programs have been setup at a number of mines to establish criteria for safe and effective blasting that minimises unwanted damage to pit walls. In these cases, the use of vibration measurement equipment forms a key part of the monitoring and review elements of the continuous improvement cycle.

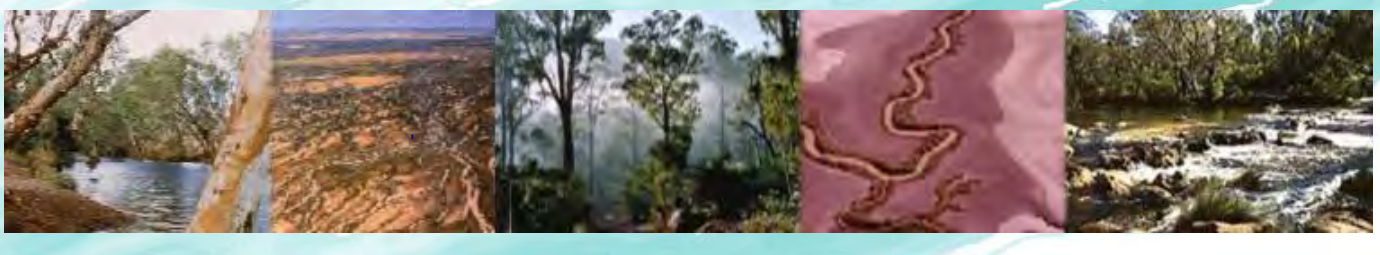
4. Conclusion

Rio Tinto follows best practice methodology in managing blast vibration risks to people, cultural heritage, threatened species and other environmental concerns. AS2187.2–2006 provides guidance on vibration control and management, and this represents the baseline (minimum requirement) for vibration management in Rio Tinto's Pilbara operations. Advanced vibration analysis techniques are used where required.

Rio Tinto has developed strong internal vibration control capability and knowledge across the mining teams. The examples provided in this report are a selection of projects across Rio Tinto's Pilbara iron ore mines where blast vibration control allows safe, effective and sustainable mining.

4.1 References

AS2187.2–2006 Explosives – Storage and use; Part 2: Use of explosives; Standards Australia, 2006.



A member of the Rio Tinto Group

River Pool Ecosystem Study
April 2017

Report ST5/2017

Streamtec Pty Ltd

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COVER PHOTOGRAPHS

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1. SUMMARY

An annual biophysical/ ecological survey of the Robe River (the Pilbara region of north-western Australia) was conducted in April 2017, as on-going commitment to assess environmental impacts of mine development at Mesa J on the adjacent and downstream aquatic ecosystem of the river (largely the permanent, 'refugial' pools). The aquatic monitoring program was undertaken by *Streamtec Pty Ltd* and commissioned by Rio Tinto (RTIO). This assessment has been conducted annually since 1991 (*i.e.* before mining at Mesa J). This sampling addresses specific commitments made under the (then) Western Australian Minister for the Environment (see Conditions, 7.2.3, 7.2.4, 7.2.5 and 7.2.7) and later under *Ministerial Statement MS208* (see Conditions 3, 4 and 5).

The long-term biophysical/ ecological surveys of the Robe River are an integrated , long-term assessment of environmental parameters including aquatic fauna (*i.e.* aquatic macroinvertebrates and fish), channel/pool morphology, riparian/bank condition, weeds, water flows and water quality.

The significant value of this program is in its long-term commitment to assess impacts, if any, of mining and evaluate these in the context of extreme natural events which typically have a long-term return frequency (*e.g.* prolonged dry-spells, tropical cyclones). The study is an upstream-downstream design, where upstream sites (those from Mesa J) serve as controls for 'impact' sites occurring in the pools downstream from Mesa J. This study has been nominated as a Global Long Term Ecological Research (LTER) site[1] where sampling design/methodology have been consistent over the near-thirty year duration of the program.

The current survey conducted April 2017 is consistent with the framework outlined by previous findings that changes in ecological conditions of the pools, are primarily the result of seasonal and annual variation in rainfall and subsequent river flows with extreme natural events (and dry spells) providing the overarching ecological 'framing' context. The April 2017 sampling was conducted following the 'wet season'. In this survey, although water levels were elevated and 13 pools were located. Additional pools were located with assistance of two local Indigenous Elders accompanying the sampling trip.

In April 2017, the pools sampled were: Martangkuna ('Permanent Pool'), Pulari Nyunangka ('Duck Pool'), Japanese Pool, Medawandy Waters, Pannawonica Hill Pool, Thintuoona[2], 'Cams Pool', Pirathalu, Gungaree[2], Ngalooin ('Mussel Pool'), Yarramudda, Gnieraoora ('Yeera Bluff') and Robe Pool[2]. Although pool water levels were low, there were measurable flows at Pannawonica Hill, Pulari Nyunangka, Yarramudda, Gungaree, Martangkuna, Cams Pool and Medawandy Waters. However, the rate of these flows was low generally at between 0.25m^3/s and 1m^3/s.

Fixed station underwater cameras were trialed for the fish surveys and found to be largely unsuitable due to the inherent high turbidity of the water. Acoustic cameras will be further tested as a technique suitable for highly turbid water (note, these camera can record at night). Additional techniques to be trialed include assessing the value of environmental DNA (e-DNA) and the required genetic 'fingerprinting' of fish. If this technique proves suitable, it will only require a pool-water sample to determine the fish present.

Detailed statistical (*e.g.* aquatic fauna) and qualitative analyses (*e.g.* of riparian condition) of April 2017 data showed there have been no statistically significant or qualitatively detectable changes to the aquatic ecology/ environmental conditions of the Robe River pools adjacent and downstream to Mesa J that could be attributable to mining and its attendant operations alone. This annual assessment is consistent with previous analyses (1991-2017) where extreme natural events (*e.g.* tropical cyclones and extended dry spells) determine the structure of pool morphology, riparian condition and consequently the pool ecological assemblages.

1. The Long Term Ecological Research (LTER) Network was created by the US National Science Foundation in 1980.
2. Signifies a newly-sampled pool in 2017. Robe Pool was visited, but not sampled due to cultural sensitivities.

Field sampling the focal Robe River pools emphasised the prior influence of wet periods on pool biodiversity; with most of the fish observed being juvenile presumably as the pools were re-colonised following hydrological re-connection. The number of aquatic macroinvertebrate species collected during April 2016 (67 taxa= 'species') was low when compared across the long-term data record. At the individual pool level, macroinvertebrate species diversity ranged from 33 species at Pannawonica Hill Pool to 40 species at Pirathalu. A total of seven species of fish were observed (Spangled Perch, Barred Grunter, Bony Bream, Fortescue Grunter, Rainbowfish, Eel-tailed Catfish and Freshwater Mullet). The dominant species observed were Bony Bream (*Nematalosa erebi*), Rainbowfish (*Melanotaenia splendida australis*) and a highly-regional endemic, the Fortescue Grunter (*Leiopotherapon aheneus*).

The water chemistry of the pools was of high biological quality with the exceedances of ANZECC (2002) Trigger Levels limited to turbidity and a small elevation of total phosphorus (0.02mg/L *vs.* ANZECC/ARMCANZ Trigger Value 0.01mg/L) at Pirathalu. This small increase over the trigger values for nutrients is considered a consequence of unrestricted livestock access to the pool. Dissolved oxygen levels were low; a consequence of high water temperatures (29-31^{O}C). Salinity/conductivity showed a gradient of increasing concentration downstream (*e.g.* 571µs/cm at Ngalooin to 996µs/cm at Thintuoona; near the railway crossing). This gradient is considered a function of the underlying geology. Pool turbidity was highly variable ranging from 2.7NTU at Martangkuna to approaching 30NTU at Gnieraoora.

Vegetation condition of the riparian zones was good and the riparian weed Mexican Poppy which, in the past, has been common was recorded at low levels of infestation in 2017, both upstream and downstream of Mesa J. The emergent aquatic weed (Indian Fern) was observed at some sites (*e.g.* Yarramudda where it occupied a small area of ~2.5m^2). Both weeds can be spread directly by human activities. The bulrush *Typha* was common at many sites and dominated the shorelines at Yarramudda.

The re-sampling of the pools in April 2017 followed significant rainfall and river flows during December 2016/ January 2017. Consequently, the ecological condition of the pools has shown a level of recovery reflecting the ability of fauna, particularly fish, to re-colonise the previously dry reaches of the river. Therefore, any artificial barriers to migration (*e.g.* badly-placed culverts) have the potential to limit upstream fish movement; however during high flows most culverts are generally 'drowned-out' (*e.g.* the low level crossing at Mesa J) and not considered to represent a significant obstacle to migration.

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2. STUDY CONTEXT

This study addresses important Ministerial Requirements and environmental commitments related to management of mining and associated activities of RTIO largely at Mesa J.

The initial Mesa J- Environmental Management Program outlined in a Consultative Environmental Review (CER) (Robe River Iron Assoc. 1992). Section 5.1 outlined a requirement for a monitoring program of key permanent river pools adjacent to Mesa J (see Streamtec 1991) both upstream and downstream of operations at Mesa J. In this design, the upstream sites serve as controls. The parameters measured in these pools by Streamtec (1992), (turbidity, salinity/ conductivity, depth, pH, dissolved oxygen, nutrients, water temperature and aquatic fauna) formed the basis of all subsequent monitoring and environmental assessments. The sampling from 1992 (Streamtec 1991-2016) addressed the following Environmental Commitments of the CER:

7.1.1 Develop and implement environmental monitoring and management programs for the mining operation and associated activities in the course of the project implementation.

7.1.4 Minimise as far as practicable, recognising the requirements of the mining and ore transfer, direct and indirect alteration of the physical environment for the duration of the project.

7.1.7 Monitor and manage dewatering of the mining area, and discharge of excess water to adjacent watercourses.

7.1.8 Take appropriate steps to protect and manage hydrology and vegetation within the adjacent riverine environment.

7.1.9 Monitor and manage any scour or siltation in the Robe River and Jimmawurrada Creek adjacent to the project.

Following the acceptance of the CER (Robe River Iron Assoc. 1992), the conditions set by the (then) Minister for the Environment were addressed by the monitoring program (Streamtec 1991-2016) where:

7.2.3 Environmentally Significant Areas: "The Robe River- Jimmawurrada Creek environment, its vegetation, water levels and water quality, and particularly the permanent pools of the Robe River, are to be protected from unacceptable direct and indirect impacts of this project during the life of the project, recognising the requirements of mining and ore transport."

7.2.4 Drainage Management: "The Robe River- Jimmawurrada Creek system needs to be protected from pollution and unacceptable sedimentation, recognising the requirements of mining and ore transport".

7.2.5 Dewatering Management: "The permanent pools and vegetation of the Robe River- Jimmawurrada Creek system are to be protected from unacceptable environmental impacts, recognising the requirements of mining and ore transport".

7.2.7 Environmental Management Programme: "A comprehensive management programme should be prepared to integrate the various components in conditions" (e.g. 7.2.3, 7.2.4, 7.2.5).

Key Project Approvals addressed by this monitoring program are under Part IV of the Environmental Protection Act 1986: Mesa J- Ministerial Statement 208.

Rio Tinto produced an Operations Environmental Management Plan (RTIO-HSE 0162720:2012). Sections 4.1 and 4.2 relate to water abstraction and discharge. Appendix 1 of that document outlines the comprehensive monitoring program developed for the Robe River.

The Rio Tinto "*Robe Valley Mesa J&K Surface Water Management Plan*" (RTIO-PDE-0068650, see http://iodms/iodms/wdk/theme/documentum/images/space.gif) outlines a framework for effective water management. The potential environmental impacts of climate change in the Pilbara were also identified as a potential risk. The long-term Streamtec study, by providing an extensive time-series (1991-2017), is clearly well-placed to assess impacts to surface water ecosystems, from both mining, natural and larger-scale anthropogenic influences (*e.g.* climate change). In addition, by including control sites (*i.e.* upstream of Mesa J in the program), any changes to ecological baselines, in the absence of mining, can be determined and consequently better-managed.

3. INTRODUCTION

The current program outlined in this report (conducted during April 2017) was commissioned by Rio Tinto (RTIO) to assess impacts, if any, from their mining activities on Robe River pools as per relevant Western Australian Ministerial Statements (see previous). This on-ground program incorporates an annual aquatic ecosystem survey of Robe River pools as part of an on-going commitment to assess any environmental impacts of mine development on the adjacent and downstream aquatic ecosystem (see ecologia/Streamtec 1992, Streamtec 1992 –2017).

The Robe River is situated in the Pilbara bioregion of Western Australia. Rivers and streams in this region are typically episodic with flow occurring following significant rainfall events. The Pilbara has an extreme and highly variable climate changing due to both natural and more recently, through global anthropogenic influences.

In the Pilbara, rainfall has recently been steadily increasing from the northeast and evaporation rates exceed rainfall by a factor of more than 10x. Following rainfall, generally there is only limited run-off and an even smaller fraction recharges groundwater. Despite this, groundwater recharge is required to maintain pool water levels during extensive dry periods. In the Pilbara, it is estimated that about 200GL of (high quality) de-watering is discharged into rivers each year (McFarlane 2015).

During the dry season, rivers are usually restricted to a series of permanent pools; providing an important refuge for both terrestrial and aquatic fauna. The faunal assemblages essentially 'contract' to these pools during dry periods, to re-invade other regions of the riverine system following significant river flow.

Research on the freshwater fauna of Australia's dryland river systems has been largely ad hoc. These systems are typically less disturbed than their counterparts in more populous regions, yet despite recognition of the importance of water-bodies in the Pilbara; there has been only short-term, generally limited scope ecological research.

The current sampling regime was initiated in 1991 offering an important set of data on an arid system within the Pilbara region. The annual assessment is important in providing knowledge of temporal and spatial variability in biological parameters. In addition to providing a better understanding of impacts, if any, associated with mining operations, long-term ecological monitoring improves our understanding of the natural variability (e.g. extended dry spells, tropical cyclones) within the Robe River catchment. This long-term assessment of the aquatic environment of the Robe River has shown natural events have an overriding influence.

To date there have been no detectable changes to aquatic fauna, water levels, water quality and riparian vegetation that could be attributed to direct mining operations at Mesa J. In addition, there have been no detectable impacts to the Robe River/Jimmawurrada Creek system from pollution, unacceptable sedimentation and unacceptable environmental impacts that could be attributed to direct mining operations at Mesa J.

Differences in ecological parameters of pools, is primarily influenced by seasonal climatic influences, with a major determinant factor of variability in both aquatic fauna biodiversity and water quality being pool morphology and permanence (*e.g.* Streamtec 1992-2015). This existing baseline data, combined with continued monitoring of the Robe River, will allow informed solutions to be made on current and future environmental issues and catchment-scale activities.

PROJECT OBJECTIVES

- The completion of an aquatic biomonitoring program (*e.g.* macroinvertebrates, fish, water quality, flows, pool morphology and riparian condition) of significant pools located on the Robe River. Sample sites included thirteen permanent pools (see Appendix 1).

- In order to gain a better understanding of broad-scale ecosystem resilience of the pools, a survey of the Robe River was conducted to identify additional permanent pools (both upstream and downstream from Mesa J).

- Document and interpret the ecological significance of patterns or differences in pools both upstream and downstream of Mesa J.

- Compare biological data collected in 2017 with the previous record and assess any observed changes to natural events in or mining activities.

4. METHODS

Since the commencement of this sampling program (1991), sampling design and methodology have been standardised (with the same operators) and consistent among surveys. This enables valid comparisons to be made across the long-term monitoring period. Consequently the strength of this sampling program is its long- term nature. A summary and general description of the standard sampling protocol is given below. Detailed information on sampling in Appendix 2 and outlined in previous reports (see Streamtec 1991- 2015).

4.1 SAMPLING PERIOD

The present survey taken in April 2017 represents an "early wet" sampling; a period of reduced environmental 'stress' for resident aquatic biota. During this period, aquatic fauna is restricted to refugial pools after flows in December 2016. Previous monitoring has also been conducted following the 'dry season and other high rainfall events, providing a database across a wide range of flow and weather conditions.

4.2 STUDY AREA

The Robe River lies in the Pilbara biogeographic region of Western Australia. For the majority of its course, the Robe River is ephemeral in flow with wide, shallow floodplains. Localised flows and pools are maintained where highly permeable underground aquifers intersect surface river channels; forming isolated ecological 'refugia' (see Figure 1).

The climate of this region is typified by high temperatures, low rainfall (~ 400mm p/a), evaporation rates about 10x rainfall and largely unpredictable cyclonic activity. Rainfall occurs largely between December and June with maximum monthly falls typically recorded between December and April. Mining is near to the rivers course, at the Mesa J deposit, in the Eastern Deepdale region to the south-west of Pannawonica.

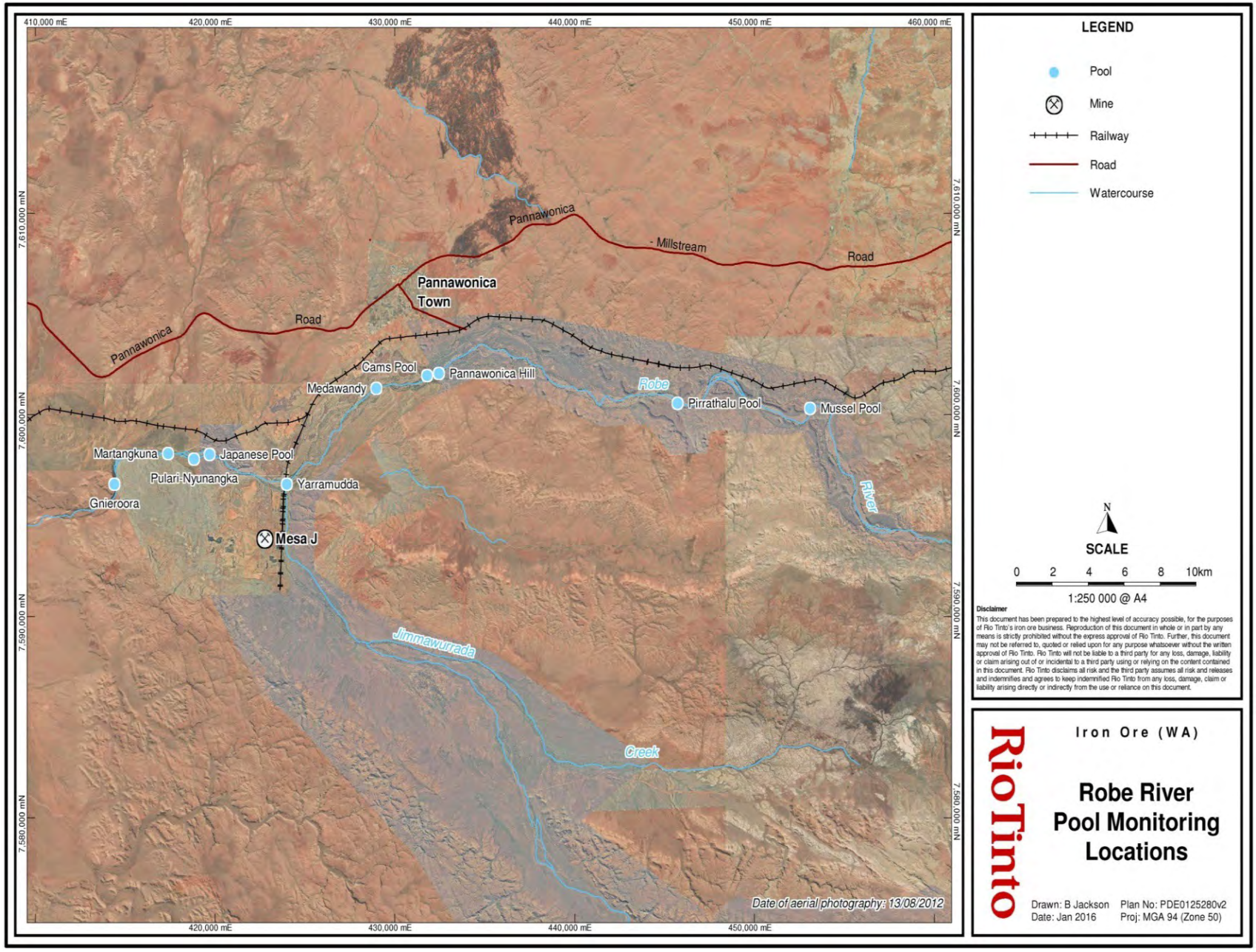


Figure 1. Position of the survey pools in the Robe River (note alternative spellings for Yeera Bluff Pool; Gnieraoora and Gnieroora). Note, Robe Pool, Thintuoona and Gungaree are off the scale of this map being further downstream (west) of these sites (see Appendix 1 for site details and coordinates).

4.3 STUDY SITES

The location of current study sites and their position relative to the Mesa J mine are shown in Figure 1. A total of thirteen focal pools were surveyed in 2017; Martangkuna ('Permanent Pool'), Pulari Nyunangka ('Duck Pool'), Japanese Pool, Medawandy Waters, Pannawonica Hill Pool, Thintuoona*, 'Cams Pool', Pirathalu, Gungaree*, Ngalooin ('Mussel Pool'), Yarramudda, Gnieraoora ('Yeera Bluff'), Robe Pool*. Although pool water levels were low, there were measurable flows at Pannawonica Hill, Pulari Nyunangka, Yarramudda, Gungaree, Martangkuna, Cams Pool and Medawandy Waters. (See Appendix 1, * represents a previously un-sampled pool).

The program's design is based on a BACI model (Before and After Control Impact) where sites upstream of Mesa J serve as control sites for downstream (potential impact) pools. The "before" sampling is represented by baseline surveys conducted in 1991, prior to significant mining operations at Mesa J.

Neither 'before' nor 'control' sites however, should be considered completely representative of pre-mine conditions as mining was initially conducted at Middle Robe between 1972 and 1982 and from Deepdale between 1972-1985.

4.4 HYDROLOGY - RAINFALL AND RIVER DISCHARGE

Patterns in rainfall river discharge were analysed to determine the relationship between hydrological indices and associated changes to pool morphology and permanence. Long-term rainfall data for Pannawonica (Station 5069) was provided by Climate Services, Bureau of Meteorology (Perth). Rainfall and temperature records for the Pannawonica were provided by RTIO.

4.5 PHYSICO-CHEMISTRY - MORPHOLOGY AND WATER QUALITY

Measurements of pool morphology and selected water quality parameters were made in conjunction with the aquatic fauna sampling at each focal pool. Water temperature, dissolved oxygen, salinity/ conductivity, turbidity, redox and pH were measured in situ (0.5 depth) using a YEO-KAL (YK-611) water quality analyser. Water samples were also taken for analysis of nutrients as both total nitrogen (TN) and total phosphorus (TP).

River pool morphology was determined with depth measurements (graduated pole) and pool width and length were qualitative measurements. Levels of fine inorganic sediment and areas of deeper water in each pool were qualitatively assessed and coded by rank (0-4), this was conducted during the fish surveys. The sediment category was assessed as the extent of deposited sediment cover over the natural shale-base of pools on an ordinal rank of 0-4; where 0=no sediment evident, 1=25% coverage, 2=50% coverage, 3=75% and 4=total streambed coverage.

4.6 MACROINVERTEBRATE FAUNA

The pool macroinvertebrate fauna was sampled at all sites (aside from Robe Pool where, due to cultural sensitivities, all sampling was conducted from the bank). Methodologies for collecting fauna were designed to sample the major aquatic habitats and maximise the number of species recorded at each site (see Appendix 2 for details). Quantitative sampling was conducted using a heel-kick (*sensu* Davies 1998) or sweep method (depending on habitat), compatible with the methodology of NRHP (National River Health Program) sampling protocols. Samples, containing sediment, detritus and aquatic macroinvertebrate fauna, were preserved on site.

In the laboratory, macroinvertebrates were removed from the samples under a binocular microscope and identified to the lowest taxon possible either by use of keys or by matching specimens to an existing voucher collection developed exclusively for the Robe River. The existence of rare, restricted or endemic species was determined by cross-referencing taxa lists for each site/habitat with a long-established database. Conclusions on the rarity of any macroinvertebrate species cannot be made with complete surety due to the inherent taxonomic uncertainties associated with this region.

4.7 FISH FAUNA

Fish were recorded by direct observation using a mask and snorkel (a two-assessment transect across 100m reach). A list of presence/absence for each species was constructed for each of the pools. Details of field methods are detailed in Appendix 2. Fish were identified to species based on taxonomy described in Allen (1989) and later in Allen *et al.* (2002). During the previous sampling trip, GoPro underwater cameras were trialed to 'de-risk' the sampling methodology. However, due to naturally high turbidity, the cameras were of limited value and in April 2017, the sampling reverted to direct observation. In the future, acoustic cameras will be trialed; these can operate in highly turbid water (including able to be operated at night).

4.8 RIPARIAN VEGETATION AND WEEDS

An assessment of local riparian vegetation condition was made on the basis of dominant plant species and relative degree of disturbance assessed as weed invasion, livestock damage and fire. Assessments were broadly based on the rapid assessment methodology outlined in Pen and Scott (1995) and WRC (1999). At each site, two 50m transects from the waters' edge upslope were made and the following parameters recorded: slope (in degrees), % leaf litter covering the soil, weeds (in area), livestock disturbance (low, medium, high), and over-story condition: 1= dead, 2= much leaf loss, many dead branches, 3= some dead branches, 4= pristine). Methods are presented in Appendix 2. Opportunistic, qualitative surveys were also made of the noxious aquatic weed Indian Water Fern, *Ceratopteris thalictroides* and the riparian weed Mexican Poppy.

4.9 STATISTICAL ANALYSES

Statistical analyses using ANOVA (analysis of variance) were used to compare spatial and temporal variations in water quality data. PRIMER (Plymouth Routines in Multivariate Ecological Research) computer package was used to describe multivariate (spatial and temporal) patterns in macroinvertebrate community structure and relate these patterns to changes in measured environmental parameters (*e.g.* water chemistry, pool morphology, riparian condition). Analyses were conducted on both species-level presence/ absence and macroinvertebrate abundance data. The relationship between community structure and the pools was analysed using a sub-set of the physico-chemical parameters measured. In summary, similarity matrices (between pools) were calculated based on macroinvertebrate assemblages. These similarity values were then represented graphically using hierarchical clustering (CLUSTER) and multidimensional scaling (MDS) to determine how similar pools were to each other in terms of aquatic fauna. Principal Components Analysis (PCA) was also used to summarise underlying patterns in environmental data.

5. RESULTS AND DISCUSSION

The sampling was conducted in the immediate post-wet period (April 2017). Previous sampling has typically been conducted during the late dry; a period of elevated environmental 'stress' to the resident aquatic fauna of the permanent pools.

5.1 HYDROLOGY - RAINFALL AND RIVER DISCHARGE

The Pilbara biogeographical region of Western Australia is characterised by low and unreliable annual rainfall and, when coupled with high annual evapo-transpiration rates (*e.g.* >10x annual rainfall), results in spatially-restricted aquatic ecosystems (pools). Rainfall is highly unpredictable with significant variation in annual rainfall. The coefficient of variation (CV) for rainfall for the Pilbara ranges 0.4 to 0.7 ('high') in comparison for south-west Western Australia CV is 0.2 ('low') and the Kimberley CV is 0.3 (see Figure 2).

Pannawonica receives the majority of its rainfall over summer in association with cyclonic events. Peaks in rainfall typically occur during January-March with months of lowest rainfall occurring in September and October (Figure 2). Natural flows in the Robe River, both upstream and downstream of Mesa J are tightly linked to annual rainfall patterns. Following trends in rainfall data, maximum flows are typically recorded following peak rainfall (Figure 2). Pool water levels during the dry period are maintained by groundwater (*i.e.* they are groundwater-dependent-ecosystems).

The Pilbara region has >3m evaporation per annum and as most permanent pools are considerably less than this depth, they are maintained by groundwater. Annual rainfall recharges levels and flows are linked to rainfall events. For analysis, these two seasons are referred to as "wet" and "dry". Long term analysis also identified two transitional seasons, the "ramp down" period where rainfall and hence flow declines following the wet and the "the ramp up period" when increasing rainfall and flow following the dry season (Figure 2).

5.2 CLIMATE

The climatic condition in the (approx.) 12 months period prior to the sampling is shown in Figures 3-4. The pattern of temperature and rainfall are considered typical for the region (10-45^{O}C). As previously discussed, heavy rainfall events and peak discharges are generally associated with tropical cyclones or monsoons. In the past, the highest category cyclones that have impacted the Pilbara coastline are listed by the Bureau of Meteorology and include TC Orson in April 1989, TC John in December 1999, TC Monty in March 2004, TC Clare in Jan 2006, and TC Glenda in March 2006.

These cyclones resulted in peak discharges and a number of significant flow events have been recorded in years following above average rainfall in consecutive months (*i.e.* January 1997). The large Robe River floods of September 1993 and January 2000 were also associated with monsoon lows. Flooding is often enhanced if flows follow rainfall that has already saturated the profile leading to elevated water levels.

These data suggest that significant flow events in the Robe River pools are either 'pulse' events that occur through peaks in monthly rainfall or when the extensive duration of rainfall is sufficient to maintain high water levels in the river.

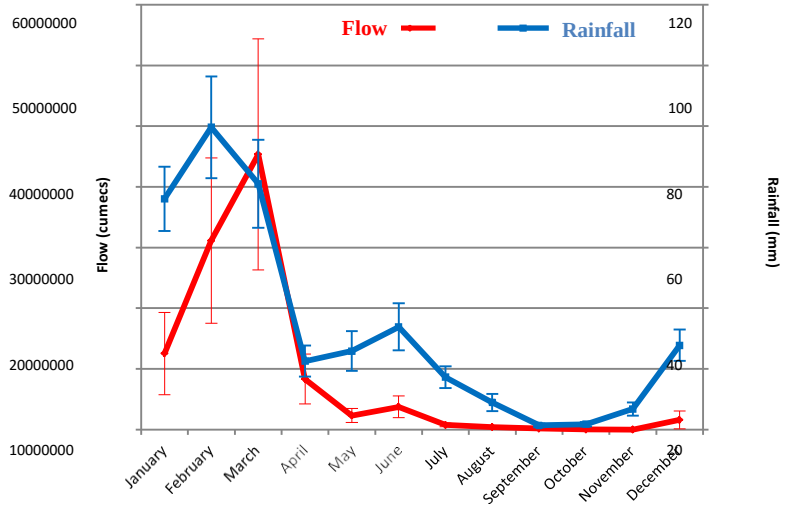


Figure 2. Average monthly flow and rainfall (± SE).
Rainfall measured at Pannawonica and flows at Yarraloola.

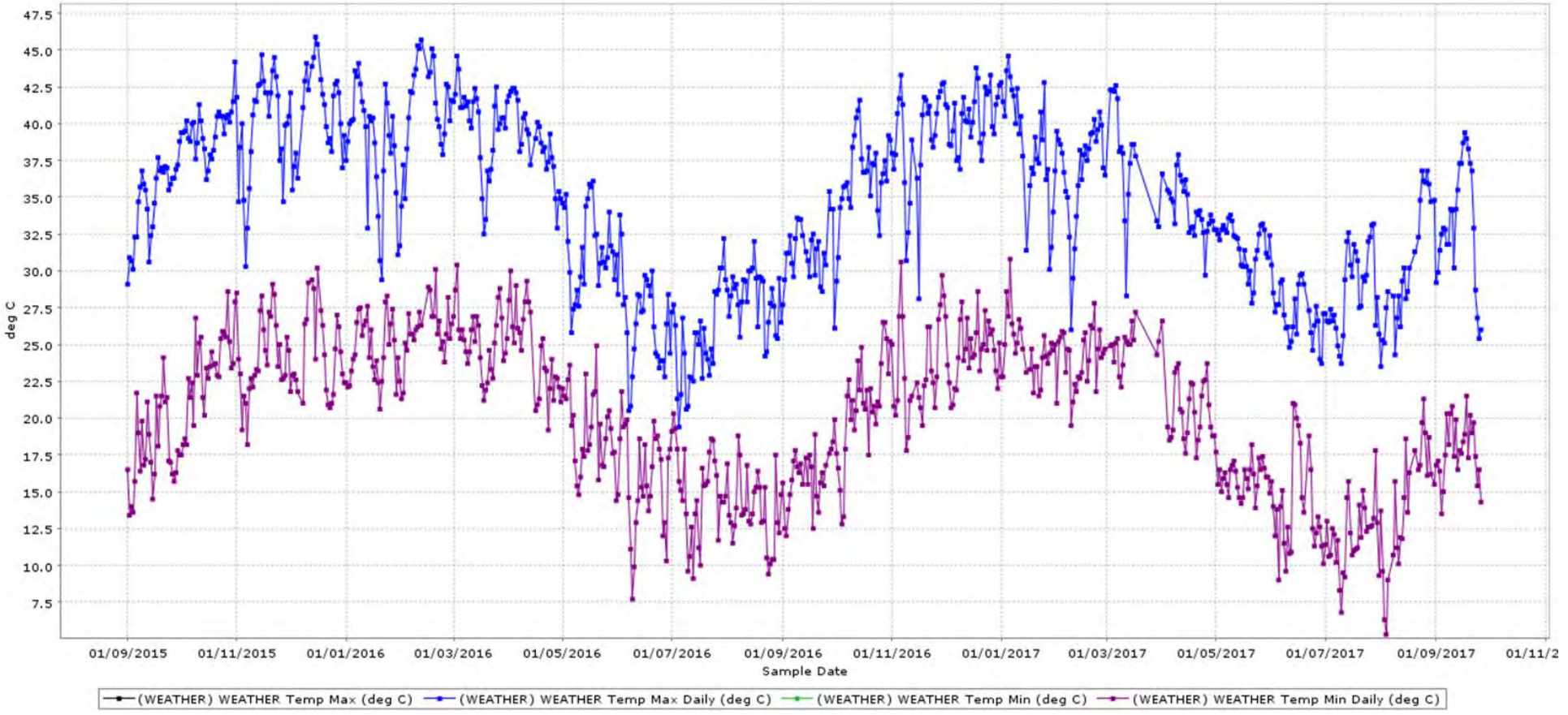


Figure 3. Maximum and minimum daily temperatures (°C) at Pannawonica townsite September 2015 to September 2017.

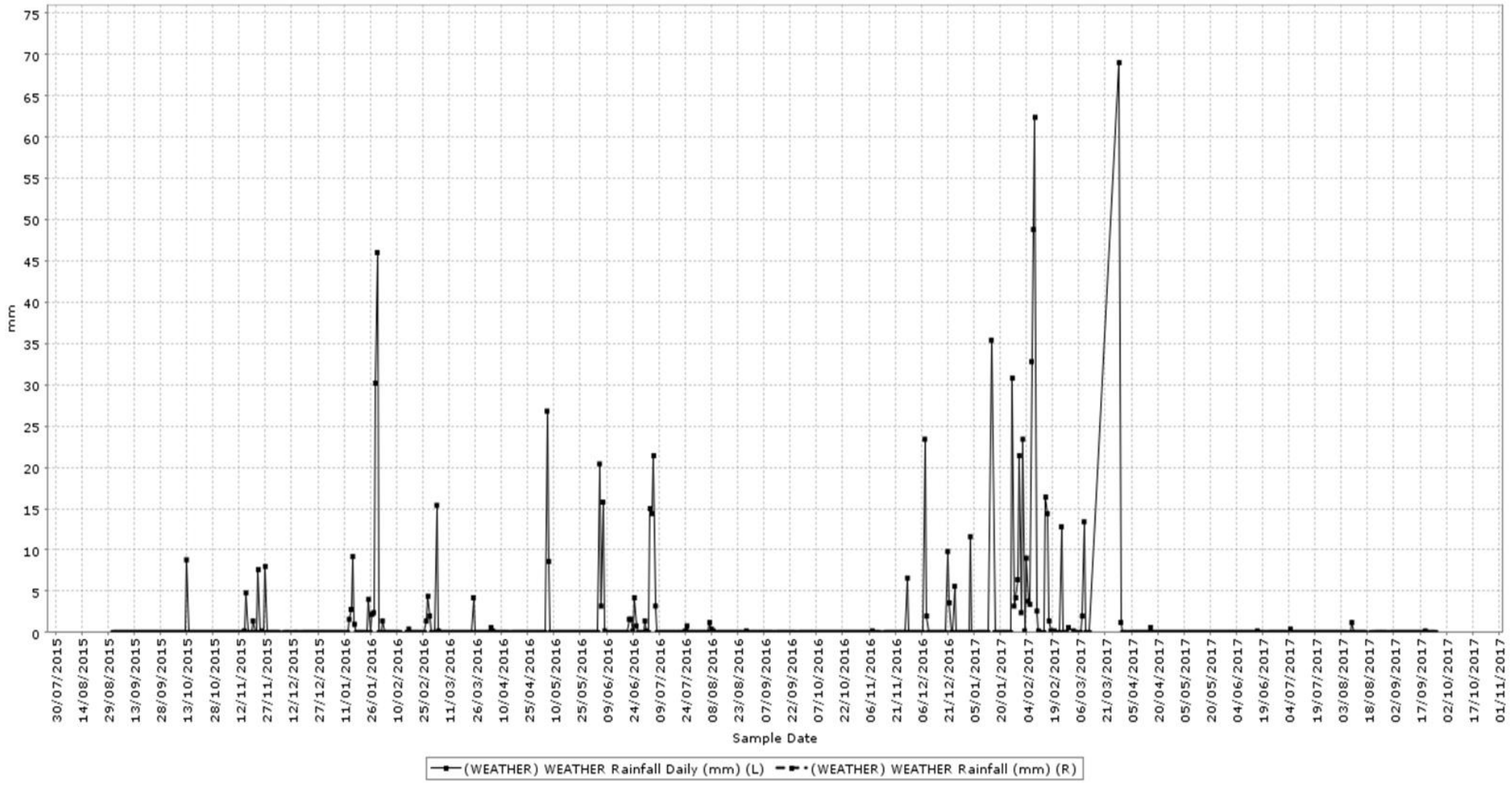


Figure 4. Daily rainfall (in mm) at Pannawonica townsite July 2015 to April 2017.

5.3 SUMMARY OF FLOW CONDITIONS

Since the establishment of the initial biomonitoring in 1991, considerable variance in rainfall and associated flow conditions have been observed within the Robe River. The timing of Robe River aquatic sampling in April 2017 followed significant rainfall in December 2016 and follow-up in 23rd March 2017 (~68mm; see Figure 4). The pool levels were high and presumably pools had been connected following the previous high- rainfall conditions.

Initial surveys in 1991 were conducted following a series of low-flow years. In September 1993, rainfall resulted in a flow event which at the time was the highest peak discharge on record. In subsequent years, relatively high water levels were maintained in pools by a number of high rainfall events. Then, from January 2001, three consecutive years' of lower than average rainfall (January 2001 to May 2003) resulted in significantly lower total annual streamflow being recorded at Yarraloola. In contrast, during March 2004, rainfall contributed from TC Monty to an above- average rainfall for the wet season (September and March). The delivery of this rain was constant over consecutive days and although significant flow was recorded at Yarraloola, there was no extensive flooding associated with this cyclone. At this time, the Yarraloola gauging station recorded the highest monthly discharge since 1972 (596611 ML), and total annual flows for 2004 were the highest on record. High flows were also observed during the sampling in 2014.

Significant rainfall events from tropical cyclones (*e.g.* Glenda and Clare) during 'summer' 2006 resulted in significant total monthly flows being recorded. Three consecutive months of higher than average rainfall resulted in high levels of discharge being maintained during January to March 2006. Following the October 2006, monthly rainfall was below average an in 2007 zero-flow was again recorded at Yarraloola. On the west coast of Western Australia a TC occurred each month from November 2007 to April 2008, resulting in higher than average rainfall recorded. The April 2017 sampling followed significant rainfall in the preceding months (*e.g.* 24mm 6th December 2016, 36mm in 20th January 2017, 63mm in February 2017 and 68mm in March 2017. Long term annual rainfall for Pannawonica is 427mm (Figure 5). There has been a trend, across the >40 year rainfall record, for increasing annual rainfall. This is consistent with some of the predictions for climate change in the Pilbara and Kimberley regions of Western Australia.

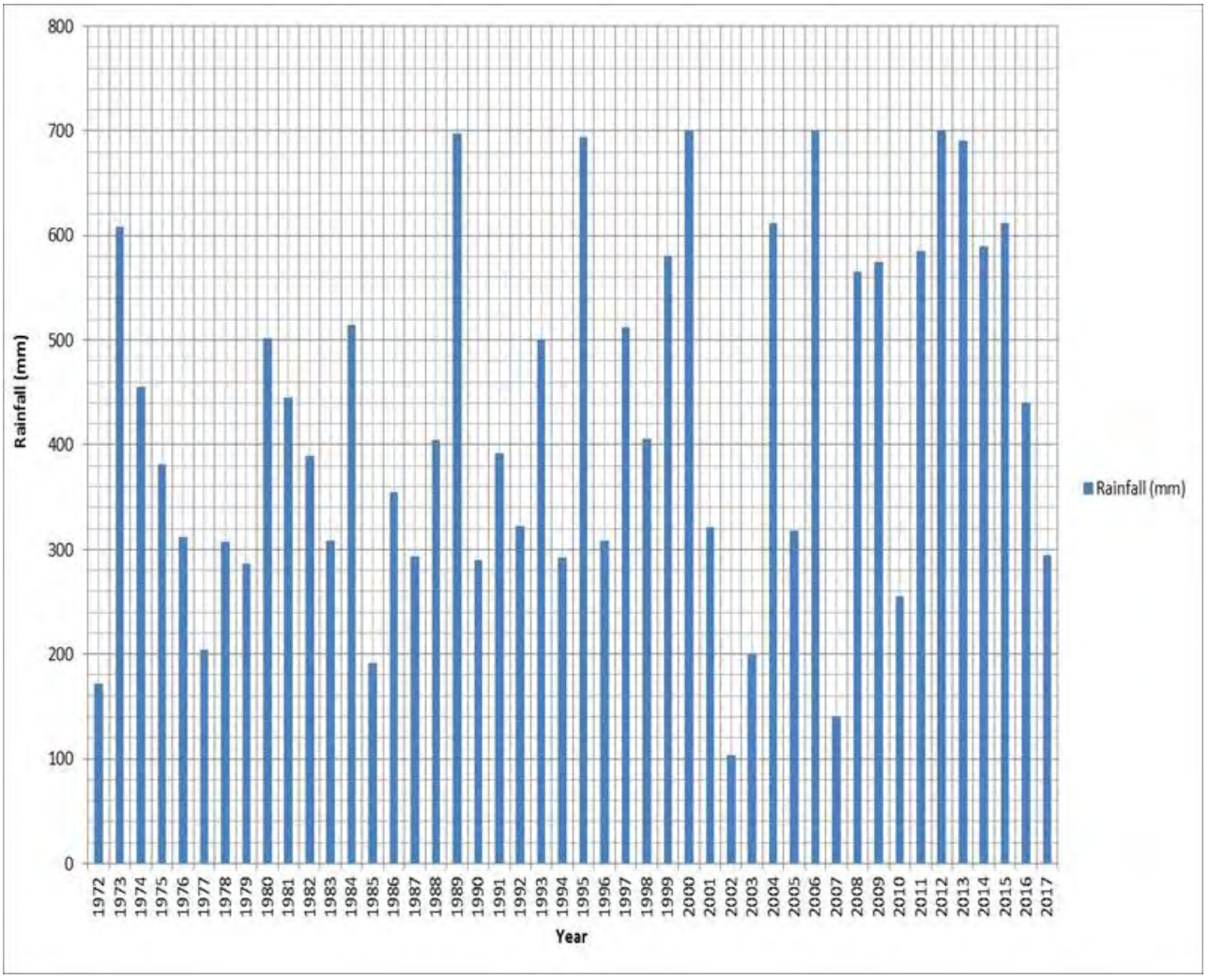


Figure 5. Total annual rainfall for Pannawonica (Station 5069). Note, the 2017 rainfall data are up to the sampling period (April). The long-term annual average is 427mm.

Total annual rainfall was above average for the three years prior to the 2017 sampling (see Figure 5). Monthly records revealed that the majority of rainfall occurred in the month of December-April (Figure 4). Peak rainfall coincided with a weak low that approached the far west Pilbara coast which then combined with a mid- latitude upper trough. Previously this low has resulted in heavy rainfall and substantial flooding in both the Robe and adjacent Fortescue rivers (BOM, 2008).

5.4 PHYSICO-CHEMISTRY

The physico-chemistry of the river system is largely dependent on local geology and riparian conditions. Large flow events can lead to increased turbidity which is transported downstream.

Pool water quality in the Robe River pools was fresh, slightly alkaline, with moderate levels of turbidity. Generally, the water chemistry of the pools was of high biological quality with the exceedances of ANZECC (2002) Trigger Levels limited to turbidity and a small elevation of total phosphorus (0.02mg/L *vs.* ANZECC/ARMCANZ Trigger Value of 0.01 mg/L) at Pirathalu. This small increase over the trigger values for nutrients is considered a consequence of unrestricted livestock access to pools. Dissolved oxygen (DO) levels were low; a consequence of high water temperatures (29-31^{O}C). Salinity/conductivity showed a slight gradient of increasing concentration downstream (*e.g.* 571µs/cm at Ngalooin to 996µs/cm at Thintuoona). This gradient is considered a function of the underlying geology rather than any anthropogenic influences; although dewatering may connect pools (see Table 1). Pool turbidity was highly variable ranging from 2.7NTU at Martangkuna to almost 30NTU at Gnieraoora (Yeera Bluff). Low levels were recorded at Pannawonica Hill Pool (Figure 6).

Long-term monitoring has revealed that water chemistry of pools show predictable levels largely associated with the sampling season (Dobbs and Davies, 2009). To date, there have been no statistically significant changes in the water quality of the Robe River that could be directly attributable to mining operations. Rainfall and river flows have been identified as having the greatest influence on pool morphology and water chemistry (Streamtec 2001-2016). A summary of the April 2017 physico-chemical parameters measured in conjunction with the aquatic survey is presented in Table 2.

5.5 MINE DEWATERING

A series of pools in Jimmawurrada Creek and in the Robe River downstream from discharge points were previously sampled for pH, DO, temperature, salinity/ conductivity, turbidity, total nitrogen and total phosphorus. Previously, the values showed considerable similarities with water in the Robe River; due to the permeability of the Robe pisolite and water being essentially 'recycled' from the mine to and from the river. The de-watering volumes into Jimmawurrada were low at point B (200kL) in March and ranged from 66-191ML in June 2017 (Table 1, Figure 7).

Table 1. Monthly discharge into Jimmawurrada Creek (points 5, 6) and the Robe River (point B) (volumes in kL).

Discharge Point	Monthly Discharge Volume (kL)							
	Jan-17	**Feb-17**	**Mar-17**	**Apr-17**	**May-17**	**Jun-17**	**Jul-17**	**Aug-17**
5	9522	285984	140248	51665	822	249	37100	0
6	5226	26045	42310	28955	17568	22555	30674	17627
B	66082	129691	192617	119042	34882	191358	14399	1490

5.6 POOL MORPHOLOGY AND SEDIMENTATION

Turbidity and sedimentation levels are generally a function of the interaction of river hydrology and underlying geomorphology. Water levels in the permanent pools have showed a trend upstream and downstream of Mesa J*; i.e.* dropping slightly over the winter dry season and rising again following summer rainfall events. At some sites turbidity exceeded ANZECC guidelines (mean values ~20NTU). These high values were measured both upstream and downstream from Mesa J (Table 1) and were considered a consequence of local pool geology.

Table 2. Physico-chemical parameters measured in conjunction with aquatic fauna surveys of the Robe River, April 2017. Shading indicates exceedance of ANZECC/ARMCANZ guidelines (2000). Blue-shaded; new pool sampled only in 2017.

* Areas of deeper water in each pool were coded by rank where: 1 = no areas > 2.5 m in depth, 2 = some areas > 2.5 m in depth, 3 = many areas > 2.5 m in depth, 4 = substantial areas > 2.5 m in depth. Cont=continuous.

Site Codes; Mart. = Martangkuna; Gnier. = Gnieraoora; Yarra. = Yarramudda; Jap. = Japanese Pool; Meda. = Medawandy Waters; Panna. = Pannawonica Hill Pool; Ngal. = Ngalooin Pool (Mussel Pool).

				Downstream						Adjacent	Upstream				
	Parameters	**Units**	**ANZECC Trigger Levels**	Thintuoona	Gungaree	Gnier.	Mart.	Pulari.	Jap.	Yarr.	Meda.	Panna.	Cams Pool	Pirathalu	Ngal.
Water Quality	Dissolved Oxygen (DO)	%		16.7	2.01	20.2	55.4	38.8	75.3	80.4	56.2	96.4	24.5	109.0	71.7
	Conductivity (EC)	υs/cm	>2500	996	822	883	805	718	764	743	782	671	692	682	571
	Salinity	ppt		0.41	0.42	0.42	0.41	0.39	0.41	0.30	0.32	0.32	0.32	0.30	0.32
	pH	pH units	6-8	6.8	7.7	7.8	8.0	7.3	7.6	6.7	7.7	7.2	7.1	8.76	7.1
	Temperature	Celsius	-	29.3	28.4	29.9	28.7	27.3	29.7	30.5	29.8	29.2	30.5	25.0	29.4
	Turbidity	NTU	<2-15	12.7	4.8	4.8	4.09	2.7	6.7	30.4	7.9	9.2	20.2	14.3	6.8
	Total Nitrogen	mg/L	0.2-0.3	0.10	0.16	0.26	0.12	0.10	0.16	0.11	0.15	0.30	0.25	0.25	0.10
	Total Phosphorous	mg/L	0.01	<0,01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	0.02	0.01
Pool Morphology	Length of main Pool	m		>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000
	Average Width	m		50	20	32	40	50	120	180	120	40	55	30	35
	Average Depth	m		2.5	0.3	1.8	0.25	0.3	0.4	2.5	2.2	1.5	2.5	1.1	2.6
	Flow	m^3/sec		0	0.28	0	0	1	0	0.5	0.5	0	0	0	0
	Area Code	1-4		2	2	4	1	2	2	4	3	3	4	3	4
	Sediment Code	1-4		2	2	1	2	1	2	3	2	3	4	3	4
Fauna	Macroinvertebrates	# taxa		37	29	39	36	34	34	37	35	33	36	40	38
	Fish	# species		5	4	6	6	6	6	7	7	6	6	6	6
	Livestock adjacent	#'s		0	0	0	0	0	0	0	0	0	0	0	0
Flora	Riparian condition	1-4		4	4	4	4	4	4	4	4	4	4	4	4
	Indian Fern	m^3		0	0	0	0	0	0	5	0	0	0	0	0
	Mexican Poppy	m^3		0	0	0	0	0	0	0	1	1	0	0	1
Catchment	Slope	%		4	4	4	4	3	4	4	4	3	4	4	4
	Riparian Width	m		cont	cont	cont	cont	cont	cont	cont	cont	cont	cont	cont	cont
	Leave Cover	%		50	40	40	25	40	35	25	20	15	20	25	45
	Vehicle Disturbance	1-4		0	0	2	1	1	2	0	1	3	3		1

Figure 6. Pannawonica Hill Pool during April 2017.

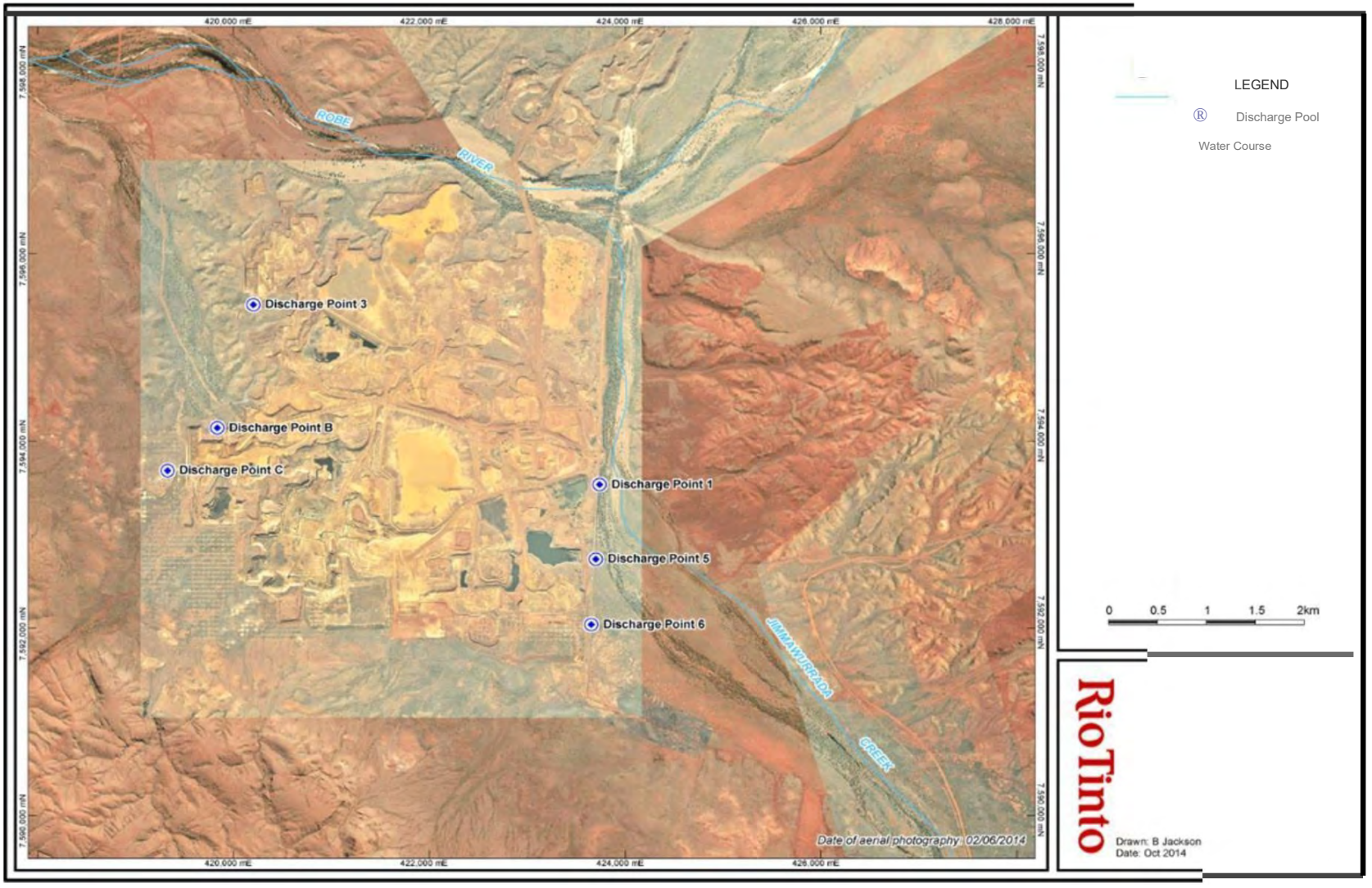


Figure 7. Dewatering points on Jimmawurrada Creek (discharge points 1, 5, and 6) and the Robe River (discharge points 3, B and C), adjacent to Mesa J.

Figure 8. Pirathalu upstream of Mesa J on the Robe River (left). Medawandy Waters (right).

5.7 WATER TURBIDITY

Natural turbidity and sedimentation are dependent on the hydrology, geomorphology and the suspended load from upstream. Turbidity levels in the Robe River have fluctuated both annually and seasonally, with elevated turbidity (70NTU; see Dobbs and Davies 2009) typically recorded immediately following flood events. Previous surveys of Robe pools have shown consistently low levels of turbidity in the dry season. Several pools, notably Yarramudda, have consistently shown elevated levels of turbidity.

5.8 SALINITY

In 2017, salinity levels within all pools were categorised as fresh[3]. The low salinity of water in the north-west of Western Australia has been attributed to long-term geochemical processes and geological history (Williams & Buckney 1976). A salinity gradient was evident in April 2017 and considered a consequence of local geomorphology. This gradient was evident prior to commencement of mining at Mesa J and not considered the direct result of mining activities.

5.9 DISSOLVED OXYGEN

Dissolved oxygen (DO) in survey pools showed significant spatial and temporal variation (Dobbs and Davies 2009). Previous spot measurements of DO, coupled with information from data- loggers have revealed concentrations ranging from overnight lows close to zero to supersaturated levels after midday. Dissolved oxygen levels of 70 – 120% (*i.e.* typically >2 mg/L) are generally considered suitable for resident aquatic fauna.

DO levels less than 2.0mg/L are considered the critical threshold at which respiration becomes difficult for many fish (ANZECC/ARMCANZ 2000). Daytime dissolved oxygen (DO) levels well-above threshold values both upstream and downstream of the mine (see Table 1). The DO of the pools reflects time of day with low levels in the morning (following night-time respiration of both plants and animals) to rise during the day due to photosynthesis by both macrophytes and algae.

[3] Fresh defined as <2,700 µS/cm; brackish/moderately saline 2,700 – 9,000 µS/cm; saline 9,000 – 55,000 µS/cm. Dept. of Agriculture, Government of Western Australia, 2002.

5.10 WATER TEMPERATURE

Long-term monitoring has highlighted the correlation between pool temperatures and ambient air temperatures both upstream and downstream from Mesa J (Figure 3). Temperature levels in 2017 were consistent with the long term averages for the month of April and generally varied between 29 and 32^{0}C.

5.11 NUTRIENTS

In long-term monitoring of the Robe River (Dobbs and Davies 2009), nutrient levels have sometimes exceeded Trigger Value guidelines. Previous high levels (see Streamtec 2001, 2015) of nitrogen and phosphorous have thought to be influenced by livestock access to the pools.

It should be noted that ANZECC guideline limits were developed primarily for water bodies other than those in the arid and semi-arid tropics of the Pilbara. The acceptable or 'normal' nutrient concentrations common to water bodies of this region remains poorly-understood and long-term monitoring of the Robe River suggest that guidelines are not directly transferable.

5.12 MACROINVERTEBRATE FAUNA

A total of 67 macroinvertebrate taxa[4] ('species') were collected and identified from the study sites in April 2017. Biodiversity of individual sites is shown in Table 2. The macroinvertebrate biodiversity recorded in 2017 approximated the 'average' when compared to the longer-term dataset (Dobbs and Davies 2009).

In 2017, the macroinvertebrate fauna was characterised by several regional endemic with no species considered rare or locally restricted. As with previous sampling, macroinvertebrate assemblages were dominated by larval stages of non-biting and biting midges (chironomids and ceratopogonids), freshwater prawns (Caridines), polychaetes (oligochaetes) and snails (gastropods). In the long-term data set 'low- occurrence' taxa (*i.e.* taxa recorded at <20% of sites) accounted for approximately 65% of all species recorded in 2017. This was similar to macroinvertebrate distributions in 2010 and 2014. Kay *et al.* (1999) conducted the first comprehensive study of aquatic macroinvertebrate distribution patterns in northern Western Australian and also found that ~25% of species occurred at most sites, while the remainder had widespread, but with a very heterogeneous spatial distribution.

The distribution of species in pools suggests that major differences are de-coupled from mining operations. Biodiversity of individual pools in 2017 ranged from 33 species at Pannawonica Hill Pool to 40 species at Pirathalu (Table 2, Figure 8). When comparing individual species, about 21% of species were exclusive to upstream sites compared to 24% of species found only in downstream sites. There was no statistically significant difference in species richness between upstream and downstream sites (one-way ANOVA, $p>0.05$; all cases). The multi-dimensional spatial patterns in macroinvertebrate community structure were investigated using multivariate classification and ordination techniques. Interpretation of the ordination (MDS) is reasonably straightforward, with sites clustering closer together representing samples that are similar in species composition and sites further apart having more different community structures.

Multi-dimensional ordination and multivariate analysis using ANOSIM revealed that there was no statistically significant difference in community structure/ clustering between sites upstream and downstream of Mesa J (Table 2).

Analysis of the long-term dataset revealed a broad separation of pools largely based on a simple measurement of pool morphology (depth and habitat) (see Figure 9, Figure 11). Highly episodic events such cyclones are important determinants of pool structure and habitat and consequently aquatic community structure (Streamtec 1991- 2017). Initially, there was a strong predictive model between simple measurements of pool size and macroinvertebrate community structure (Streamtec 1992). This indicated a structured, deterministic relationship. Following significant cyclones and extended dry periods, this model has shown less predictive success as recolonisation of species can be opportunistic and largely unpredictable. The biodiversity of pools is highly linked to pool morphology both upstream and downstream of Mesa J.

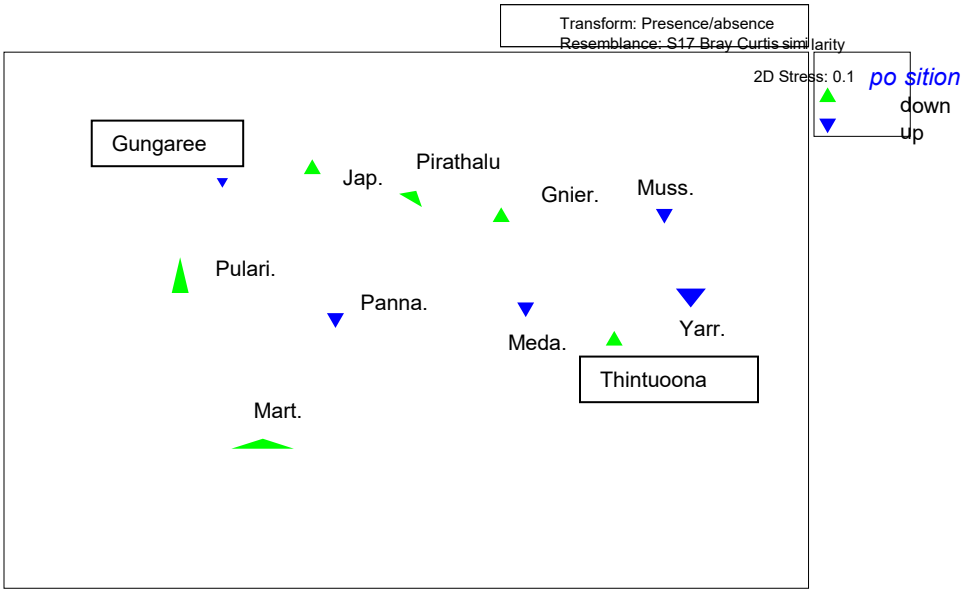


Figure 9. MDS ordination of 2017 macroinvertebrate presence/absence data set showing separation of sites (NB position of pools in relation to Mesa J has been overlaid showing no pattern in community structure based on this parameter).

5.13 TEMPORAL VARIATION

In the Pilbara bioregion, highly episodic and events with an extended return-period (*i.e.* cyclones) are important determinants of freshwater habitat and consequently aquatic community structure. A comparison of community structure across the long-term dataset shows significant rainfall and flow events the overriding determinants of ecological patterns. However, following high flow events, changes to macroinvertebrate community structure does not occur in a predictable manner with stochastic differences/shifts in species, recovery time and response (see Figure 9, Figure 11).

Changes to the macroinvertebrate community structure in April 2017 include an increase in juvenile species when compared to the previous sampling occasions. The macroinvertebrate community assemblages have shown significant resilience across the data record.

Figure 10. Measuring flow using cross sectional measurement methodologies.

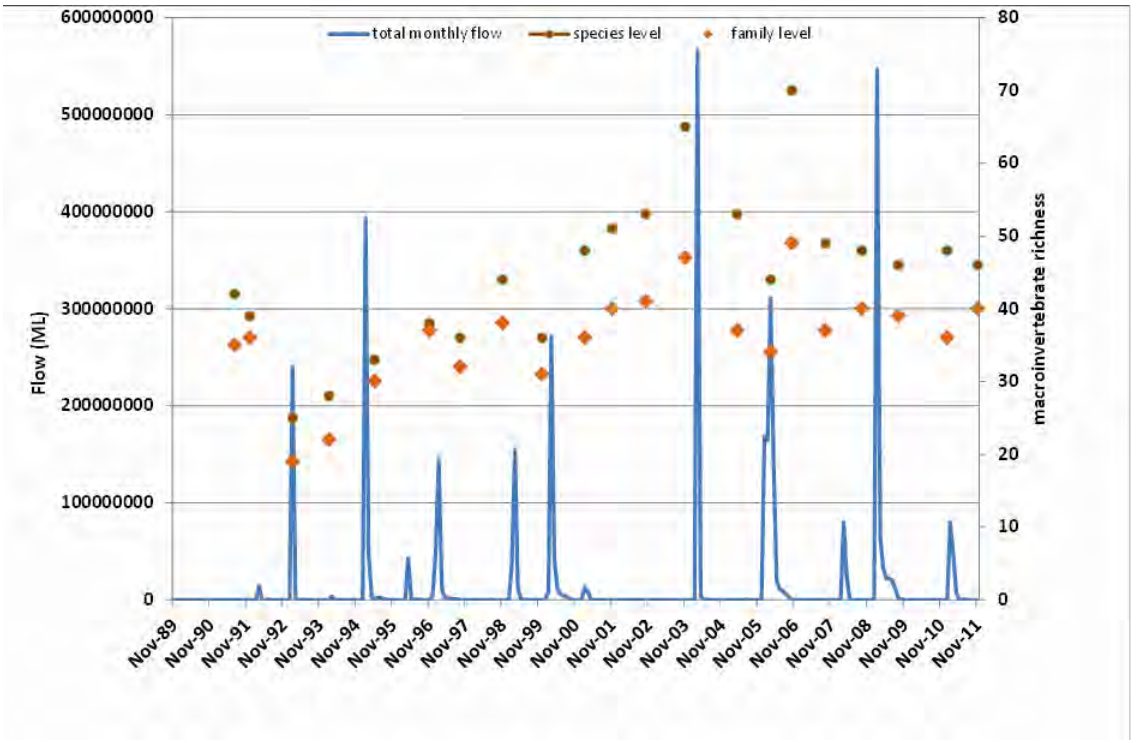


Figure 11. Species richness of macroinvertebrates as a function of flow (note, using previous data).

5.16 FISH FAUNA

A history of isolation of river systems of the north-west results in a low biodiversity of freshwater fish with few fish being recorded from the Pilbara (12 species) (Allen *et al,* 2002). A total of ten species have been recorded in the Robe River during aquatic surveys since 1991. Six of these species are classified by Allen *et al* (2002) as freshwater and the remaining four as freshwater/estuarine species (Table 3). To date, no introduced species have been recorded.

Seven species of fish were recorded in April 2017. Previously, patterns in fish biodiversity and distribution were consistent with the importance of habitat as per the long-term monitoring of pools, showing that biodiversity was linked to pool water levels, habitat and previous hydrological connectivity. All the seven fish species were recorded in both upstream and downstream sites. Mangrove jack, the striped butterfish and other estuarine species, previously observed in small downstream pools were absent in 2017 Patterns of fish species diversity and distribution were not related to the position of sites in relation to Mesa J.

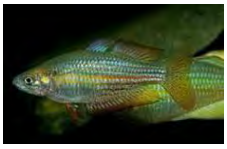
In April 2017, fish were again numerically dominated by freshwater species from the Tetrapontidae (Grunters) group particularly species of Rainbowfish (*Melanotaenia splendida australis*) (Table 2). The patterns of fish species distribution were unrelated to the position of sites in relation to Mesa J (*e.g.* similar patterns upstream and downstream). The distribution of fish species along the length of the river showed that all seven species were recorded both upstream and downstream of Mesa J. Previously, variations in fish diversity and distribution between upstream and downstream sites were correlated to pool depth and volume (see Figure 12). These patterns in species distribution are consistent with long-term trends and consistent with current knowledge of tropical fish (see Warfe *et al.* 2011). Freshwater/estuarine species, have exhibited the greatest variations temporally across surveys. Mangrove Jack, absent in early 2011, were sampled during September 2015 and again absent in 2017. The April 2017 sampling was characterised by high numbers of juvenile species of fish, presumably recently recolonising pools after the recent flows of December 2016 to March 2017. There has been anecdotal information about freshwater mullet being present in some pools (*e.g.* Cams Pool); however this is yet to be verified.

Table 3. Fish species recorded in the Robe River pools in all surveys.

	FRESHWATER SPECIES	
CLUPEIDAE - HERRINGS	*Nematalosa erebi* GUNTHER	Bony Bream
PLOTOSIDAE - EEL-TAILED CATFISH	*Neosilurus hyrtlii* STEINDACHNER	Eel-tailed Catfish
MELANOTAENIIDAE - RAINBOWFISH	*Melanotaenia splendida australis* PETERS	Western-Rainbow Fish
TERAPONTIDAE - GRUNTERS	*Amniataba percoides* GUNTHER	Barred Grunter
	Leiopotherapon aheneus MEES	Fortescue Grunter
	Leiopotherapon unicolor GUNTHER	Spangled Perch
	ESTUARINE SPECIES	
MEGALOPIDAE - TARPONS	*Megalops cyprinoides* BROUSSONET	Ox-eye Herring
SCATOPHAGIDAE-SCATS	*Selenotoca multifasciata* RICHARDSON	Striped Butterfish
GERREIDAE - SILVER BIDDIES	*Gerres filamentosus* CUVIER	Threadfin Silver-biddy
LUTJANIDAE-SNAPPERS	*Lutjanus argentimaculatus* FORSSKAL	Mangrove Jack

Freshwater and Estuarine Species present in the Robe Pools

(Photos courtesy of Allen G, 2002).



Western Rainbowfish

Spangled Perch

Barred Grunter

Fortescue Grunter

Eel-tailed Catfish

Bony Bream

Ox-eye Herring

Striped Butterfish

Mangrove Jack

Silver biddy

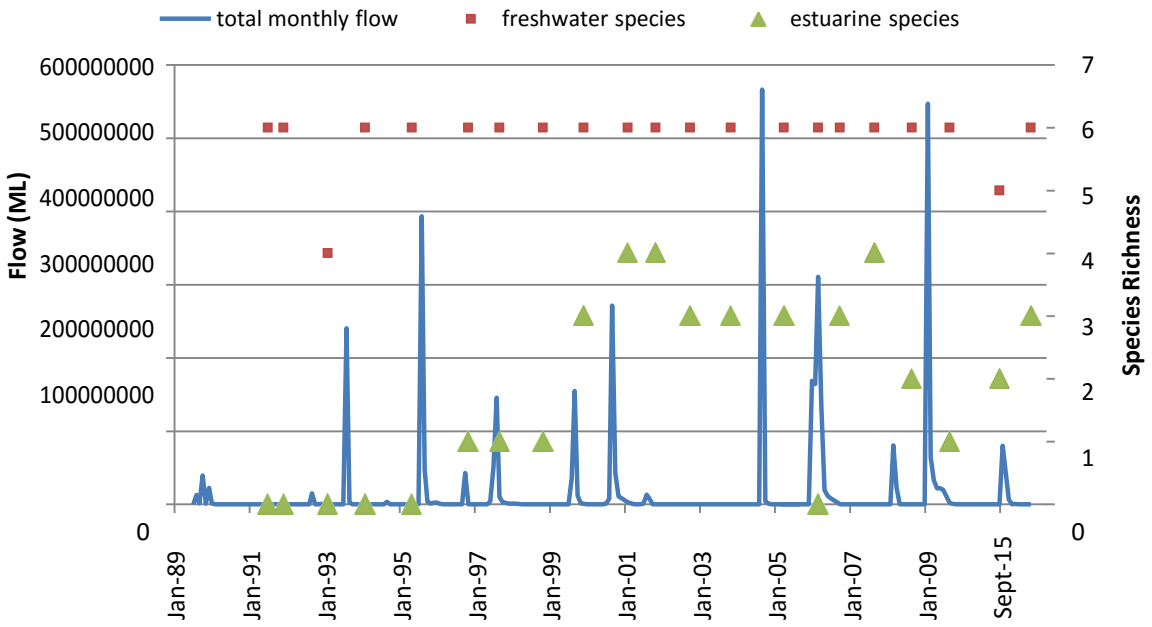


Figure 12. Comparison of fish species richness and total monthly flow at Yarraloola on the Robe River.

5.17 RIPARIAN VEGETATION

The Robe River riparian zone is dominated by moderately-dense to dense mixed woodland of Cadjeput *Melaleuca leucadendra*, River Gum *Eucalyptus camaldulensis* and Coolibah *E. microtheca*. In all cases, the riparian vegetation was in excellent condition.

The open understory of tall shrubs is dominated by *Petalostylis labicheoides*, with scattered *Sesbania formosa* and *Gossypium robinsonii* over sedges and mixed herbs. Filamentous green algae are common in the waterways, together with emergent macrophytes, such as *Potamogeton* and *Vallisneria* species, and fringing rushes, such as *Eleocharis* sp. The bulrush *Typha* was dominant on the shorelines of some pools, particularly Yarramudda.

The introduced Indian Fern (*Ceratopteris thalictroides*), common in previous surveys, was extremely restricted in 2017. The riparian weed, Mexican Poppy, was largely absent in April 2017. Vegetation condition was similar upstream and downstream of Mesa J (*e.g.* over story tree health was good with no significant difference upstream to downstream; ANOVA $p>0.05$; all cases).

5.18 REGIONAL ASSESSMENT

Broader scale and longer-term multivariate analyses of the structure of freshwater fauna in a range of sites in the Pilbara (including Turner Creek, Yule Brook, Fortescue River, Ashburton River) showed the Robe River sites, both upstream and downstream of Mesa J, "grouped" on a gradient of sites largely based on pool size, habitat and water permanence (see Vorosmarty *et al.* 2010). The larger permanent pools in the Fortescue River were the most diverse of the sites (due to presence of v- tailed catfish and freshwater turtles; absent in the Robe River) and the least diverse were the smaller, more ephemeral pools in the Turner River and Yule Brook. Sites in the Robe were transitory between these extremes and grouped with similar sized pools in the Ashburton River.

6. CONCLUSIONS

In April 2017, there were no statistically significant changes to the ecology of river pools from the long-term envelope. The long term database that exists from these Robe surveys allows informed analysis and interpretation of these changes. The current survey supports previous findings that difference in environmental characteristics of pools are primarily a result of overriding climatic influences determining pool permanence and local morphology (see Davies 2010, Catford *et al.* 2013).

These findings support previous analysis showing that rainfall and river flows have had influence on pool morphology, water chemistry and the resulting aquatic fauna (Streamtec 2001-2016). Highly episodic and extreme events such as cyclones appear to be an important determinant of aquatic biodiversity and fundamental ecological processes.

To date, there have been no detectable changes in the aquatic ecology of the Robe River that could be attributed to mining operations alone. Long Term Ecological Research (LTER) is an important global initiative providing extensive data bases of temporal and spatial variability in biological parameters. The current sampling regime was initiated in 1991 and offers a unique dataset on an arid system in the Pilbara region (see Pettit *et al.* 2011, Jardine *et al.* 2012). In addition to providing a better understanding of impacts, if any, associated with mining operations, long-term ecological monitoring improves our understanding of the natural variability within the Robe River catchment. The support of RTIO for this LTER is gratefully acknowledged.

The continued investigation of new pools greatly increases the knowledge of the larger scale distribution of refugial habitat. A 2-D model of the hydrology of the Robe River *(e.g.* map when flows connect pools and the required antecedent conditions (rainfall) leading to pool connectivity will assist modelling dewatering movement and pool condition.

The use of Indigenous locals in the sampling program has been valuable (particularly for developing 'stories' about the pools, historic names and traditional ecological knowledge). This emphasises the important link between ecological condition and community 'health' (see Speldewinde *et al.* 2009).

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8. APPENDICES

APPENDIX 1. POSITION OF STUDY SITES SAMPLED IN THE ROBE RIVER (also see Figure 1).

A pool name in inverted commas indicates a provisional naming. Grid references in MGA94. Highlighted= sampled in 2017.

Pool	Easting	Northing
Cameron's Pool	431800	7602021
Pannawonica Hill	432444	7602133
Medawandy	428965	7601388
Yarramudda	424044	7596692
Japanese Pool	419714	7598110
Duck Pool	418837	7597875
Martangkuna	417396	7598134
Pirathalu	445718	7600650
Yeera Bluff	414408	7596619
Mussel Pool	453089	7600382
Ooranah Pool	392656	7603524
Gungaree	400726	7594557
Thintuoona	399920	7594475

Description	Position relative to Mesa 'J'	Northing Zone 50	Easting Zone 50
Most upstream site surveyed. Upstream from A1.	upstream	7600396.71	453906.68
Upstream, adjacent to Water Corporation gauging station (flying fox)	upstream	7600650.05	445718.12
Adjacent to Pannawonica Hill.	upstream	7602138.34	433354.72
3km downstream of Pannawonica Hill.	upstream	7600894.25	430026.59
2km downstream of Pannawonica Hill.	upstream	7601451.43	430886.25
Downstream of confluence with Jimmawurrada Creek.	adjacent	7596946.50	420850.66
Adjacent to Mesa J.	downstream	7597951.51	418920.71
Adjacent to Mesa J & upstream of Japanese Pool.	downstream	7597650.40	420186.37
2km upstream of Deepdale.	downstream	7597949.17	418461.02
Adjacent to Yeera Bluff; downstream of Deepdale homestead.	downstream	7595961.06	414592.93

'Mesa C'	Furthest downstream site, new large pool sampled in 2011	downstream	7593929.71	414230.39
Additional Sites				
Site 10	Left Turnoff just before Rocky Creek	upstream	7600836.501	550573.993
Site 11	Turnoff at Hollow Log, and straight towards Mesa	upstream	7601641.977	551562.173
Site 12	Turnoff at Mesa near the white drum	upstream	7600428.612	554026.502
Site 13 Mesa C	Near Railway Bridge (on left)	downstream	7603493.646	607325.702
Site 14 Mesa C	Turnoff right into river bed towards Railway Bridge	downstream	7603859.150	607388.508
Thintuoona Pool	Adjacent (to the north) of Robe Pool	downstream	7594475.522	399920.422
Gungaree Pool	Adjacent (to the north) of Robe Pool	downstream	7594556.710	400726.350

APPENDIX 2. SAMPLING METHODS (BASED ON ANZECC 2000 GUIDELINES AND THE NATIONAL RIVER HEALTH MONITORING PROGRAM (SEE DAVIES 1998).

WATER QUALITY

Water samples were collected using clean 250ml polyethylene bottle; one per site. Bottles washed thoroughly three times with site water (with lid attached).

Undisturbed water collected at 0.5 depth for laboratory analyses of total nitrogen and total phosphorus (analysed by Natural Resources Chemistry Laboratory, Chemistry Centre (WA)). Both the bottle and lid labelled.

Sample kept cool in esky on ice or stored at 4^0C where possible. Measured dissolved oxygen, temperature, salinity, electrical conductivity and pH *in situ*.

MACROINVERTEBRATES – Qualitative – D-net sampling

Sampled all habitats with 250µm D-net (heel-kick with opening of net facing into flow). Standardised protocol (see below). Fixed composite sample in ethanol in plastic bag with label.

Qualitative sampling was conducted using a 'heel-kick' or sweep method (depending on habitat) compatible with the methodology of NRHP/MRHI (National River Health Program and Monitoring River Health Initiative) protocols. 'Heel-kick' and sweep sampling was conducted with a dip net with 250µm mesh, a 350 x 250mm opening, 50-75cm depth and a 1-1.5m handle. The net was washed thoroughly after sampling each site to remove any adhering animals left from previous sampling. For channel and riffle habitats, the substratum was vigorously disturbed whilst holding the net downstream with its mouth facing the disturbed area and into the stream-flow.

Cobbles were picked-up, turned over and rubbed by hand to dislodge attached organisms into the net. This process continued upstream over a total distance of about 50m, covering both the fastest and slowest flowing sections of the specific habitat. Macrophytes were sampled by vigorously sweeping the net within the aquatic vegetation over a length of about 10m. All sweep samples, containing sediment, detritus and macroinvertebrate fauna, were preserved in 80% ethanol in sealed plastic bags. In the laboratory, samples were washed in a flume-hood to remove formalin.

Organic sediments, including macroinvertebrates, were then separated from the inorganic material by water elutriation. The organic sediments were then washed through 3mm, 500µm and 250µm mesh sieves to partition the sample into 'large' and 'small' fractions. The small fractions were sorted under a binocular microscope and collected macroinvertebrates transferred to 100% ethanol. For each sample, the entire 3mm and 500µm fractions were sorted, while 250µm fractions were sub-sampled by one fifth. All animals were identified to the lowest practicable taxonomic level.

FISH

Standardised the time/effort (see Methods). Fish identified to species by direct observation. For most sites, direct observation proved the most efficient method for surveying species presence.

CHANNEL MORPHOLOGY

The channel morphology was measured as pool length, width and depth. This was measured using a range-finder.

To estimate water discharge, a narrow segment of stream of uniform shape was selected and velocity measured, at 0.1m intervals across the segment. Bank-full widths were interpreted from debris zones and high-water marks on banks and riparian trees. River bed materials were qualitatively assessed (e.g. sand, gravels, cobbles, organics *etc*). Measured velocity (Marsh-McBirney Model 201M meter) across channel at 0.6 maximum depth (*sensu* Newbury & Gaboury 1993). Depth measured average depth (graduated pole or metal tape measure).

Sedimentation, as pool aggradation, was assessed as the relative amount of fine inorganic material covering the typical bed substrate. This was completed as a visual assessment by a single operator using mask/snorkel across a 50m transect, where 0= no sediment, 1 = present (0-25%) covering of the pool bed by sediment, 2= common (25-50%), 3= dominant (50-75%) of the pool bed covered by sediment, 4= total covering (100%) of pool bed by sediment.

Areas of deeper water are considered a strong surrogate of habitat complexity. Typically in Robe River pools, areas of deeper water formed around tree roots and large woody debris (LWD). Qualitative measurements of deeper water were made by a single operator using a mask/snorkel across a 50m ('zig-zag') transect, where = 0 areas of water deeper than 2.5m, 1= areas of deeper water (>2.5m) between 0 and 25% of the total pool bed area, 3= areas of deeper water (>2.5m) between 25 and 50% of the total pool bed area, 4= areas of deeper water (>2.5m) greater than 50% of the total pool bed area.

RIPARIAN VEGETATION CONDITION

This is a qualitative assessment of riparian condition with a note of dominant species. At each site, two 50m transects from the waters' edge upslope were made and the following parameters recorded: slope (in degrees), % leaf litter covering the soil, weeds (in area), livestock disturbance (low, medium, high), and over-story condition: 1= dead, 2= much leaf loss, many dead branches, 3= some dead branches, 4= pristine). Opportunistic, qualitative surveys were also made of the noxious aquatic weed Indian Water Fern, *Ceratopteris thalictroides* and the weed Mexican Poppy.

Assessments were broadly based on the rapid assessment methodology outlined in Pen and Scott (1995) and WRC (1999). At each site, two 100m transects from the waters' edge upslope were made and the following parameters recorded: slope (in degrees), % leaf litter covering the soil, weeds (in area), and livestock disturbance (*e.g.* low, medium, and high).

Pen, L. & Scott M. (1995). Stream Foreshore Assessment in Farming Areas. Blackwood Catchment Co-coordinating Group. National Landcare Program. Department of Agriculture WA. June 1995.

WRC (1999). Planning and Management: Foreshore Condition Assessment in Urban and Semi-rural Areas of South-west Western Australia. Water and Rivers Commission River Restoration Report No. RR2. ISBN 0-7309-7443-X. October 1999.

VEHICLE DISTURBANCE

Multi-year sampling of the Robe River pools has been associated increasing levels of recreational 4WD vehicle use (particularly around some important pools, Pannawonica Hill and Gnieraoora). Consequently a qualitative coding was developed based on a visual assessment of the level of car tracks across two 100m vertical transect from the waterline, where 0= no tracks, 1= 1-5 tracks ('tracks' were coded as one per vehicle, so two tracks is one 4WD), 2= 5-10 tracks, 3= 10-20 tracks and 4= > 20 tracks.

STATISTICAL ANALYSES: PRIMER

To identify spatial (between sites) and temporal (between-sampling occasions) differences in water quality and macroinvertebrate community structure, data was classified and ordinated using PRIMER (Plymouth Routines in Multivariate Ecological Research) software (Clarke and Gorley, 2001). PRIMER performs multivariate analyses on data sets commonly recorded in biological monitoring of environmental impacts and is widely used for interpretation of community patterns.

Analyses of macroinvertebrates were conducted on presence/absence and abundance data. Similarity matrices were calculated using the Bray Curtis association measure which is appropriate for ecological data in freshwater systems. Sites were classified using hierarchical clustering (CLUSTER) which produces a dendrogram in which samples are grouped according to the similarity of their water quality or macroinvertebrate community composition. Hierarchical clustering is designed to provide ecological information on the occurrence of an assemblage of species from a number of sites - members of each division or group in the dendrogram have a more similar community structure and therefore more similar ecology.

Analysis of Variance (ANOVA)-type tests were then performed to determine if there was a significant separation between groups. This was done by ANOSIM, which compares the mean within-group similarity to the mean between-group similarity. Data were then ordinated using non-metric multi-dimensional scaling MDS. The ordination represents the samples as points in low-dimensional space where sites closest together have more in common than those further apart. Groups identified in the CLUSTER analysis are then overlaid onto the ordination. Species contribution to similarity of groups was calculated using the SIMPER routine. By looking at the overall percentage of contribution each species makes to the average dissimilarity between groups, species can be listed in decreasing order of their importance in discriminating the two groups.

In order to link environmental variables with patterns seen in community structure, physico- chemical data was analysed separately and then its multivariate pattern was compared to that of species data. Ordination of environmental data utilised Principal Components Analysis (PCA). The BIOENV routine was then used to examine whether a particular environmental variable or groups of variables distinguished sites in the as that of community structure.

APPENDIX 3. ANZECC/ARMCANZ (2002) WATER GUIDELINES

Default trigger values for nutrients, dissolved oxygen and pH for protection of aquatic ecosystems for tropical Australia for slightly disturbed ecosystems (from ANZECC/ARMCANZ 2002).

Trigger values are used to assess risk of adverse effects due to nutrients, biodegradable organic matter and pH in various ecosystem types. Data derived from trigger values supplied by Australian states and territories, for the Northern Territory and regions north of Carnarvon in the west and Rockhampton in the east.

TP = total phosphorus, FRP = filterable reactive phosphate, TN = total nitrogen, NOx = oxides of nitrogen, NH4+ = ammonium, DO = dissolved oxygen.

Ecosystem type	TP (mg/L)	FRP (mg/L)	TN (mg/L)	NOx (mg/L)	NH4+ (mg/L)	DO[2] (%)	pH
Upland River[1]	0.01	0.005	0.15	0.03	0.06	90-120	6.0-7.5
Lowland River[1]	0.01	0.004	0.2-0.3[4]	0.01[b]	0.01	85-120	6.0-8.0
Freshwater lakes & reservoirs	0.01	0.005	0.35	0.01	0.01	90-120	6.0-8.0
Wetlands	0.01-0.05[3]	0.005-0.025[3]	0.35-1.2[3]	0.01	0.01	90-120	6.0-8.0

1 = no data available for tropical WA estuaries or rivers. A precautionary approach should be adopted when applying default trigger values to these systems;
2 = percent saturation dissolved oxygen values were derived from daytime measurements. Dissolved oxygen concentrations may vary diurnally and with depth. Monitoring programs should assess this potential variability;
3 = higher values are indicative of tropical WA river pools;
4 = lower values from rivers draining rainforest catchments.

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Mesa H Project

Baseline Aquatic Ecosystem Survey
Wet Season Sampling 2016

WRM
Wetland Research & Management

Final Report
April 2017

Mesa H Project

Baseline Aquatic Ecosystem Survey
Wet Season Sampling 2016

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Frontispiece (left to right): freshwater mussels (*Velesunio* spp.) at RRU6, upstream of the Jimmawurrada-Robe confluence; RRD5 at Gnieraoora/Dthulurat; measuring milkfish (*Chanos chanos*) at RRD4 in the Medawandy Waters area.

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Disclaimer

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EXECUTIVE SUMMARY

This report summarises the results of a baseline sampling program for aquatic ecosystems of the Robe River system, both upstream and downstream of the proposed Mesa H iron ore development ("the Project"), managed by Rio Tinto on behalf of the Proponent (Robe River Mining Co. Pty Ltd) in the West Pilbara region of Western Australia. The aim of the sampling program was to document the current ecological condition of the Robe River prior to the implementation of the Mesa H development, which will require dewatering and surplus water discharge, which will result in a surface discharge footprint along the Robe River. The baseline survey included a number of named permanent pools in the Project area known to have ecological and cultural value, such as Gnieraoora (or Dthulurat) at Yeera Bluff. This report also includes a review of previous aquatic fauna surveys of the Robe River, and other nearby systems (*e.g.* Bungaroo Creek, Jimmawurrada Creek and Mungarathoona Creek), including conservation significant species known to occur in the vicinity of the Project area, which provides regional context for the sampling program.

The sampling design included six sites downgradient of the confluence of Jimmawurrada Creek and the Robe River (immediately upstream of the existing Mesa J operation) (RRD1 - 6), which are likely to fall within the zone of dewatering discharge (*i.e*. 'potentially exposed' sites), and six sites (RRU1 - 6) located upstream of the confluence (*i.e.* 'reference' sites). Sites were surveyed during the late wet season (April/May) 2016. The permanency and consistency of flow in the Robe River is already influenced by groundwater abstraction and dewatering discharge from the existing Mesa J mine operation, and so the current sampling program documents "current" ecological condition, more so than "natural" condition. Water quality, microinvertebrates (zooplankton), hyporheic fauna, macroinvertebrates and fish were successfully sampled at each of the 12 sites.

The main findings of the baseline survey were:

- Water quality was highly variable amongst sites, with salinity levels ranging from fresh (592 µS/cm) to brackish (1,700 µS/cm), pH from circum-neutral (6.9) to slightly alkaline (7.9) and dissolved oxygen from hypoxic (14.5%) to supersaturated (134.9%). There were no obvious longitudinal gradients in water quality parameters upstream or downstream. Site RRU6 (~1 km upstream of the Jimmawurrada-Robe confluence) and the downstream sites tended to have higher salinity (as electrical conductivity and total dissolved solids), alkalinity, hardness and concentrations of associated ions, than sites upstream. Some of this variability was attributed to differences in volume of the remnant pools sampled and evapoconcentration effects under recessional flows, however, higher concentrations of some ions downstream of the Jimmawurrada-Robe confluence (most notably magnesium and sulfate) was considered a possible artefact of current mining operations.
- Exceedances of ANZECC/ARMCANZ (2000) default trigger values for the protection of 95% of species in slightly-moderately disturbed tropical northern Australian systems were recorded for nitrogen nutrients (N-total, N-NO_x and N-NH_3) at most sites upstream and downstream of the Jimmawurrada-Robe confluence. Elevated background levels of N-NO_3 and N-NH_3 within the Project area are unsurprising, given that the Robe River catchment is already effected by current and historic pastoral practices, with groundwaters also appearing to be enriched. Elevated N-total and N-NO_x downstream of the Jimmawurrada-Robe confluence may also reflect discharge of nitrogen-enriched groundwater from existing mine operations, though the relative contribution of anthropogenic and natural sources to nitrogen enrichment in surface and groundwater of the Project area is unknown. The majority of heavy metal analytes, with the exception of dissolved zinc at RRU5 and RRD3, did not exceed ANZECC/ARMCANZ (2000) default 95% trigger values in the Project area.
- A total of 81 microinvertebrate taxa were recorded from the Project area, of which 46 were present at potentially exposed sites downstream of the Jimmawurrada-Robe confluence, and 69

were recorded at upstream reference sites. The microinvertebrate fauna was generally typical of that commonly recorded from tropical/sub-tropical freshwater systems, comprising Protista, Rotifera, Copepoda, Cladocera (water fleas) and Ostracoda (seed shrimp), with species from the family Lecanidae dominating within the Rotifera. There were no significant differences in total mean microinvertebrate taxa richness between reference and potentially exposed sites, nor was there any significant difference in richness of any of the major microinvertebrate groups (protists, rotifers, micro-crustaceans) between these sites. One microinvertebrate species listed for conservation significance, the copepod *Eodiaptomus lumholtzi* (IUCN Vulnerable), was recorded at potentially exposed site RRD6. The conservation listing of this species is considered in need of revision because it is known to occur at numerous locations across the Pilbara region, including sites along the Fortescue River, Coondiner Creek, Kalgan Creek, Weeli Wolli Creek, Mindy Mindy Creek, Koodaideri Springs, Caves Creek, Duck Creek and the Cane River, as well as Papua New Guinea.

- A total of 59 taxa were recorded from hyporheic samples, the majority of which were species not specially adapted to groundwater environments (stygoxene). Of these 59 taxa, 8% were considered stygobitic (obligate groundwater inhabitants), 31% occasional hyporheic stygophiles (species that use the hyporheic zone seasonally or during early life history stages), and 2% possible hyporheic taxa. There were no obvious longitudinal gradients or patterns in hyporheic taxa richness between reference and potentially exposed sites, though hyporheic taxa richness was relatively high at RRD1, RRU6, RRD2 and RRU4, suggesting strong connectivity between ground- and surface waters at these sites. Stygobitic taxa collected included the amphipod *Nedsia* sp., the thermosbaenacean *Halosbaena tulki,* and the ostracods *Candonopsis* cf. *tenuis* and *Vestalenula marmonieri.* Of these, *Nedsia* sp. is considered a potential short range endemic (SRE) species. *Nedsia* sp. was collected from sites potentially exposed to dewatering discharge (RRD1 – 4), as well as upstream reference sites (RRU3, RRU4 and RRU6).
- A total of 148 macroinvertebrate taxa were recorded from surface waters (117 from upstream reference sites, and 116 from downstream potentially exposed sites), with composition typical of freshwater systems throughout the world, being dominated by Insecta, in particular Diptera (true flies) and Coleoptera (aquatic beetles). There were no clear upstream/downstream gradients in macroinvertebrate richness within the Project area, with no significant difference in mean total taxa richness, or mean richness of most major macroinvertebrate groups, between reference and potentially exposed sites. Similarly, multivariate analysis detected no distinguishable separation of reference or potentially exposed sites based on macroinvertebrate species assemblage structure. One macroinvertebrate species listed for conservation significance, the Pilbara pin damselfly *Eurysticta coolawanyah* (IUCN Near Threatened), was recorded at potentially exposed downstream sites RRD3 and RRD4.
- A total of 3,515 individual fish, representing 11 species, were recorded in the Project area. True freshwater species included western rainbowfish, spangled perch, Pilbara tandan (eel-tailed catfish), Fortescue grunter, barred grunter, Terapontidae (grunter) hybrids and bony bream. Estuarine/marine vagrant fish species included milkfish, tarpon/ox-eye herring, mullet and banded scat/striped butterfish, the majority of which were recorded at the downstream reach. The conservation listed Fortescue grunter (*Leipotherapon aheneus*; IUCN Lower Risk/Near Threatened; Parks and Wildlife Priority 4) was the second most abundant fish species of the Project area, recorded at all upstream and downstream sites. Similar to other fauna indices, there was no significant difference in mean total abundance of fish between upstream and downstream sites, nor was there any significant difference in mean abundance of each individual species within the Project area. Healthy (breeding) populations of western rainbowfish, the most abundant fish species of the Project area, were recorded from upstream and downstream reaches; however, spangled perch and Pilbara tandan recruitment appeared to be low throughout the Project area.

1 INTRODUCTION

1.1 Background

Robe River Mining Co. Pty Ltd (the Proponent) is evaluating the potential development of the Mesa H iron ore deposit, located 16 km south-west of Pannawonica, in the West Pilbara region of Western Australia (Figure 1). The development envelope for Mesa H traverses the Robe River and lies adjacent to the existing Mesa J mine operation.

As part of the Mesa H development, dewatering of underlying groundwater will be required to allow mining of sections of ore (~20%) which occur below the water table (BWT). Options for disposal of excess dewatering water from the Mesa H development include discharge to an unnamed ephemeral tributary of the Robe River, between Mesa H and Mesa J, and/or discharge into Jimmawurrada Creek, east of Mesa J (Figure 1, or potentially an additional location north of Mesa H). The former two discharge points are currently used by the Mesa J operation.

The permanency and consistency of flow in the Robe River is already influenced by groundwater abstraction and dewatering discharge from existing mine operations (Aquaterra 2004). Groundwater drawdown and discharge from Mesa H may also affect aquatic ecosystems in the local vicinity. This includes a number of named permanent pools known to have ecological and cultural value, such as Gnieraoora (or Dthulurat) at Yeera Bluff (Figure 1).

Astron Environmental Service Pty Ltd (Astron) commissioned *Wetland Research & Management* (WRM) to design and conduct a baseline sampling program encompassing aquatic ecosystems of the Robe River both upstream and downstream of the Mesa H development (the "Project area"). The aim of the sampling program is to document current ecological condition of the system, and procure benchmark aquatic fauna and water quality data against which any future changes may be assessed post-commencement of the Mesa H development, including cumulative effects from dewatering drawdown ('drying') and discharge (quality and quantity). The permanency and consistency of flow in the Robe River is already influenced by groundwater abstraction and dewatering discharge from the Mesa J mine, and so the current sampling program will document "current" ecological condition moreso than "natural" condition. Where possible, monitoring sites established by Streamtec Pty Ltd (Streamtec) and The University of Western Australia (UWA) on the Robe River (Figure 1) have been included in the program. Since 1991, annual sampling for fish and benthic macroinvertebrates has been conducted by Streamtec/UWA as part of long-term monitoring for the Mesa J Project (Streamtec 1996, 1999, 2003, 2007, 2009, 2010, 2012 and 2014, Dobbs and Davies 2009).

1.1.1 Legislative framework

At a State level, native aquatic fauna are protected under the *Wildlife Conservation Act 1950* (WC Act) and their environment is protected under the *Environmental Protection Act 1986* (EP Act). This includes freshwater turtles, frogs, fish and invertebrates (including hyporheic and stygal invertebrates). Hyporheic invertebrates inhabit subsurface interstitial spaces in coarse creek bed sediments. Stygal invertebrates are aquatic, obligate groundwater-dwelling species known to be present in a variety of rock types and are often also present in the hyporheos.

The EP Act provides for environmental impact assessment (EIA) of proposals (and schemes) likely to have a significant effect on the environment. As part of the EIA process, the Act requires the Environmental Protection Authority of Western Australia (EPA) to report on key environmental factors to the Minister for Environment. Environmental factors and associated objectives are the EPA's basis for assessing whether a proposal (or scheme's) impact on the environment is acceptable. Two key environmental factors relate to water resources:

i) Hydrological Processes - with the objective "To maintain the hydrological regimes of groundwater and surface water so that environmental values are protected".

ii) Inland Waters Environmental Quality - with the objective "To maintain the quality of groundwater and surface water so that environmental values are protected".

Proponents are required to provide baseline information on these two factors (and others) in order to inform the EIA process.

The WC Act provides for species and ecological communities to be specially protected and listed as either 'threatened' because they are under identifiable threat of extinction, or 'priority' because they are rare, or otherwise in need of special protection. This encompasses species with small distributions (occupying an area of less than 10, 000 km^2) defined as short range endemics, or SREs (Harvey 2002, EPA 2009). The EPA's Guidance Statement 20 (EPA 2009) requires that impacts on SRE invertebrates be considered during the EIA process.

It can be difficult to determine whether or not a species belonging to a SRE Group is actually a species with a range <10,000 km^2. The Western Australian Museum (WAM) uses a three-tier classification scheme for SRE species which we have applied to hyporheic fauna in this report:

- **Confirmed SREs** are species with a known distribution range <10,000 km^2. The taxonomy is well known and the group is well represented in collections and/or via comprehensive sampling.

- **Potential SREs** are species that belong to a group where there are gaps in our knowledge of the taxon, either because the group is not well represented in collections, taxonomic knowledge is incomplete, or the distribution is imperfectly understood because sampling has been patchy.

- **Widespread (not SRE) species** have a known distribution range >10,000 km^2. The taxonomy is well known and the species is well represented in collections and/or via comprehensive sampling.

WAM further uses five sub-categories if a species is determined to be a "Potential SRE". These sub-categories are:

1. Data deficient: There are insufficient data available to determine SRE status, either because there is a lack of geographic and taxonomic information, or because the individuals sampled cannot be identified to species level (*e.g.* wrong sex, juvenile, damaged);

2. Habitat Indicators: The status of a species can be elucidated through its association with a particular habitat and vice versa;

3. Morphological Indicators: The status of a species can be determined through its morphological characteristics;

4. Molecular Evidence: DNA sequence data reveal patterns congruent or incongruent with SRE status for a species; and

5. Research & Expertise: Available research data and/or WAM expertise provide the basis for a decision about the species' status.

The Department of Parks and Wildlife (Parks and Wildlife) also maintains a list of priority fauna species that are of conservation importance but, for various reasons, do not meet the criteria for listing as threatened. Parks and Wildlife uses the International Union for Conservation of Nature (IUCN) Red List

criteria for assigning species and communities to threat categories. Not all Western Australian species listed by the IUCN are also listed by Parks and Wildlife.

Objectives for the management of potential impacts on water-dependent ecosystems are also outlined in the Western Australian Department of Water (DoW) Western Australian Water in Mining Guideline (DoW 2013) and include:

- Minimise the adverse effects of the abstraction and release of water on environmental, social and cultural values;
- Ensure the cumulative effects of mining operations are considered and managed;
- Use a monitoring and evaluation process, to adaptively manage the effects of abstractions and releases on the water resources;
- Maximise cooperation in water management activities between nearby water users, to reduce impacts on the environment;
- Plan for, and manage, the effects of climate variability and change.

At a Federal level, the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) provides for native fauna and their habitats to be specially protected and listed as nationally or internationally important. Relatively few aquatic species in Western Australia are listed as threatened or endangered under the WC Act or EPBC Act. Lack of knowledge of their distributions often precludes aquatic invertebrates for listing as threatened or endangered. The EPA has stated that listing under legislation should therefore not be the only conservation consideration in EIA (EPA 2004).

The current baseline sampling constituted a Level 1 survey for EIA, as described under the EPA's Environmental Assessment Guideline (EAG) No. 12 (EPA 2013), and in accordance with EAG No. 8 (EPA 2015), with the focus on hydrological processes and ecosystem maintenance. At the time of the survey (April/May 2016), the aforementioned EAGs were the most up-to-date EAGs availaible.

1.1.2 Other relevant policy - ANZECC/ARMCANZ (2000) Guidelines

The Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ 2000) "… provide an authoritative guide for setting water quality objectives required to sustain current, or likely future, environmental values (users) for natural and semi-natural water resources in Australia and New Zealand". These guidelines form part of the National Water Quality Management Strategy (NWQMS), a joint national approach to improving water quality in Australian and New Zealand waterways. The NWQMS was originally endorsed by two Ministerial Councils - the former Agriculture and Resources Management Council of Australia and New Zealand (ARMCANZ) and the former Australian and New Zealand Environment and Conservation Council (ANZECC).

State regulators have been known to apply the trigger values detailed in the ANZECC/ARMCANZ (2000) guidelines as compliance values for mining companies in the Pilbara, where developments may impact creeklines through dewatering and discharge operations. Yet, in some systems water quality data recorded during baseline surveys, conducted prior to any disturbance, do not actually meet the default ANZECC/ARMCANZ (2000) trigger values. Therefore, it is important to obtain adequate baseline water quality data and develop system-specific guidelines, as recommended in the ANZECC/ARMCANZ (2000) guidelines, to avoid issues with non-compliance as a result of inappropriate trigger values being used by regulators.

The ANZECC/ARMCANZ (2000) guidelines are currently under review and updates are provided by the Joint Steering Committee for the Revision on the Federal Department of the Environment and Energy website (www.environment.gov.au/water/quality/national; downloaded on 30 May 2016).

1.2 Scope of Works for Current Study

The scope of works for the current study was to establish riverine baseline monitoring sites, and to develop a robust dataset to allow statistical testing for potential change over time. Specifically, the scope of work included:

- Identification of baseline and future riverine monitoring sites, and where possible, include long-term monitoring sites established previously by Streamtec/UWA;
- Semi-qualitative sampling for aquatic fauna (microinvertebrates, hyporheic invertebrates, benthic macroinvertebrates, fish) and water quality to allow statistical comparison of any changes overtime;
- Qualitative visual assessment of general habitat conditions at all sites;
- Record opportunistic visual sightings of any turtle and frog species present;
- Identification of all specimens to the lowest taxonomic level practicable;
- An assessment of the conservation status of aquatic fauna recorded;
- Report water quality data against ANZECC/ARMCANZ (2000) guidelines for freshwater ecosystems;
- Preparation of a detailed technical report of all findings.

1.3 Rationale for Sampling Components of Aquatic Fauna

Microinvertebrates

Aquatic microinvertebrate fauna consists of microscopic fauna including micro-crustacea (ostracods, copepods and cladocera), protists and rotifers (nominally <53 μm in size). Aquatic microinvertebrates are used as bioindicators throughout the world for many reasons. The microinvertebrate community holds a strategic position in food webs (Bunn and Boon 1993, Zrum and Hann 1997, Jenkins and Boulton 2003). They provide a food source for higher trophic levels, such as macroinvertebrates (Bunn and Boon 1993, Jenkins and Boulton 2003), fish (King 2004, Vilizzi and Meredith 2009), and waterbirds (Crome 1985). Most fish species depend on microinvertebrates for their first feed after hatching (Geddes and Puckridge 1989). Therefore, any change in the microinvertebrate community will ultimately result in changes to the entire aquatic ecosystem. Microinvertebrates also have intimate contact with the surrounding environment, being planktonic, and continually exposed to the ambient water quality. Hence, they are vulnerable to environmental pollutants and can be a useful biomonitoring tool (Kaur and Ansal 1996).

Hyporheic fauna

The hyporheic zone, comprising subsurface interstitial spaces in coarse creek bed sediments, is recognised as a critical component of many streams and rivers (Edwards 1998). The hyporheic zone creates habitat and connectivity between surface and sub-surface (groundwater) zones, provides a rearing habitat and important refuge for aquatic invertebrates, and importantly in the context of the Pilbara region, buffering from floods (Palmer *et al.* 1992, Dole-Olivier and Marmonier 1992), disturbance in food supply (Edwards 1998) and drought (Cooling & Boulton 1993, Coe 2001, Hose *et al*. 2005). The aquatic fauna of hyporheic zones is collectively referred to as hyporheos. Typically, hyporheos have poor dispersal capabilities, are confined to discontinuous habitats, are highly seasonal (usually more active in the wet season following significant flows) and have low levels of fecundity, and are therefore commonly classified as SRE as defined by Harvey (2002)[1]. A number of taxa frequently encountered in hyporheic zones, including stygal amphipods, isopods and syncarids (crustaceans) are classified as SRE, and are therefore of high conservation value. The subterranean fauna of the Pilbara is characterised by high levels of diversity and short range endemism (Eberhard *et al*. 2005, Halse *et al*. 2014), with increasing aridity and cessation of surface flows over the last 60 – 70 million years causing once epigean

[1] Short range endemic as defined by Harvey (2002): a species occupying an area of less than 10, 000 km^2.

(surface dwelling) fauna to disperse and become isolated in groundwater environments (Finston *et al*. 2011).

Macroinvertebrates

Aquatic macroinvertebrates (nominally 53 - 250 µm in size) typically constitute the largest and most conspicuous component of aquatic invertebrate fauna in both lentic (still) and lotic (flowing) waters. Macroinvertebrates are used as a key indicator group in the bioassessment of the health of Australia's streams and rivers under the National River Health Program (Schofield and Davies 1996), and have inherent value for biological monitoring of water quality (ANZECC/ARMCANZ 2000). Macroinvertebrates are considered to be temporary residents if their life-cycle contains a winged-adult form (*e.g.* dragonflies, damselflies, mayflies, aquatic beetles, caddisflies, *etc.*), therefore being proficient in aerial dispersal between waterbodies (Gray and Fisher 1981). Permanent residents include those which can persist as larvae during periods of drought by aestivating or encysting in sediments (*e.g.* Baetidae, Simuliidae, Ceratopogonidae, Chironomidae), or produce desiccation-resistant propagules or eggs which hatch upon inundation (*e.g*. ciliates, rotifers, flatworms, nematodes, segmented worms and crustaceans) (Radzikowski 2013).

Fish

Historically, fish diversity has been used worldwide as an indicator of ecosystem health (*e.g.* Hugueny e*t al*. 1996, Oberdoff *et al.* 2002, Pont *et al.* 2006). Because fish continually inhabit the receiving water, they integrate the chemical, physical and biological 'histories' of the watercourse. Most fish species have a long life span and therefore reflect both long-term and current water quality. Sampling fish assemblages can be used to assess a range of environmental disturbances, such as changes in habitat, water quality and land use (Hugueny *et al.* 1996). Fish also tend to be the most conspicuous biota in freshwater systems, have significant social amenity and are relatively easy to sample and identify.

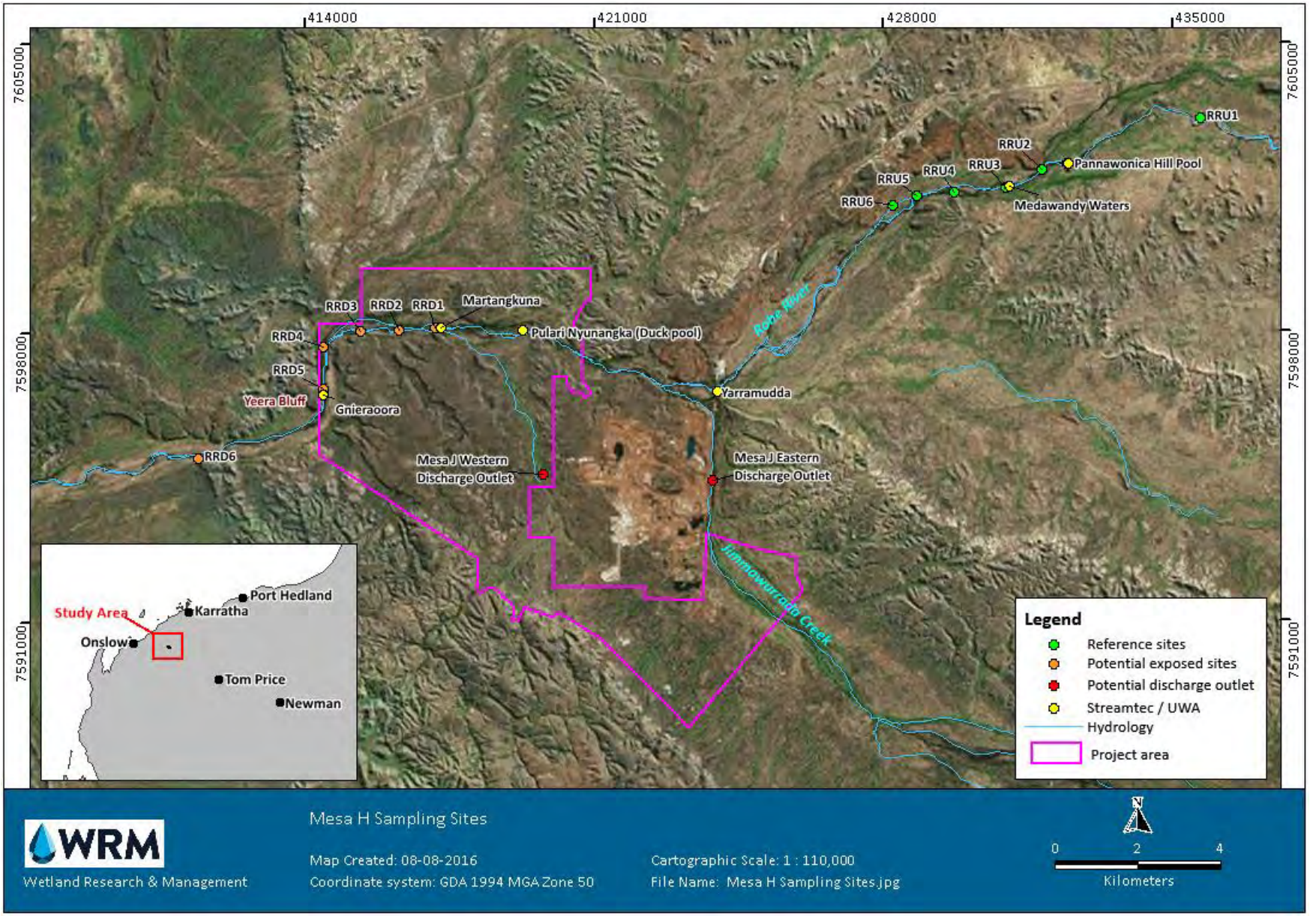


Figure 1. Location of Mesa H Project area and baseline aquatic ecosystem sampling sites (reference, potential exposed) and historic Streamtec/UWA sites ( ).

2 STUDY AREA

2.1 Climate

The Project area is located on the western edge of the Hamersley Ranges, approximately 100 km south-west of Karratha and south-west of Pannawonica. Climate of the region is semi-arid, with relatively dry winters and hot summers. The nearest long-term Bureau of Meteorology (BOM) gauging station is Pannawonica (no. 005069; 1971 - 2016), where total annual rainfall ranges from 113 to 700 mm, and monthly rainfall from 0 to 444 mm. Most rainfall occurs during the summer months (November to March) and is predominantly associated with cyclonic events; when flooding frequently occurs along creeks and rivers. Due to the nature of cyclonic events and thunderstorms, total annual rainfall in the region is highly unpredictable and individual storms can contribute several hundred millimetres of rain at one time.

Prior to sampling in April/May 2016, slightly above-average monthly rainfall was recorded in the latter part of 2015 (October & November) (Figure 2). However, total monthly rainfall was well below the 45-year average in the mid to late wet season of 2016, particularly during February, March and April (Figure 2). As such, there was no surface flow connecting pools along the Robe River at the time of sampling between 1st and 8th May. However, toward the end of the sampling period, a major storm event on the 5th - 6th May caused widespread flooding across the Robe River catchment, resulting in above average total rainfall for May (Figure 2). Pannawonica also recorded above average rainfall in June and July (Figure 2).

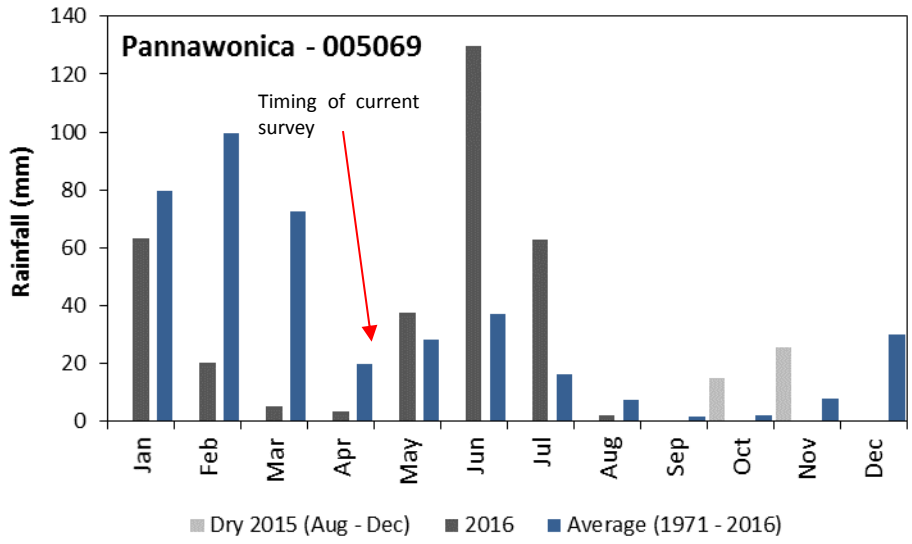


Figure 2. Average monthly rainfall (1971 – 2016) and total monthly rainfall (2016) for Bureau of Meteorology (BOM) Pannawonica Gauging Station (005069).

2.2 Hydrogeology

The Project area lies within the Robe River catchment, a significant river system in the region, with a catchment area of 7,571 km^2 and numerous braided tributaries (DoW 2012). The Robe River channel covers a linear distance of 190 km, 63% of which lies upstream of the Project area (EPA 1991). The immediate valley is 300 - 500 m wide. Jimmawurrada Creek is the only major tributary in the vicinity of the Project area, flowing northward along the eastern flank of Mesa J.

Jimmawurrada Creek joins the Robe River upstream of Mesa J (Figure 1). The Jimmawurrada Creek sub-catchment has an area of approximately 400 km^2 and constitutes the lower section of Bungaroo Creek

catchment, with a combined area of around 1,261 km^2 (DoW 2012). Both the Jimmawurrada and Bungaroo Creek catchments are included in the Bungaroo Creek Water Reserve that protects the water resources in these catchments and underlying aquifer that supply the West Pilbara Water Supply Scheme (WPWSS) (RDA 2013). The WPWSS delivers public drinking water to the towns of Karratha, Dampier, Roebourne, Cape Lambert and Point Samson (DoW 2012).

Surface flow in the Robe and tributary rivers is naturally ephemeral, typically only occurring in response to significant rainfall events and continuing for one to two months. There is one DoW streamflow gauging station on Robe River; Yarraloola (no. 707 002; 1972 - 2016), at the North West Coastal Highway crossing, 36 km west of the Project area. The maximum total monthly river discharge for the period of record at Yarraloola is 773.9 GL (February 2009) and the maximum instantaneous discharge is 12,203 m^3/sec (February 2009). Low or no flow typically occurs from July to December, when the river is reduced to a series of isolated pools. The number and permanence of these pools is dependent on antecedent rainfall and groundwater levels (Antao & Braimbridge 2010). Since streamflow records began at Yarraloola in 1972, 14 zero-flow years have been recorded, including seven in the last two decades (2002, 2003, 2007, 2010, 2012, 2013 & 2014).

The major aquifer underlying the Robe River is the gravelly alluvium which has a saturated thickness of up to 15 m adjacent the main channel and extends laterally up to 5 km across the Robe River Valley (Antao & Braimbridge 2010). Groundwater flow through the gravels maintains permanent pools in the Robe River. The gravelly aquifer is underlain by fractured, permeable Trealla Limestone and highly transmissive Robe Pisolite. Robe Pisolite is an iron-enriched pisolitic alluvial sedimentary rock that fills the broad valley between ridges of the Brockman Iron Formation, originally as ancestral drainage channels (palaeochannels) of the Robe River (commonly known as a Channel Iron Deposits (CID), and forms the target ore deposit at Mesa H (and Mesa J).

Groundwater flow in the Pisolite is towards the Robe River and where the Pisolite is deepest, probably contributes to baseflow within the Robe River (Aquaterra 2005). The gravel and Pisolite aquifers are recharged primarily *via* river discharge. Modelling by DoW indicates the aquifers have the potential to absorb a significant percentage of river flow; however, due to the unpredictable flow regime, recharge is very low in two out of every five years (Antao & Braimbridge 2010). Near the Jimmawurrada-Robe confluence, the Pisolite is very shallow and unsaturated. Stream-aquifer interaction upstream in the Bungaroo and Jimmawurrada valleys contributes to recharge along with direct rainfall infiltration.

2.3 Water Quality

2.3.1 Surface water

Water quality monitoring has been conducted quarterly at five pools in the Robe River and at the existing dewatering discharge point on Jimmawurrada Creek. The Robe River pools are located upstream (Medawandy Waters), adjacent to (Yarramudda) and downstream (Japanese, Martangkuna, Gnieraoora) of the existing mine operation (refer Figure 1 & Section 3). Pools have been monitored for pH, conductivity (EC), total dissolved solids (TDS), nitrogen and phosphorus, turbidity, total suspended solids (TSS) and biological and chemical oxygen demand. Dewatering discharge has been monitored for pH, TDS, TSS and concentration of dissolved metals (Al, As, Cd, Cr, Cu, Fe, Mn, Ni, Pb, Zn). Unfortunately, the limit of reporting for most metals was not sufficiently low to allow comparison against ANZECC/ARMCANZ (2000) default trigger values (TVs) for the protection of freshwater ecosystems. In general, dewatering discharge to Jimmawurrada Creek appeared to be of low salinity (< 800 mg/L TDS), low TSS (< 5 NTU) and with a pH range of 6.2 - 8.5. The water is a predominantly sodium bicarbonate and calcium bicarbonate type, indicative of recharge water (Aquaterra 2004).

Available long-term quarterly monitoring data for the Robe River pools (1992 - 2004) indicates surface waters to be fresh (453 - 1,400 µS/cm EC; 300 - 904 mg/L TDS), with pH values typically in the range 7.0 - 9.0, and relatively low turbidity (< 10 NTU) under baseflow conditions. Maximum salinity levels recorded during quarterly monitoring were in 2003 following two years of low rainfall. Salinity generally tends to be lower in upstream pools than in pools adjacent to, and downstream of Mesa J. Background levels of total nitrogen (N-total) and nitrate-nitrogen ($N\text{-}NO_3$) often exceed default ANZECC/ARMCANZ (2000) TVs for protection against eutrophication (0.15 mg/L N-total; 0.03 mg/L $N\text{-}NO_X$), with levels of up 3.45 mg/L N-total and 3.1 mg/L $N\text{-}NO_3$ recorded at Medawandy waters, upstream of Mesa J. In general $N\text{-}NO_3$ appears to constitute most of the N-total present in surface waters in the pools. There are no data on dissolved metal concentrations in the pools.

Long-term annual monitoring of Robe River pools by Streamtec/UWA indicated similar physicochemical water quality characteristics to those identified from quarterly monitoring by the Proponent; fresh (EC < 1,200 µS/cm), slightly acidic to alkaline (pH 6.6 - 8.3) waters with relatively low turbidity during the dry season (< 8 NTU), becoming markedly more turbid following wet season flood events (often exceeding 70 NTU) (Dobbs & Davies 2009, Streamtec 2014). There was significant spatial and temporal variation in dissolved oxygen (DO) levels (< 2 mg/L to > 12 mg/L), depending on time of day sampled and permanency of pools. N-total and total phosphorus (P-total) often exceeded ANZECC/ARMCANZ (2000) default TVs (Dobbs & Davies 2009, Streamtec 2014).

2.3.1 Groundwater

At the time of reporting, groundwater quality sampling in the Project area had been conducted on three occasions, in December 2015 and twice during 2016. A comprehensive suite of parameters was sampled in 10 bores; MB15MEH001 to 4, 6 to 9, and 13 to 14. This sampling will be followed by more comprehensive groundwater assessment during 2016. The December 2015 sampling suggests groundwater quality in the majority of the bores to be similar to surface waters, *i.e.* fresh (489 - 1,110 µS/cm, 452 - 822 mg/L TDS), circum-neutral to slightly alkaline (pH 7.3 - 7.7) and with relatively high DO levels (7.2 - 9.1 mg/L). Two bores had brackish water; MB15MEH013 (3,040 µS/cm, 2,770 mg/L) and MB15MEH014 (1,920 µS/cm, 1,450 mg/L). Groundwaters in most bores (except MB15MEH001) were enriched in $N\text{-}NO_3$ relative to ANZECC/ARMCANZ (2000) default TVs for surface waters for protection against eutrophication. Maximum concentration was 23.9 mg/L $N\text{-}NO_3$ in MB15MEH014. Default TVs have yet to be developed for groundwaters. In their absence, ANZECC/ARMACANZ (2000) recommend that default TVs for surface waters be applied with caution, acknowledging that they may not be representative of natural background concentrations in groundwater.

In three bores, dissolved concentrations of chromium (Cr), manganese (Mn) and/or zinc (Zn) were also in exceedance of ANZECC/ARMCANZ (2000) default 95% species protection level TVs[2] for surface waters. This included MB15MEH001 (Mn, Zn), MB15MEH004 (Zn), MB15MEH013 (Cr, Zn) and MB15MEH004 (Cr).

2.4 Cultural and Ecological Values

The Project area is located within the Hamersley sub-region of the Pilbara Biogeographic Region as categorised under the national Interim Biogeographic Regionalisation for Australia (IBRA). Existing tenure in the area is a mixture of unallocated and leased Crown land. The Mesa H development would be implemented under Mining Lease ML248SA, which covers the Project area and other deposits

[2] Note, default TV for Ni should be modified for water hardness (as $CaCO_3$) at the time of sampling using algorithms provided in Table 3.4.3 of ANZECC/ARMCANZ (2000).

throughout the Robe River valley. In addition to ML248SA, the Project area lies substantially within Yarraloola Station pastoral lease (PL 3114-1127). The lease is held by Robe River Iron Associates joint venture through the Yarraloola Pastoral Company, and managed by Rio Tinto. The Station was established in 1916 as a sheep station, but currently runs cattle.

Numerous Aboriginal sites of significance have been identified within the Robe River valley. The Native Title Claim of the Kuruma Marthudunera Native Title Claimant Group covers 15,717 km^2 south of Karratha, incorporating the Project area and Yarraloola Station (YMAC 2011). The entire Robe River, also known as Jajiwarra, is of significant cultural value to the Kuruma and Marthudunera people, in particular permanent pools such as Yarramudda and Weedai immediately upstream of the Project area, Dthulurat (Gnieraoora) at Yeera Bluff, Joordi (or Jongardi) 14 km downstream of Yeera Bluff, and Chalyarn Pool on Mungarathoona Creek, a tributary of the Robe River.

As the Pilbara has an arid and variable climate with irregular episodic rainfall events, sources of water are of high ecological value. The permanent pools of the Robe River are an important component of the river ecosystem, supporting a diverse range of aquatic fauna and specialised flora such as yellow bladderwort (*Utricularia australis*) and water chestnut (*Eleocharis dulcis*). The pools act as refuges for fauna during periods of drought (EPA 1991). The riparian zone in the vicinity of the Project area also supports woodlands of silver cadjeput (*Melaleuca argentea*) and eucalypt (*Eucalyptus camaldulensis*, *E. victrix*). Lower tree and shrub layers in these woodlands are atypical of the Fortescue Botanical District, and as such, warrant conservation (EPA 1991). Cyclonic events and associated rainfall can severely affect the riparian vegetation, re-arrange braided channels and alter the size and position of permanent pools through scouring and aggradation (Dobbs & Davies 2009). In March 2004 for example, a rain depression in the wake of tropical cyclone Monty resulted in record rainfalls (376.6 mm) that caused widespread flooding throughout the Robe River valley and its surrounding catchments (Aquaterra 2004). High flows and flash flooding associated with cyclone Monty uprooted much of the Cadjeput woodland along the river channel in the vicinity of the Jimmawurrada-Robe confluence.

A number of potential short range endemic (SRE) aquatic invertebrates are known from the vicinity of the Project area and potentially occur within drawdown and dewatering impact zones. These species include stygal amphipods, isopods and syncarids, which are also known to occur in the hyporheic zones of the Robe River and/or tributary rivers. Further discussion of these species is provided in Section 3.

3 REVIEW OF PREVIOUS AQUATIC FAUNA AND STYGOFAUNA SURVEYS

The most comprehensive surveys of aquatic fauna within the Project area are those of Streamtec/UWA, who have conducted annual sampling of Robe River pools since 1992 (Dobbs & Davies 2009, Streamtec 1996 - 2014). Other recent studies include the Parks and Wildlife Pilbara Biological Survey (PBS); a region-wide survey of aquatic invertebrates conducted between 2003 and 2006, as part of a broader biodiversity survey (see Pinder *et al.* 2010). The PBS featured a number of ephemeral, long-term and permanent waterbodies within the vicinity of the Project area, including Mungarathoona Creek to the west, Myannore Creek and Yarraloola Station Claypan to the north-west, Nyeetbury Spring on upper Bungaroo Creek to the south-east, Kumina Creek in the upper Robe, and two pools on the Cane River to the south-west (Pinder *et al*. 2010). Morgan and Gill (2004) studied the distribution of fishes in inland waters of Pilbara, sampling 171 sites across 21 river systems between 2000 and 2002. Nearby sites included two pools on the Robe River close to the Project area; two on the lower Robe west of Mesa A/Warramboo, two on the lower Fortescue River to the north-west, and one on the Cane River. WRM previously sampled aquatic invertebrates and fish at Nyeetbury Spring (2009 - 2015) and Yalleen Pool (2010 - 2011) on Bungaroo Creek under the Proponent's Regional Aquatic Fauna Program (see WRM 2016). In 2008 and 2009, baseline surveys for the Australian Premium Iron (API) West Pilbara Iron Ore Project (WPIOP) were conducted, including sites on Mungarathoona Creek, Red Hill Creek and the Cane River (WRM 2009).

Additionally, stygofauna[3] have been sampled by Biota Environmental Sciences in the Mesa A/Warramboo Yarraloola Borefield to the west (Biota 2006a), and within the Ken's Bore and Cardo Bore areas along Red Hill Creek to the south-west (Biota 2010). Bennelongia Environmental Consultants surveyed stygofauna within the Bungaroo Creek catchment in the Buckland Hills area (Bennelongia 2013). Stygofauna were also surveyed by Parks and Wildlife as part of the PBS, including 36 bores within the Robe River catchment, sampled between 2002 and 2005 (see Eberhard *et al*. 2009, Halse *et al.* 2014).

A review of previous aquatic fauna surveys conducted within 100 km of the Project area, including sites sampled, methods used, and notable fauna found, is presented in the following sub-sections. A summary of the studies is provided in Table 1 and the sampling locations are shown in Figure 3. Studies referenced in this review were either conducted by WRM for the Proponent, or were publicly available, or records sourced from the Parks and Wildlife database NatureMap (http://naturemap.dpaw.wa.gov.au). In addition, direct requests were therefore made to Parks and Wildlife in order to obtain additional information on distribution of threatened, priority and vulnerable aquatic fauna.

For each species, conservation significance was assessed by reference to the IUCN Red List of Threatened Species, Parks and Wildlife Threatened and Priority Fauna Lists, as well as The Australian Faunal Directory, The Australian National Insect Collection Database and WRM's in-house database for distribution and occurrence information. Collectively, the previous studies have identified a number of species of conservation significance and/or scientific interest, which have the potential to reside, either seasonally or permanently, within the Project area and its expected drawdown zone and/or dewatering discharge footprint (acknowledging hydrological modelling for drawdown and dewatering discharge was not completed at the time of the survey or reporting).

A summary of aquatic species (including hyporheic species) of conservation and/or scientific value known to occur, or likely to occur within the Project area, is provided in Table 2, at the end of Section 3.

[3] Obligate inhabitants of groundwater environments, *e.g.* aquifers, caves and hyporheic (interstitial) spaces. Morphological adaptations to such environments include reduced body size, lack of pigmentation, reduced or absent eyes, and elongated appendages (*e.g.* antennae).

Table 1. Summary of previous recent aquatic fauna studies (invertebrates and fish) conducted within a 100 km radius of the Mesa H Project area, together with methodologies. Studies are listed in chronological order. Stygofauna assessments appropriate to the Project area are also included. Codes for 'Fauna sampled': Macro = macroinvertebrate; Micro = microinvertebrate; Hypo = hyporheos; Stygo = stygofauna).

Program	Sampled by	Locations sampled	Fauna sampled	Methods used	Taxonomic level	Sampling dates	Reference
Aquatic Fauna (Surface Water and Hyporheos)							
Proponent Mesa J Project Aquatic Ecosystem Study (long-term)	Streamtec / UWA	Robe River pools: • Gnieraoora, Martangkuna, Pulari-Nyunangka, Japanese pool, Yarramudda, Medawandy Waters, Pannawonica Hill pool, Chundy Pool, Ngalooin, Mussel Pool.	Macro Fish	• Macro – kick sampling (250 µm net) all habitats, • Fish – seine net and visual observation (mask and snorkel).	Species	Annually between Nov - Mar, 1991 - 2013.	Streamtec (1996, 1998, 2002, 2007-2009, 2011, 2014); Dobbs and Davies (2009)
Fish Fauna of Pilbara inland waters	Murdoch Uni	• Robe River near Mesa H and J, • Lower Robe River, west of Mesa A/Warramboo, • Lower Fortescue River (40 km NE), • Cane River (75 km SW).	Fish	• Fish – seine nets, gill nets, cast nets, rod and line, and visual observation (mask and snorkel).	Species	Once between Dec 2000 - Nov 2002.	Morgan and Gill (2004)
Hyporheos of five Pilbara springs	Parks and Wildlife	• Nyeetbury Spring on Bungaroo Creek, Robe River catchment (33 km SE).	Hypo	• Stirring up sediments and sweeping with a 250 µm mesh dip net, • Digging up sediments to a depth of 30 cm and collecting fauna caught with 50 µm and 250 µm mesh nets (Karaman-Chappuis method).	Species	Sep 2001.	Halse *et al*. (2002)
Pilbara Biological Study (PBS)	Parks and Wildlife	• Chalyarn Pool, Mungarathoona Creek, Robe River catchment (20 km W), • Red Hill Creek Pool, Robe River catchment (30 km SW), • Nyeetbury Spring on Bungaroo Creek (33 km SE), • Duck Creek Pool on Duck Creek, Ashburton River catchment (46 km SE), • Myannore Creek (49 km NNW), • Yarraloola Station Claypan (65 km NNW), • 2 sites on Cane River; House Pool and Creek Pool (70-75 km SW), • Kumina Creek (74 km SW).	Macro Micro	• Macro - kick sampling (250 µm net) all habitats, • Micro – sweep netting (50 µm mesh).	Species	Aug/Sep 2003, Aug/Sep 2004, May 2005, May 2006.	Pinder *et al*. (2010)

Program	Sampled by	Locations sampled	Fauna sampled	Methods used	Taxonomic level	Sampling dates	Reference
Aquatic Fauna (Surface Water and Hyporheos)							
API WPIOP Baseline Aquatic Fauna Survey	WRM	• 2 sites on Mungarathoona Creek (20 km W), • 6 sites on Red Hill Creek, (40 km SW).	Macro Micro Hypo Fish	• Macro – kick sampling (250 µm net) all habitats, • Micro – sweep netting (53 µm net) water column, • Hypo – Karaman-Chappuis method (53 µm net), • Fish – seine nets and gill nets.	Species	Dec 2008, Apr 2009.	WRM (2009)
Proponent Regional Aquatic Program (long-term)	WRM	• Yalleen Pool on Bungaroo Creek (23 km SE), • Nyeetbury Spring on Bungaroo Creek (33 km SE).	Macro Micro Hypo Fish	• Macro – kick sampling (250 µm net) all habitats, • Micro – sweep netting (53 µm net) water column, • Hypo – Karaman-Chappuis method (53 µm net), • Fish – seine nets and gill nets.	Species	Ongoing, wet and dry seasons since 2009.	WRM (2013, 2016)
Stygofauna							
Pilbara Biological Study (PBS)	Parks and Wildlife	• 36 bores across the Robe River catchment	Stygo	• Replicate hauls with weighted plankton nets (50 µm and 150 µm mesh).	Species	3 wet and 3 dry season occasions 2002 - 2005.	Eberhard *et al.* (2005, 2009); Halse *et al.* (2014)
Robe River Mining Co. Mesa A/Warramboo Baseline Stygofauna Assessment	Biota	• 21 bores within the Warramboo area, Robe River catchment (45 km W) • 20 bores within the Yarraloola area, Robe River catchment (40 km W)	Stygo	• Hauls with weighted plankton nets (150 µm mesh).	Species	Oct 2005.	Biota (2006a)
API WPIOP Baseline Stygofauna Assessment	Biota	• 58 bores within the WPIOP tenement areas, Red Hill Creek catchment (40 km SW)	Stygo	• Hauls with weighted plankton nets (70 µm mesh).	Species	Jun 2008, Sep 2009.	Biota (2010)
Iron Ore Holdings Bungaroo South Subterranean Fauna Assessment	Bennelongia	• 61 bores within Bungaroo South tenement, immediately south of the Project area.	Stygo	• Replicate hauls with weighted plankton nets (50 µm and 150 µm mesh).	Species	Jul 2012, Oct 2012.	Bennelongia (2013)

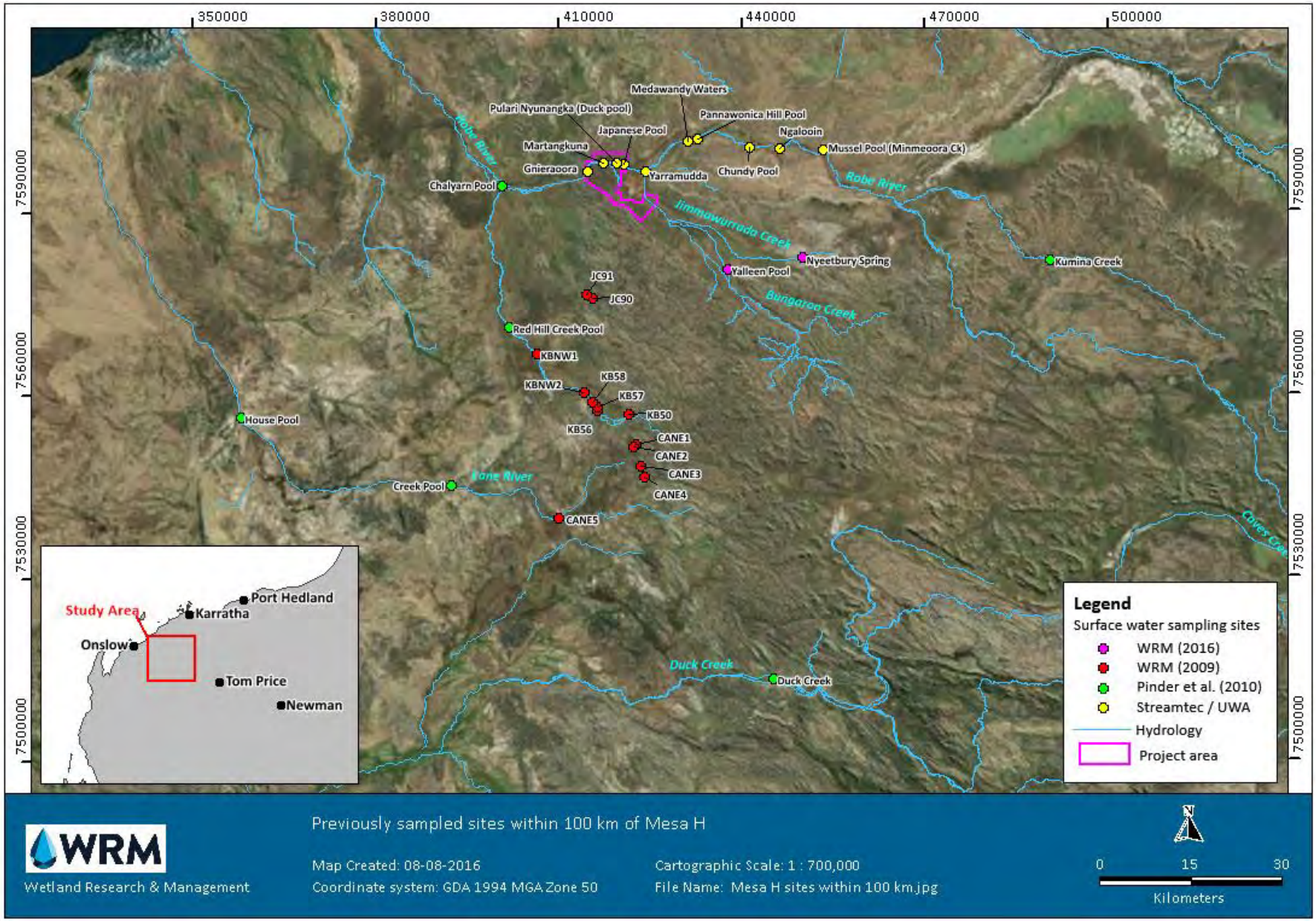


Figure 3. Locations previously sampled for aquatic invertebrates (Streamtec/UWA 1991 - 2014, WRM 2009 - 2016, Pinder *et al.* 2010) and fish (Streamtec 1991 – 2014) within 100 km of the Mesa H project area. Note, individual groundwater bores sampled for stygofauna (Biota 2006a, 2010, Eberhard 2009, Bennelongia 2013, Halse *et al.* 2014) are not detailed. Morgan and Gill (2004) did not provide GPS co-ordinates for their study of Robe River fish fauna.

3.1 Microinvertebrates (zooplankton)

The microinvertebrate fauna within the vicinity of the Project area is poorly known. Eight sites within 100 km of the Project area were sampled for microinvertebrates as part of the Parks and Wildlife PBS (Table 1). Pools sampled within the Robe River catchment included Chalyarn Pool (Mungarathoona Creek) and pools along Red Hill Creek, Myannore Creek, Kumina Creek, Nyeetbury Spring, Yalleen Pool and an ephemeral claypan on Yarraloola Station (Figure 3). Locations sampled outside the Robe River catchment included two pools on the Cane River to the south-west, and one on Duck Creek in the Ashburton River catchment (Figure 3). A combined total of 216 microinvertebrate taxa were recorded from these sites both within and outside of the Robe River catchment, sampled in August and September 2003/2004 (dry season) and May 2005/2006 (wet season). Wet season sampling appeared to favour microinvertebrate richness, with some of the most specious samples taken in May 2005 at House Pool on the Cane River (45 taxa), Red Hill Creek (42 taxa) and Chalyarn Pool (35 taxa).

WRM (2009) surveyed microinvertebrates in Mungarathoona Creek (two sites adjacent to the Jewel Cochrane development, to the south-east) and Red Hill Creek (six sites adjacent to Ken's Bore development) to the south east, as part of baseline aquatic surveys for API's WPIOP (Figure 3). A total 135 microinvertebrate taxa were recorded across two sampling events, conducted in December 2008 and April 2009 (WRM 2009).

WRM also conducts an ongoing aquatic fauna surveys under the Rio Tinto Pilbara Regional Program, which has previously included the microinvertebrate fauna of Yalleen Pool and Nyeetbury Spring on Bungaroo Creek (Figure 3). Biannual surveys collected a total 45 microinvertebrate taxa from Yalleen Pool, sampled between 2010 and 2011 (WRM 2013), and 160 taxa from Nyeetbury Spring, sampled between 2009 and 2016 (WRM 2016).

In each study, the microinvertebrate fauna was generally found to be typical of systems in the arid tropics (*e.g.* Koste and Shiel 1983, Tait *et al.* 1984, Smirnov and De Meester 1996, Segers *et al*. 2004). For example, in the nine featured PBS sites within the Robe River catchment (Table 1), species from the family Brachionidae (Rotifera) were poorly represented (14 taxa). This family tends to dominate temperate rotifer plankton, but is largely replaced by Lecanidae in tropic zones, as appears to be the case in the Pilbara (27 taxa; Pinder *et al.* 2010).

Microinvertebrate fauna of note (*i.e*. of conservation or scientific value) recorded from these studies included the stygal ostracod *Vestalenula matildae*, the rotifers *Colurella oblonga* and *Lecane noobijupi* and the cyclopoid copepod *Paracyclops* sp. 6. All these species have been recorded from within the Robe River catchment.

Vestalenula matildae was recorded at Mungarathoona Creek (Chalyarn Pool) during the PBS (Pinder *et al*. 2010). *V. matildae* is a recently described stygal species of ostracod known from groundwater (bores and wells) in the Ashburton River catchment (Government Well, Divide Well), DeGrey River catchment (Kylena Well, Home Well), and Sherlock River (Muorena Well). It has been recorded from hyporheic zones in the Ashburton (Yindabiddy Pool) and Fortescue River catchments (Weeli Wolli Spring), as well as surface waters in the Ashburton (Horrigans Pool), Fortescue (Gregory Gorge) and DeGrey (Coppin Gap, Chinaman Spring, Running Waters) (Martens and Rosetti 2002, Halse *et al*. 2002, Pinder *et al.* 2010, Schön *et al*. 2010). It appears to be endemic to the Pilbara, with no record to date of occurrence outside the region.

Colurella oblonga was collected at Nyeetbury Spring by WRM in 2012. This constituted the first record of *Colurella oblonga* from the Australian continent. This species is previously known from the southwest islands of Japan and from Europe (Dr Russel Shiel, University of Adelaide, pers. comm.).

Lecane noobijupi was collected from Nyeetbury Spring by WRM in 2011 and 2012, and from Red Hill Creek in 2009. This species is endemic to Western Australia, and appears to have a highly disjunct distribution. It was described from specimens collected from a wetland in the Muir-Unicup catchment in the south-west of the state (Lake Noobijup), and it had been thought to be restricted to that catchment (Segers and Shiel 2003). WRM has since recorded *Lecane noobijupi* from a number of locations throughout the Pilbara region, including Weeli Wolli Creek, Marillana Creek, Coondiner Creek, Mindy Mindy Creek and Kalgan Creek and (WRM 2016). Pinder *et al*. (2010) also recorded it from the DeGrey River. It would now appear that the Pilbara may be the normal locality of this species, and the Muir location in the south-west was an isolated occurrence.

Closer to the Project area, *Paracyclops* sp. 6 was collected from Chalyarn Pool, as well as Nyeetbury Spring and Kumina Creek (Pinder *et al*. 2010). This species is endemic to the Pilbara and is known from only 20 locations across the region, including the Ashburton River (Bobswim Pool, Fork Spring, Whiskey Pool, Cheela Spring, Paperbark Spring, Innawally Pool), Fortescue River (Palm Pool, Gregory Gorge, Palm Spring near Millstream, Joffre Creek), DeGrey River (Pelican Pool, Glen Herring Pool, Chinaman Spring, Minigarra Creek pools, Skull Springs and Bonnie Pool), Harding River (Springs Creek, Harding River Pool) and Sherlock River (Erawallana Spring and Pool Spring) (Pinder et al. 2010, WRM unpub. data).

Of the above-mentioned species, *Lecane noobijupi, Vestalenula matildae* and *Paracyclops* sp. 6 potentially occur within the Project area and its immediate vicinity but have a widespread distribution across the Pilbara.

3.2 Hyporheos

The hyporheos was not sampled by Streamtec/UWA during their long-term study of Robe River pools upstream, nor during the PBS (Pinder *et al.* 2010, Halse *et al.* 2014). However, biannual surveys of the hyporheos of upper Bungaroo Creek by WRM recorded a total of 22 hyporheic taxa from Yalleen Pool (WRM 2013) and 103 from Nyeetbury Spring (WRM 2016). Halse *et al.* (2002) recorded 62 hyporheic taxa from Nyeetbury Spring during one-off sampling in 2001. WRM (2009) also sampled the hyporheos of upper-Mungarathoona Creek and Red Hill Creek in 2008/2009, recording a combined total of 45 taxa.

Fauna of note collected during these studies included stygal amphipods and isopods that are likely SREs. Amphipods from the family Paramelitidae were collected from Yalleen Pool (WRM 2013), one site on Mungarathoona Creek, and three sites on Red Hill Creek (WRM 2009). These specimens were not able to be identified further than family level due to immaturity of life stage; however, they were considered likely to be SREs, given that most stygal Paramelitidae species are restricted to a small number of river systems within close geographical proximity to one-another (Finston *et al.* 2011).

At least three large isopod species are known from the subsurface zone of the Robe River catchment; *Pygolabis* sp. (Tainisopidae), *Tainisopus* sp. (Tainisopidae) and *Pilbarophreatoicus platyarthricus* (Amphisopodidae). Keable and Wilson (2006) documented *Pygolabis* sp. as occurring in the Robe River catchment but did not disclose the specific locality. Bennelongia (2013) also recorded P*ygolabis* sp. from two groundwater bores in the Bungaroo South area. All species of *Pygolabis* appear to be restricted to groundwaters and/or hyporheic zones of one or several creek drainages of the Pilbara region (Fortescue, Ashburton or Robe River catchments) (Keable and Wilson 2003) and at least some appear to be restricted to single sub-basins (Finston *et al.* 2009). Another undescribed, but closely related species, *Tainisopus* sp., is known to occur in the hyporheos of Nyeetbury Spring (Halse *et al.* 2002), as is *Pilbarophreatoicus platyarthricus* (WRM 2016). *P. platyarthricus* was first identified by Knott and Halse (1999) from Robe River specimens (including Chalyarn Pool), which were exclusively collected during the wet season "under cobbles in slow-flowing riffles … maintained by groundwater discharge." This species was also collected in surface water samples at Chalyarn Pool during the PBS (Pinder *at al.* 2010).

Although not specifically targeting hyporheic fauna, there have been a number of surveys of stygal communities in the vicinity of the Project area. These communities have taxa frequently encountered in hyporheic zones including SRE amphipods and isopods. These species may potentially occur in hyporheic zones within dewatering and drawdown zones in the Project area and the immediate vicinity.

The PBS sampled a total of 507 wells and drill holes across the Pilbara between 2002 and 2005, including 36 within the Robe River catchment area (Eberhard *et al.* 2005, 2009, Halse *et al.* 2014). A total of 110 stygal invertebrate taxa were recorded from bores in the Robe River catchment, including taxa belonging to the groups Oligochaeta (segmented worms), Polychaeta (bristle worms), Nematoda (round worms), Turbellaria (flat worms), Gastropoda (snails), Acarina (mites), Rotifera (wheel animals), Copepoda (copepods), Ostracoda (seed shrimps), Isopoda (aquatic slaters), Amphipoda (amphipods/side swimmers), Syncarida (syncarids) and Themosbaenacea (thermosbaenaceans). These taxa are also likey to occur within hyporheic zones of the Robe River. Out of the 110 taxa captured in the Robe River area, 83 were recorded from three or less bores (*i.e*. present at < 10% of bores), while just eight taxa were recorded from more than eight bores (*i.e.* present at > 20% of bores). It is possible that many of the uncommonly recorded stygofauna in this study are SREs.

Biota (2006a) sampled stygofauna from 21 bores within the Mesa A/Warramboo Project area and 20 bores in the Yarraloola area during 2005. In this study, a number of species which are occasionally encountered in hyporheic zones, such as stygal amphipods, copepods, and the themosbaenacean *Halosbaena tulki* were recorded, though it was noted that "there appears to be little in the way of a stygal community present at Warramboo". DNA sequencing delineated four new stygal amphipod species (Melitidae spp.), including two from the bores within the Mesa A/Warramboo Project area (Melitidae sp. A and sp. F), which currently are known only from the Mesa A/Warramboo Project area (Biota 2006a).

Biota (2010) sampled 58 bores in the Cardo East and Ken's Bore areas of the Red Hill Creek catchment. A number of potential SREs were recorded, including Paramelitidae (*Pilbarus* nr *millsi*, Paramelitidae sp. 2 and sp. 6), Melitidae (*Nedsia* spp., nr *Norcapensis* sp.), isopods (*Haptolana yarraloola*, *Kagalana tonde*, *Pygolabis* sp., *Pilbarophreatoicus platyarthricus*) and syncarids (*Bathynella* spp., Billibathynella sp. *Hexabathynella* sp. *Notobathynella sp.*).

Bennelongia (2013) sampled stygofauna in 61 bores within the Bungaroo South area in July and October 2012. Potential SREs recorded included Paramelitidae (Genus 2 sp. B12), Melitidae (*Nedsia* spp.), Neoniphargidae (nr *Wesniphargus*), the isopod *Pygolabis* sp. and syncarids (*Bathynella* spp., *Billibathynella* sp.).

3.3 Macroinvertebrates

Since 1991, Streamtec/UWA have conducted annual surveys for macroinvertebrates at seven long-term pools on the Robe River (Streamtec 1996 - 2014, Dobbs and Davies 2009). Pools include Medawandy Waters, Yarramudda, Japanese Pool, Martangkuna, Pannawonica Hill Pool, Pulari-Nyunangka, Gnieraoora (Figures 1 and 3). Four additional pools were included in the program during the 1990s; Chundy Pool, A1, Ngalooin and Mussel Pool (Figure 3). To date, over 112 macroinvertebrate taxa from 64 families have been recorded by Streamtec/UWA from 16 sampling occasions between February 1991 and December 2013. The most commonly encountered groups were the segmented Oligochaeta, Atyidae (freshwater prawns), Ephemeroptera (mayflies), Chironomidae (non-biting midges) and Dytiscidae (diving beetles). Streamtec/UWA noted that caddisflies (Trichoptera) were susceptible to changes in flow regime and water quality, with a decline in the number of species recorded following 1993, 2005, and 2012 cyclone events (Streamtec 2014).

The macroinvertebrate fauna of Chalyarn Pool (Mungarathoona Creek) was sampled during the PBS (Pinder *et al.* 2010). A total of 70 macroinvertebrate taxa were recorded at Chalyarn Pool in the wet season (May 2005), and 97 taxa were recorded in the dry season (August 2003). Other locations surveyed for macroinvertebrates in the vicinity of the Project area during the PBS included Red Hill Creek pools, Myannore Creek Pool and the Yarraloola Station claypan (Figure 3). A total of 196 macroinvertebrate taxa were recorded across these sites, sampled in August 2003/2004/2005 (dry season) and May 2003/2005/2006 (wet season). The most specious samples among these were collected at Red Hill Creek, with 90 taxa collected in both the wet and dry seasons (Pinder *et al.* 2010).

Macroinvertebrates from Mungarathoona Creek and Red Hill Creek were also sampled as part of baseline aquatic surveys for API's WPIOP area (WRM 2009). A total of 128 macroinvertebrate taxa were recorded across two sampling events; dry season (December) 2008 and wet season (April) 2009 (WRM 2009). The taxonomic list comprised Nematoda (roundworms), Hydrozoa (freshwater hydra), Oligochaeta (segmented worms), Gastropoda (snails and bivalves), Acarina (aquatic mites), Ephemeroptera (mayflies), Odonata (dragonflies and damselflies), Hemiptera (true bugs), Coleoptera (aquatic beetles), Diptera (aquatic fly larvae, including Chironomidae/midges), Trichoptera (caddisflies) and Lepidoptera (aquatic caterpillars).

The macroinvertebrate fauna of Yalleen Pool and Nyeetbury Spring on Bungaroo Creek have been sampled as part of the ongoing Pilbara Regional Aquatic Program for the Proponent (see WRM 2016). A total of 83 macroinvertebrate taxa were collected from Yalleen Pool from a total three sampling occasions; wet (March) and dry season (October) 2010 and wet season (March) 2011 (WRM 2013). A total of 190 macroinvertebrate taxa were recorded from Nyeetbury Spring from a total 13 occasions during biannual sampling (wet and dry seasons) between and October 2009 and May 2016 (WRM 2016).

The composition of macroinvertebrate taxa recorded during all of the above studies was typical of freshwater systems throughout the world (Hynes 1970), being dominated by Insecta (insects), within which Diptera (flies) and Coleoptera (beetles) were particularly well represented.

Of the macroinvertebrate fauna recorded from the Robe River catchment, two species are listed for conservation significance (IUCN Red List), and six are of scientific interest, being Pilbara endemics and/or relatively new to science. All potentially occur within the Project area. Three other Pilbara endemics have the potential to occur within the Project area (having been recorded within 100 km), and based on their known dispersal capabilities (*i.e.* with winged-adult forms with strong capacity for flight). These species are as follows:

- Conservation listed species recorded from the Robe River catchment:

  Eurysticta coolawanyah (Pilbara pin damselfly) (IUCN Near Threatened);
  Hemicordulia koomina (Pilbara emerald dragonfly) (IUCN Near Threatened);

- Pilbara endemic species recorded from the Robe River catchment:

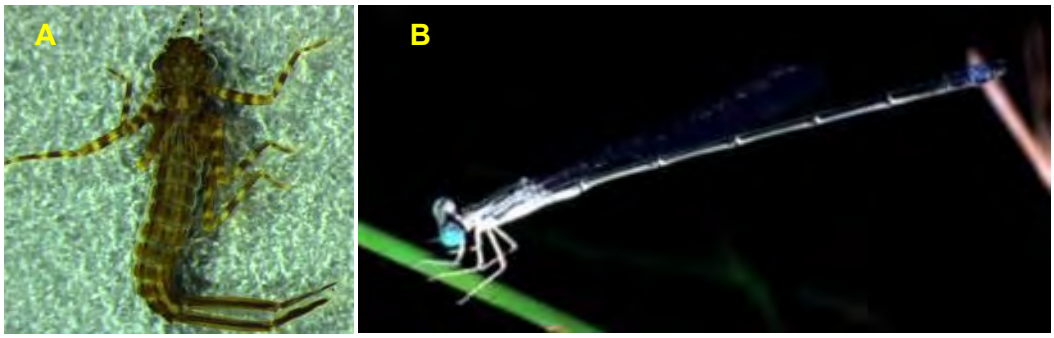
  Agriocnemis kunjina (Pilbara wisp damselfly);
  Ictinogomphus dobsoni (Pilbara tiger dragonfly);
  Nannophlebia injibandi (Pilbara archtail dragonfly);
  Tiporus tambreyi (diving beetle);
  Laccobius billi (water scavenger beetle);
  Haliplus halsei (crawling water beetle);

- Pilbara endemic species recorded from other locations within 100 km of the Project area:
  - *Sternopriscus pilbaraensis* (diving beetle);
  - *Tiporus lachlani* (diving beetle);
  - *Haliplus pilbaraensis* (crawling water beetle).

The Pilbara pin damselfly, *Eurysticta coolawanyah* (Plate 1A-B), is restricted to the Pilbara region, where it prefers riverine pools with an abundance of perching mediums (*e.g.* emergent reeds or overhanging riparian vegetation). *E. coolawanyah* has been collected from Robe River pools by Streamtec/UWA, and from Bungaroo Creek by WRM (2013, 2016). It has also been previously recorded at Chalyarn Pool (Pinder *et al.* 2010). *E. coolawanyah* is listed as Near Threatened[4] on the IUCN Red List of Threatened Species (IUCN 2016), based on its (initially recorded) restricted distribution to an area of less than 500 km^2, and it being thought to occur at less than five locations (Millstream Station, Nanuturra Pools, Palm Pool and the Millstream area); however, it has since been recorded from over 40 locations throughout the Pilbara (Pinder *et al*. 2010). Hawking (2009a) lists no known threats currently, or in the near future, to this species. WRM has encountered *E. coolawanyah* in habitats with a range in frequency of inundation and degree of persistence, including permanent/semi-permanent pools, permanent springs, ephemeral pools and sites permanently inundated and flowing due to dewatering discharge operations, for example at Weeli Wolli Spring.

The Pilbara emerald dragonfly, *Hemicordulia koomina* (Plate 1C-D), has been recorded by Streamtec/UWA from the Robe River, and from Red Hill Creek by Pinder *et al.* (2010). It is known to prefer large, permanent/semi-permanent pools. *H. koomina* is currently listed as Near Threatened on the IUCN Red List (IUCN 2016) but this listing is in need of revision given its more recent collections from numerous localities across several river catchments, including the Fortescue River (Hamersley Gorge, Fortescue Falls, Kalgan Creek), DeGrey River (Bamboo Springs, Minigarra Creek), Ashburton River system (Moreton Pool, Creek Pool near Mt Amy, Henry River pools, Pool at Gorge Junction), Sherlock River (Pool Spring) and Shaw River (Panorama Spring). Despite its widespread occurrence, *H. koomina* is infrequently collected, likely due to its preference for large, permanent pools, which are somewhat uncommon in the Pilbara region and inherently difficult to sample. The major threat to this species is considered to be loss of habitat (*i.e.* drying of permanent pools/waterways) through groundwater abstraction (Hawking 2009b).

Both of these species, particularly the large dragonfly *H. koomina*, are likely to have excellent dispersal capabilities in their winged-adult form (see Plate 1). Dispersal (the movement of individuals from one site to another) is an integral factor in determining the composition of biological communities (Palmer et *al*. 1996, Leibold *et al*. 2004). Aerial dispersal by winged-adult invertebrate fauna (*e.g.* Odonata, Coleoptera, Hemiptera, Ephemeroptera, Diptera and Trichoptera, *etc*.) has been recognised as the most important pathway for colonisation in arid and semi-arid wetlands (Gray and Fisher 1981). Heavy rainfall during the wet season also serves as a cue for many aquatic invertebrate taxa to migrate from perennial wetlands to colonise more ephemeral bodies of water (Lytle and Poff 2004). Given their proficient dispersal capabilities, and the record of these species at multiple locations within close proximity to the Project area, it is considered likely that macroinvertebrate sampling could reveal the presence of one or both of *E. coolawanyah* or *H. koomina* within the Project area.



[4] A species is listed under the IUCN Red List as Near Threatened when it has been evaluated against the criteria but does not qualify for Critically Endangered, Endangered or Vulnerable now, but is close to qualifying for or is likely to qualify for a threatened category in the near future (IUCN 2016).

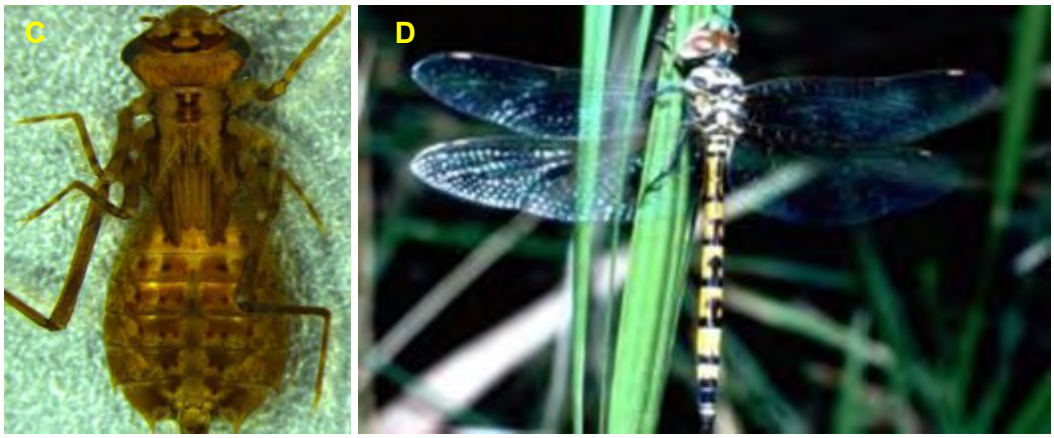


Plate 1. Pilbara pin damselfly, *Eurysticta coolawanyah* (A) nymph and (B) adult, and Pilbara emerald dragonfly *Hemicordulia koomina* (C) nymph and (D) adult (photos A and D courtesy of Jan Taylor ©).

The endemic Pilbara tiger dragonfly, *Ictinogomphus dobsoni*, is recorded infrequently and in low abundances from permanent still or sluggish waters of the Pilbara region (Watson 1991). It is known from a number of sites along the Fortescue, Robe, Ashburton, Yule, DeGrey and Sherlock rivers (DEC 2009, Pinder *et al*. 2010, CSIRO 2015). Near the Project area, *I. dobsoni* has been recorded from pools along the Robe River (Streamtec/UWA), Mungarathoona Creek (Chalyarn Pool) and Red Hill Creek (Pinder *et al*. 2010).

The Pilbara archtail dragonfly, *Nannophlebia injibandi*, is also restricted to the Pilbara region. This species was recorded infrequently during the PBS at Millstream Delta and Gregory Gorge in the Fortescue River catchment (Pinder *et al.* 2010). Within the vicinity of the Project area, *N. injibandi* has been recorded from Robe River pools near Mesa H (Streamtec/UWA) and from Red Hill Creek (WRM 2009).

The Pilbara wisp damselfly *Agriocnemis kunjina,* is a Pilbara endemic rarely encountered. It is previously known from Millstream, Harding River, and Tanberry Creek (ANIC Database); however, it was not recorded during the PBS (Pinder *et al.* 2010). *A. kunjina* is known from both still and flowing waters (Theischinger and Hawking 2006), and has been recorded from Robe River pools in the vicinity of the Project area (Streamtec/UWA) and from Yalleen Pool (WRM 2013).

The aquatic hydrophilid beetle *Laccobius billi* is a Pilbara endemic species that also is rarely collected. *L. billi* was only recorded from one site during the PBS; Cangan Pool on the Yule River (Pinder *et al.* 2010). WRM (2009) recorded *Laccobius billi* at Mungarathoona Creek and from a number of Red Hill Creek sites.

The haliplid beetles *Haliplus halsei* and *H. pilbaraensis* are both endemic to the Pilbara region, and are relatively new to science, having only been recently described (Watts and McRae 2010). Each species appears to occur widely throughout the Pilbara, and have been recorded at localities such as Glen Ross Creek, Coondiner Pool, the Fortescue Marsh, Moreton Pool, Paradise Pool, Munreemya Billabong, Wackilina Creek Pool, West Peawah Creek Pool, Harding River Pool, and an un-named creek in Millstream (Watts and McRae 2010). Closer to the Project area, *Haliplus halsei* has been recorded from Chalyarn Pool and Myannore Creek during the PBS (Pinder *et al*. 2010), while *Haliplus pilbaraensis* has been recorded from Red Hill Creek by WRM (2009).

The dytiscid beetle *Sternopriscus pilbaraensis* is endemic to the Pilbara, is relatively common and known from a range of systems, including Red Hill Creek, the Fortescue River (Gregory Gorge and Kalgan Pool), Ashburton River (Bobswim Pool, Yandabiddy Pool, Whiskey Pool, Ashburton at Gorge Junction, Innawally Pool and Rocky Island Pool), DeGrey River (Pool at Yarrie Homestead, Pelican pool on

Nullagine, Tanguin Rockhole, Paradise Pool, Munereemya Billabong, Carleecarleethong Pool, Minigarra Creek Pools, Bonnie Pool, Cookes Creek Pools, Running Waters and Pool on Tongolock), Rudall River (Watrara Creek Pool), Shaw River (Panorama Spring), Sherlock River (Kangan Pool) and the Harding River (Harding River Pool) (Pinder *et al.* 2010).

The diving beetles *Tiporus tambreyi* and *T. lachlani* are also relatively common and widespread across the region (Pinder *et al.* 2010, WRM unpub. data), though *T. lachlani* is less frequently encountered than its congener (Pinder *et al.* 2010, WRM unpub. data). In the vicinity of the Project area, *T. tambreyi* has been recorded from Robe River pools (Streamtec/UWA), Chalyarn Pool (Pinder *et al.* 2010) and Red Hill Creek (WRM 2009, Pinder *et al.* 2010), while *T. lachlani* has only been previously recorded from Red Hill Creek (Pinder *et al.* 2010).

3.4 Fish

The fish fauna of the Pilbara region is unique, with 13 freshwater species recorded from inland waters to date, including catadromous[5] species (Allen *et al.* 2002, Morgan and Gill 2004). Of the freshwater species, three (or possibly four) are considered endemic to the region. These include the golden gudgeon (*Hypseleotris aurea*), the Murchison River hardyhead (*Craterocephalus cuneiceps*), one undescribed eel-tailed catfish, the Pilbara tandan *Neosilurus* sp.[6], and the conservation listed Fortescue grunter (*Leiopotherapon aheneus*) (Morgan and Gill 2004). *L. aheneus* (Plate 2) is currently listed on the IUCN Red List of Threatened Species as Lower Risk/Near Threatened (IUCN 2016), and as a Priority 4 (P4)[7] species on the Parks and Wildlife Priority Fauna List (Parks and Wildlife 2016). The Fortescue grunter has a restricted distribution within the Pilbara, and is only known from the Fortescue, Robe and Ashburton River systems (Allen *et al*. 2002, Morgan and Gill 2004). This species is considered to be reasonably common within its range.

Plate 2. Fortescue grunter *Leiopotherapon aheneus.* Photo by Chris Hofmeester (WRM) ©.

Other known species from Pilbara inland waters include the spangled perch (*Leiopotherapon unicolor*), barred grunter (*Amniataba percoides*), western rainbowfish (*Melanotaenia australis*), bony bream (*Nematalosa erebi*), flathead goby (*Glossogobius giuris*), empire gudgeon (*Hypseleotris compressa*), Hyrtl's tandan (eel-tailed catfish; *Neosilurus hyrtlii*), blue catfish or lesser salmon catfish (*Arius graeffei*), and the Indian short-finned eel (*Anguilla bicolor*) (Allen *et al.* 2002, Morgan and Gill 2004, Beesley 2006). The most common and widespread species are spangled perch, western rainbowfish and bony bream (Plate 3). The western rainbowfish, for example, has a range extending from the Ashburton River in the Pilbara to the Adelaide River near Darwin, inhabiting rivers, creeks, swamps, lakes and reservoirs

[5] Catadromous fishes live in freshwater as juveniles or sub-adults, but migrate to marine habitats to spawn.

[6] Previously referred to as *Neosilurus hyrtlii*. Recent genetic evidence indicates the Pilbara species is distinct from elsewhere in Australia (Peter Unmack, National Evolutionary Synthesis Centre, North Carolina, pers. comm.).

[7] P4 species are those with limited distributions "in need of monitoring" (Parks and Wildlife 2016).

(Allen *et al.* 2002). Spangled perch and bony bream are considered to be two of Australia's most widespread freshwater fish species, found in drainages throughout the Pilbara, Kimberley, Northern Territory, Queensland, northern New South Wales, as well as in Lake Eyre and the Murray-Darling system (Allen *et al.* 2002).

In addition, the Pilbara Drainage Division contains two endemic cave fishes restricted to the North West Cape region; the blind gudgeon (*Milyeringa veritas*) and the blind cave eel (*Ophisternon candidum*) (Allen *et al.* 2002, Morgan and Gill 2004). Both *M. veritas* and *O. candidum* are listed as Vulnerable under the EPBC Act.

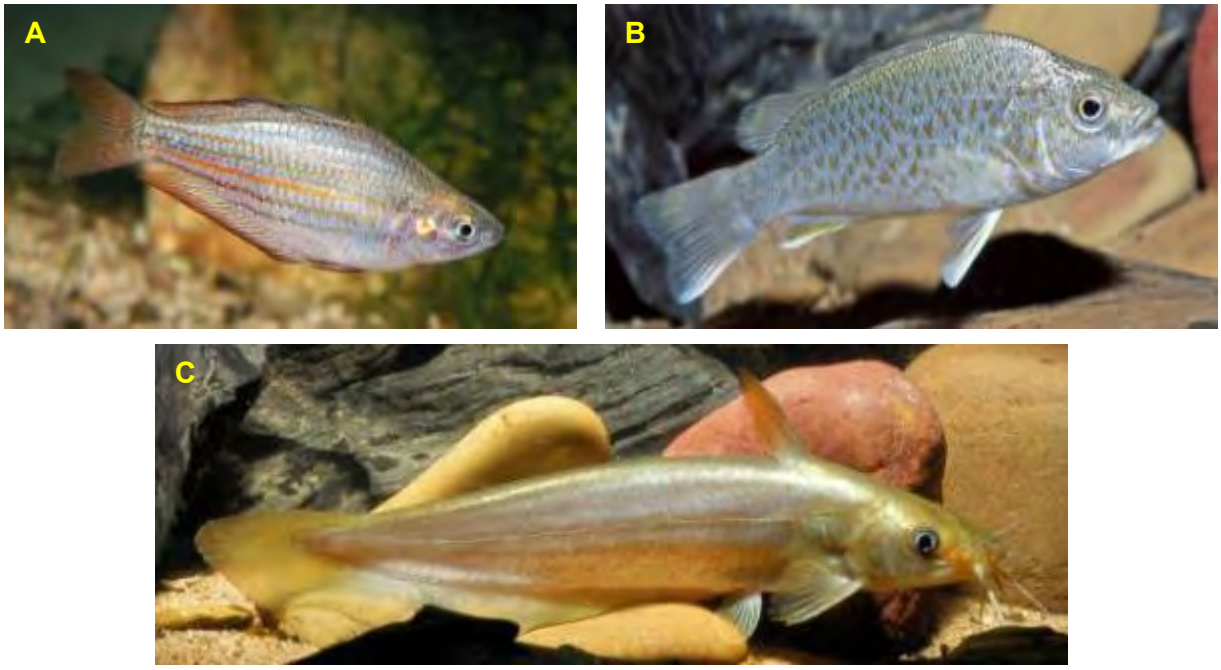


Plate 3. The three most commonly encountered freshwater fish species in the Pilbara; (A) western rainbowfish *Melanotaenia australis*, (B) spangled perch *Leiopotherapon unicolor* and (C) Pilbara tandan *Neosilurus* sp. (photos courtesy of Mark Allen ©).

Freshwater systems of the Pilbara also host a number of species that are considered to be of marine or estuarine origin, most of which have a non-obligatory freshwater juvenile phase. These commonly include barramundi (*Lates calcarifer*), mangrove jack (*Lutjanus argentimaculatus*), sea mullet (*Mugil cephalus*) and tarpon or ox-eye herring (*Megalops cyprinoides*) (Morgan and Gill 2004). The presence of marine/estuarine species in freshwater systems of the Pilbara is likely to be influenced by the frequency, timing and duration of flood events; the species listed above would only enter rivers if flooding coincided with their recruitment phase, while distance moved upstream is governed by the duration of the flood event (Morgan and Gill 2004). As floods recede, it is common for these species to become isolated in permanent upstream pools, forming small remnant populations that are cut-off from marine habitats (Morgan and Gill 2004).

Streamtec/UWA sampled the fish fauna of Robe River pools using seine nets, dip nets, and visual observation. Six freshwater fish species were recorded, including western rainbowfish, spangled perch, Pilbara tandan, barred grunter, bony bream and the conservation listed Fortescue grunter. Additionally, five marine vagrant/estuarine species were recorded, including tarpon, banded scat or striped butterfish (*Selenotoca multifasciata*), threadfin silver-biddy (*Gerres filamentosus*), sea mullet and mangrove jack.

Morgan and Gill (2004) surveyed four Robe River sites for fish using a combination of sampling methods (refer Table 1). Six freshwater species were again recorded (western rainbowfish, spangled perch, Pilbara tandan, barred grunter, bony bream and Fortescue grunter); however, no marine/estuarine

species were reported. Morgan and Gill (2004) also included historic records from the Western Australian Museum (WAM) that list empire gudgeon as occurring in the Robe River in the vicinity of the Project area.

The Department of Water (DoW) conducted a review of the ecological values of the lower Robe River, west of the North West Coastal Highway crossing point and Mesa A/Warramboo deposits, which included a summary of the freshwater and estuarine fish fauna of that reach (Antao and Braimbridge 2010). The review did not document any species from the lower Robe River that were not recorded by Streamtec/UWA or Morgan and Gill (2004).

WRM (2016) has recorded seven species from Nyeetbury Spring on upper Bungaroo Creek; Pilbara tandan, western rainbowfish, flathead goby, spangled perch, Fortescue grunter, barred grunter, and a fish that appears to be a hybrid between two of the three co-occurring terapontids (grunters; spangled perch, barred grunter and Fortescue grunter). At Yalleen Pool on Bungaroo Creek, WRM (2013) recorded only western rainbowfish, spangled perch and Pilbara tandan. WRM (2009) also surveyed the fish fauna of upper-Mungarathoona Creek, recording five species; western rainbowfish, spangled perch, Pilbara tandan, barred grunter and Fortescue grunter.

3.5 Other Fauna

3.5.1 Turtles

Although not typically targeted in aquatic surveys, one species of native turtle is known from the Pilbara region; the flat-shelled *Chelodina steindachneri.* This species has a widespread distribution throughout the Pilbara, having been recorded from most major river systems in the region, from the DeGrey River in the north to the Murchison River in the south (Kuchling 1988, WRM unpub. data). These turtles are adapted to survive drought by burrowing into the dry river beds (Kuchling 1988). Only one clutch of seven to eight relatively small eggs is laid each year; a pattern that appears to be adapted to a relatively long period of aestivation of up to three years (Kuchling 1988).

EPA (1991) note *Chelodina steindachneri* as present at Gnieraoora and Martangkuna, but do not state the source of the records, which was possibly the 1991 survey by Streamtec/UWA. Neither Antao and Braimbridge (2010) nor Pinder *et al.* (2010) document turtles. Similarly, turtles were not recorded or observed at upper-Mungarathoona Creek or Red Hill Creek by WRM (2009); however, given its widespread distribution across the Pilbara region, it is possible that *Chelodina steindachneri* may reside in pools in the vicinity of the Project area.

3.5.2 Frogs

The Pilbara is host to 13 species of frogs, three of which are endemic to the region; *Pseudophryne douglasi* (Gorge toadlet), *Uperoleia glandulosa* (Glandular toadlet) and *U. saxatilis* (Pilbara toadlet) (Tyler and Doughty 2009, Doughty *et al*. 2011). None of these species are currently listed for conservation significance, though *U. saxatilis* has only recently been described (Catullo *et al.* 2011). *U. saxatilis* is broadly distributed throughout the Pilbara, occurring in or near rocky creeks, and appears to be adapted to rocky landscapes (Catullo *et al.* 2011, Doughty *et al*. 2011). *U. glandulosa* has a more restricted distribution in the northern coastal Pilbara but penetrates inland along the Yule River drainage (Catullo *et al.* 2011, Doughty *et al*. 2011). *Pseudophryne douglasi* is a rare species that has an ancient relictual arid distribution separate from other toadlets (Doughty *et al*. 2011, WA Museum).

The Pilbara, Gascoyne and Murchison populations of the desert tree frog, *Litoria rubella*, are separated from Kimberley and Northern Territory populations by the Great Sandy Desert. *L. rubella* is known to

occur in a wide range of habitats across northern Australia, including northern Western Australia, Northern Territory, north-east of South Australia, Queensland, and northern New South Wales (Tyler and Knight 2011). The desert tree frog is commonly found sheltering under stones or bark around creeks and waterholes, and can breed at any time of year if water is present (Tyler and Knight 2011).

Frogs are difficult to survey in the Pilbara region, as captures are typically dependent on rainfall that is spatially and temporally variable (Doughty *et al*. 2011). Many frog species of the Pilbara aestivate over dry periods to avoid desiccation, emerging following rains to opportunistically breed and spawn (Tyler and Doughty 2009). No data were available on targeted frog surveys in the vicinity of the Project area, and although there have been a number of terrestrial vertebrate surveys (*e.g.* Biota 2005, 2006b, 2009, Strategen 2006), few have recorded frogs. Biota (2006a) recorded two species of Hylidae (tree frogs): *L. rubella* and *Cyclorana maini* - and one Myobatrachidae (southern frog) species *Uperoleia russelli* during baseline surveys for the Mesa A/Warramboo project area. In addition to *L. rubella* and *U. russelli*, Biota (2009) recorded the ornate burrowing frog *Platyplectrum ornatus* (formerly *Limnodynastes ornatus)* from the Red Hill Creek catchment.

3.6 Summary of Known Species of Conservation and/or Scientific Interest

Table 2 below provides a summary of known aquatic invertebrates (including hyporheos) and fish of conservation and/or scientific interest.

Table 2. Aquatic species (invertebrates and fish) of conservation and/or scientific value known to occur, or likely to occur, within the Project area.

Species	Common name	Scientific value	Conservation listing	Occurrence within 100 km of Project area	Likelihood of occurrence within the Project area	Occurrence elsewhere
Microinvertebrates						
Lecane noobjupi	Rotifer	WA endemic	N/A	Nyeetbury Spring, Red Hill Creek	High in surface waters	Weeli Wolli Ck, Marillana Ck, Coondiner Ck, Mindy Mindy Ck, Kalgan Ck and Un-named Ck, DeGrey R. Also in SW Western Australia
Paracyclops sp. 6	Copepod (micro-crustacean)	Pilbara endemic	N/A	Chalyarn Pool	High in surface waters	20+ locations Pilbara-wide
Vestalenula matildae	Ostracod (micro-crustacean)	Pilbara endemic	N/A	Chalyarn Pool	High in surface waters	Various systems of the Ashburton R., DeGrey R., Fortescue R. and Sherlock R.
Hyporheos						
Paramelitidae spp.	Stygal amphipods	Potential SRE	N/A	Yalleen Pool, Red Hill Ck, Mungarathoona Ck.	High in ground-waters and hyporheos	Unknown given family level identification.
Melitidae spp.	Stygal amphipods	Potential SRE	N/A	Bores across the Robe River catchment area	High in ground-waters; Low-moderate in hyporheos	Unknown given family level identification
Haptolana yarraloola	Stygal isopod	Potential SRE	N/A	Bores in the lower Robe River catchment area – Mesa A/Warramboo/Yarraloola	Low	Recently described species; known only from Mesa A/ Warramboo/Yarraloola bores
Kagalana tonde	Stygal isopod	Potential SRE	N/A	Bores in the lower Robe River catchment area – MesaA/Warramboo/Yarraloola	Low	Recently described genus and species; elsewhere known from Cane River and Hardey River catchments
Pilbarophreatoicus platyarthricus	Stygal isopod	Potential SRE	N/A	Chalyarn Pool, Nyeetbury Spring, Bores in the Robe River catchment area	High in ground-water and hyporheos	Weeli Wolli Ck, Coondiner Ck, Bobswim Pool (Ashburton R.)
Pygolabis sp.	Stygal isopod	Potential SRE	N/A	One undescribed species known from the Robe River catchment	High in ground-water and hyporheos	Uncertain. Members of this genus restricted to either Fortescue, Ashburton or Robe catchment groundwater and hyporheos
Tainisopus sp.	Stygal isopod	Potential SRE	N/A	Nyeetbury Spring	Low-moderate; only known from Nyeetbury Spring hyporheos	Unknown given genus level identification

Species	Common name	Scientific value	Conservation listing	Occurrence within 100 km of Project area	Likelihood of occurrence within the Project area	Occurrence elsewhere
Parabathynellidae spp.	Stygal syncarids	Potential SRE	N/A	Unknown given genus level identification	High in ground-waters; Low-moderate in hyporheos	Unknown given genus level identification
Macroinvertebrates						
Hemicordulia koomina	Pilbara emerald dragonfly	Pilbara endemic	IUCN, Near Threatened	Robe River pools, Red Hill Ck.	High in surface waters	Fortescue R., Coondiner Ck; now known to be widespread throughout the Pilbara, though infrequently collected
Eurysticta coolawanyah	Pilbara pin damselfly	Pilbara endemic	IUCN, Near Threatened	Chalyarn Pool, Robe River pools, Yalleen Pool	High in surface waters	Ashburton R. (Bobswim Pool); Kalgan Ck; Coondiner Ck; Fortescue R.
Ictinogomphus dobsoni	Pilbara tiger dragonfly	Pilbara endemic	N/A	Chalyarn Pool, Robe River pools, Red Hill Ck.	High in surface waters	Fortescue, Ashburton, Yule, DeGrey and Sherlock rivers
Nannophlebia injibandi	Pilbara archtail dragonfly	Pilbara endemic	N/A	Robe River pools, Red Hill Ck.	Low-Moderate in surface waters	Fortescue R. catchment, but uncommonly collected
Agriocnemis kunjina	Pilbara wisp damselfly	Pilbara endemic	N/A	Robe River Pools, Yalleen Pool	Low-Moderate in surface waters	Millstream, Harding River, Tanberry Ck; rarely collected
Haliplus halsei	Aquatic beetle	Pilbara endemic	N/A	Chalyarn Pool, Myannore Ck.	Low-Moderate in surface waters	Uncommonly collected from ephemeral systems and claypans, *e.g.* the Fortescue Marsh and Coondiner Pool
Haliplus pilbaraensis	Aquatic beetle	Pilbara endemic	N/A	Red Hill Ck.	Low-Moderate in surface waters	Uncommonly collected from ephemeral systems and claypans, *e.g.* the Fortescue Marsh and Coondiner Pool
Sternopriscus pilbaraensis	Diving beetle	Pilbara endemic	N/A	Red Hill Ck.	Moderate in surface waters	A range of systems across the Pilbara, fairly commonly collected
Tiporus tambreyi	Diving beetle	Pilbara endemic	N/A	Chalyarn Pool, Robe River pools, Red Hill Ck.	Moderate-High in surface waters	A range of systems across the Pilbara, very commonly collected
Tiporus lachlani	Diving beetle	Pilbara endemic	N/A	Red Hill Ck.	Low-Moderate in surface waters	A range of systems across the Pilbara, infrequently collected
Laccobius billi	Aquatic beetle	Pilbara endemic	N/A	Mungarathoona Ck, Red Hill Ck.	Low-Moderate in surface waters	Yule R. and Fortescue R.

Species	Common name	Scientific value	Conservation listing	Occurrence within 100 km of Project area	Likelihood of occurrence within the Project area	Occurrence elsewhere
Fish						
Leiopotherapon aheneus	Fortescue grunter	Pilbara endemic	IUCN Near Threatened; Parks and Wildlife P4	Robe River pools, Red Hill Ck., Mungarathoona Ck.	High in surface waters	Fortescue R (below Fortescue Marsh); Ashburton R.

4 METHODS FOR BASELINE SURVEYS

4.1 General

For the current baseline field sampling, WRM employed sampling design, methods and general approaches consistent with the following:

- Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ 2000);
- Environment Protection Authority (EPA) Guidance No. 20, Sampling of Short Range Endemic Invertebrate Fauna for Environmental Impact Assessment in Western Australia (EPA 2009);
- EPA Position Statement No. 3, Terrestrial Biological Surveys as an Element of Biodiversity Protection (EPA 2002);
- EPA Guidance No. 56, Terrestrial Fauna Surveys for Environmental Impact Assessment in Western Australia (EPA 2004).

Aquatic fauna sampling methods were also similar to the following:

- Streamtec/UWA surveys of benthic macroinvertebrates of the Robe River (see Dobbs and Davies 2009, Streamtec 2014);
- Parks and Wildlife surveys of benthic macroinvertebrates for the regional Pilbara Biological Survey (PBS) (see Pinder *et al.* 2010).

4.2 Licences

This study was conducted under Department of Fisheries (DoF) Exemption #2706 (Authority to Take Fish for Scientific Purposes), and Parks and Wildlife Licence SF010732 (Licence to Take Fauna for Scientific Purposes).

As a condition of these licences, taxa lists and reports are required to be submitted to the respective government departments, and have been done so.

4.3 Sampling Design and Sites

The sampling design is an mBACI (multiple Controls - Before/After - Control/Impact) type design (Keough and Mapstone 1995). Location and number of sites were selected to provide data for robust statistical analysis and to meet requirements of such a design. An mBACI design is considered ideal for impact assessment, as impacts may be placed in context with natural temporo-spatial catchment changes. An mBACI type design provides both benchmark information as well as a strong basis to detect future changes. Reference sites upstream of the Project area were selected to serve as the "control" for potentially impacted sites. Surveys conducted in April/May 2016 are part of the benchmark or "before" phase against which to assess any potential future changes.

Sampling was conducted during the late wet season, between 28th April and 7th May 2016.

A total of 12 pools were sampled along the main channel of the Robe River (Table 3 and Figure 1). Sites included six potentially exposed sites within the predicted surface extent of dewatering discharge, and six reference sites upstream of the Jimmawurrada Creek-Robe River confluence.

Table 3. Aquatic ecosystem sampling sites on the Robe River. Equivalent sites monitored by Streamtec/UWA are also indicated.

Type	WRM Site	Description	GPS co-ordinates (zone 50 K)		Date sampled	Maximum wetted width, length and depth of pool (m)			Streamtec/ UWA site
			Easting	Northing		Width	Length	Depth	
Reference	RRU1	Approx. 3.7 km upstream of Pannawonica Hill.	435628	7603253	05-05-16	20	100	1.2	
	RRU2	Approx. 600 m downstream of Streamtec/UWA site at Pannawonica Hill Pool; upper end of Medawandy Waters area, adjacent Mesa N.	431811	7602046	28-04-16	9	55	3.0	Pannawonica Hill
	RRU3	Approx. 1.6 km downstream of Pannawonica Hill, near Mesa N; within the Medawandy Waters area.	430912	7601562	28-04-16	5	3	1.0	Medawandy
	RRU4	Approx. 1.5 km downstream of RRU3; within the Medawandy Waters area, in the vicinity of Mesa M.	429677	7601439	28-04-16	20	120	1.0	
	RRU5	Approx. 1 km downstream of RRU4; within the Medawandy waters area, adjacent Mesa L.	428769	7601342	29-04-16	10	40	1.2	
	RRU6	Approx. 1 km upstream of Jimmawurrada Creek confluence; lower end of the Medawandy waters area, at base of Mesa L.	424573	7597240	07-05-16	12	40	0.6	
Potentially Exposed	RRD1	Martangkuna; approx. 600 m downstream of existing Mesa J dewatering discharge point (*i.e.* western discharge point).	417110	7598094	30-04-16	3	7	0.8	Martangkuna
	RRD2	Approx. 0.9 km downstream of RRD2.	416245	7598031	30-04-16	6	12	0.7	
	RRD3	Approx. 1 km downstream of RRD3.	415309	7598013	30-04-16	5	25	1.0	
	RRD4	Approx. 1.1 km downstream of RRD3; 1 km upstream of Yeera Bluff.	414419	7597633	29-04-16	20	150	2.0	
	RRD5	Gnieraroora / Dthulurat* at Yeera Bluff; 8.6 km downstream of existing Mesa J western discharge point.	414426	7596622	29-04-16	25	45	4.0	Gnieraoora
	RRD6	Approx. 12.5 km downstream of existing Mesa J western discharge point; within projected discharge footprint (at 20 ML/day).	411415	7594924	30-04-16	30	20	1.2	

* Dthulurat = Western Guruma name.

The original intent was that the assessment would utilise, wherever possible, long-term data from sites sampled by Streamtec/UWA; however, only two of these sites are located within the predicted footprint of surface discharge extent; Martangkuna (RRD1) and Gnieraoora/Dthulurat (RRD5). Therefore, four new sites (RRD2, RRD3, RRD4 and RRD6) were added to allow a more robust characterisation of ecological condition within this reach (Table 3 and Figure 1). These sites may also be exposed to any runoff from the Project area.

Of the sites sampled by Streamtec/UWA upstream of the Jimmawurrada-Robe confluence, two were selected as reference sites for the Project area; Medawandy and Pannawonica Hill Pool; however, only Medawandy (RRU3) held surface water at the time of sampling in April-May 2016. Therefore, five new reference sites were established within the Medawandy Waters area; RRU1, RRU2, RRU4, RRU5 and RRU6 (Table 3 and Figure 1). Site photographs are provided in Appendix 1.

The 2016 sampling was timed to correspond with recessional flow conditions at the end of the wet (April-May) season. It was considered that the end of the wet season would be a more ecologically important time of year to sample, as biological diversity would be expected to be at its highest. By comparison, lower biological diversity may be expected at the start of the wet season, as many invertebrate fauna would not yet have emerged/colonised the seasonal creeks.

4.4 Water Quality

At each site, pH, dissolved oxygen and temperature were measured *in situ* using hand-held Wissenschaftlich-Technische-Werkstätten (WTW) field meters. Meters were calibrated immediately prior to field surveys. Water depth was measured using a graduated pole. Undisturbed water samples were collected for laboratory analyses of major ions, alkalinity, dissolved metals, nutrients and total suspended solids (TSS). Water samples for nitrogen and phosphorus nutrient and dissolved metal analyses were filtered in the field through 0.45 µm nitrocellulose filters. To avoid contamination, all sample bottles and filtering equipment used for dissolved metals were acid-washed (0.1% nitric acid) prior to use. Bottles and filters used for nutrients weren't acid washed to avoid nitrogen contamination from nitric acid. Water samples for analysis of dissolved metals and nutrients were collected using nitrile gloves. All samples were double-wrapped in polyethylene zip-lock bags and kept cool on ice-packs in an esky while in the field and during transport. At the end of each field day, samples were either refrigerated (ions and metals) or frozen (nutrients). Samples were stored refrigerated or frozen for a maximum of 10 days prior to transport on ice to analytical laboratories at ChemCentre, Bentley, together with chain-of-custody forms. All water quality variables measured are summarised in Table 4.

4.4.1 Comparison against ANZECC/ARMCANZ Guidelines

Water quality data were compared against default ANZECC/ARMCANZ (2000) guidelines (trigger values) for the protection of freshwater ecosystems (provided in Appendix 2). Default trigger values (TVs) for 95% aquatic species protection were considered more appropriate than default TVs for 99% protection, given that the Robe River catchment in the vicinity of current mining operations is already slightly to moderately disturbed by historic mining and pastoral practices (Strategen 2006). In accordance with ANZECC/ARMCANZ (2000) however, the default 99% TVs were applied to bioaccumulating metals such as selenium. For metals and nutrients, dissolved concentrations (0.45 µm filtered samples) were compared to the default TVs. Filtered concentrations were considered a better reflection of the fraction that may be bioavailable. By contrast, comparison of the default TVs to the total metal or total nutrient concentration may overestimate the risk to the environment (ANZECC/ARMCANZ 2000).

Table 4. Measured and derived water quality and habitat parameters. Metals (Al, As, B, Ba, Cd, Co, Cr, Cu, Fe, Mn, Mo, Ni, Pb, S, Se, U, V, Zn) and nutrients ($N\text{-}NH_3$, $N\text{-}NO_2$, $N\text{-}NO_3$, $N\text{-}NO_X$, N-total, P-total) were measured as dissolved concentration. All units for water quality parameters are mg/L unless stated otherwise.

Water Quality Parameters	Code	Habitat Parameters	Code
Temperature (°C)	Temp	Maximum pool depth (m)	depth
pH (H^+)	pH	Maximum wetted length of pool (m)	length
Dissolved oxygen (%)	DO%	Mean wetted width of pool (m)	width
Dissolved oxygen (mg/L)	DO	Mineral substrates (total % cover within habitat)	min
Conductivity (µS/cm)	EC	Bedrock (% cover)	bedr
Redox (mV)	Redox	Boulders >256 mm (% cover)	boul
Alkalinity (as $CaCO_3$)	Alk	Cobbles 64-256 mm (% cover)	cobb
Ammonia	$N\text{-}NH_3$	Pebbles 16-64 mm (% cover)	pebb
Arsenic	As	Gravel 4-16 mm (% cover)	grav
Barium	Ba	Sand 1-4 mm (% cover)	sand
Boron	B	Silt <1 mm (% cover)	silt
Cadmium	Cd	Mean particle size (from substrate proportions)	phi
Calcium)	Ca	Emergent macrophyte (% cover)	emerg
Carbonate	CO_3	Submerged macrophyte (% cover)	submerg
Chloride (mg/L)	Cl	Floating macrophyte (% cover)	float
Chromium (µg/L)	Cr	Algae (% cover)	algae
Copper (µg/L)	Cu	Detritus (% cover)	detr
Hardness (as $CaCO_3$)	Hard	Riparian vegetation canopy (% canopy cover)	ripvegco
Hydrogen carbonate	HCO_3	Large woody debris (>10 cm diameter) (% cover)	LWD
Iron	Fe	Root mats (% cover)	rootm
Lead	Pb	Trailing riparian vegetation (% cover)	ripveg
Magnesium	Mg	Habitat diversity (total no. of habitat types)	habdiv
Manganese	Mn	Substrate compaction (1 = loose, to 5 = armoured)	compct
Nickel	Ni	Substrate diversity (total no. substrate types)	subdiv
Nitrate-nitrogen	$N\text{-}NO_3$		
Nitrite-nitrogen	$N\text{-}NO_2$		
Nitrogen oxides	$N\text{-}NO_X$		
Nitrogen-total	N-total		
Phosphorus-total	P-total		
Potassium	K		
Selenium	Se		
Sodium	Na		
Sulfate	$S\text{-}SO_4$		
Sulfur	S		
Total dissolved solids	TDS		
Total suspended solids	TSS		
Uranium	U		
Vanadium	V		
Zinc	Zn		

4.5 Habitat Characteristics

Details of habitat characteristics at each site were recorded (Table 4) to assist in explaining any patterns in faunal assemblages, particularly due to existing differences in benthic substrate composition. Habitat parameters were assessed for the approximately 10 m section of river over which each macroinvertebrate sample was collected. Water depth was measured with a graduated pole. Substrate type was visually assessed and recorded as estimated percent cover by bedrock, boulders, cobbles, pebbles, gravel, sand, silt and clay, from which mean particle size was determined using the phi scale. As an indication of habitat heterogeneity, the number of organic and inorganic substrate types

represented at each site was totalled. Habitat characteristics recorded included estimated percent cover by inorganic sediment, submerged macrophyte, floating macrophyte, emergent macrophyte, algae, large woody debris, detritus, roots and trailing vegetation.

WRM has specific worksheets for this task to ensure qualitative habitat recordings between sites are as comparable as possible. To limit variation due to different observers, all estimations were made by the same sampler.

4.6 Microinvertebrates (zooplankton)

Microinvertebrate samples were collected from each site by gentle sweeping over an approximate 15 m distance with a 53 µm mesh plankton net (Plate 4). Care was taken not to disturb the benthos (bottom sediments) during sampling. Samples were preserved in 70% ethanol and sent to Dr Russell Shiel at the University of Adelaide, South Australia, for processing. Dr Shiel is a world authority on microfauna, with extensive experience in fauna survey and impact assessment across Australasia, including the Pilbara.

Plate 4. Microinvertebrate sampling at RRD4.

Microinvertebrate samples were processed by identifying the first 200-300 individuals encountered in an agitated sample decanted into a 125 mm^2 gridded plastic tray, with the tray then scanned for additional missed taxa also taken to species and recorded as 'present'. Specimens were identified to the lowest taxon possible, *i.e*. species or morphotypes. Abundance data were reported as log_{10} scale abundance classes (*i.e.* 1 = individual, 2 = 2-10 individuals, 3 = 11-100 individuals, 4 = 101-1000 individuals, 5 = >1000). Where specific names could not be assigned, vouchers were established. These vouchers are held by Dr Shiel at Adelaide University, Adelaide, Australia.

4.7 Hyporheos

At each site, hyporheic sampling was conducted using the Karaman-Chappuis method (Delamare Deboutteville 1960). This involved digging a hole approximately 20 cm deep and 40 cm diameter in alluvial gravels in dry streambed adjacent to the water's edge, allowing the hole to infiltrate with water, and sweeping the water column with a modified 110 µm mesh plankton net (Plate 5). The water column was swept immediately after the hole had filled, and again after approx. 30 minutes, once other sampling had been conducted.

Plate 5. Hyporheic sampling at RRU3.

Samples were preserved in 70% ethanol and returned to the laboratory for processing. Any aquatic fauna present was removed from samples by sorting under a low power dissecting microscope. In-house expertise was used to identify the majority of hyporheic taxa using available published keys and through reference to the established voucher collections held by WRM. External specialist taxonomic expertise was sub-contracted to assist with Chironomidae (Dr Don Edward, UWA) and micro-crustacea (Dr Russel Shiel, University of Adelaide).

All taxa recorded from hyporheic samples were classified using the categories of Boulton (2001):

- stygobite, *i.e.* obligate groundwater species, with special adaptations to survive such conditions,
- permanent hyporheos stygophile, *i.e.* epigean[8] species that may occur in both surface and groundwaters, but is a permanent inhabitant of the hyporheic zone,
- occasional hyporheos stygophile, *i.e.* species that use the hyporheic zone seasonally or during early life history stages, or
- stygoxene, *i.e.* species that appear rarely and apparently at random in groundwater habitats; there by accident or seeking refuge during spates or drought; not specialised for dwelling permanently underground.

4.8 Macroinvertebrates

Macroinvertebrate sampling was conducted with a 250 μm mesh FBA pond net (Plate 6). All meso-habitats were sampled, including trailing riparian vegetation, woody debris, open water column and benthic sediments with the aim of maximising the number of species recorded. Each sample was washed through a 250 μm sieve to remove fine sediment, while leaf litter and other debris were carefully washed in the sieve and removed by hand. Samples were then preserved in 70% ethanol. In the laboratory, macroinvertebrates were removed from samples by sorting under a low power dissecting microscope.

Plate 6. Macroinvertebrate sampling at RRU5.

Collected specimens were identified to the lowest practicable level (typically genus or species) and enumerated to $\log_{10}$ scale abundance classes (*i.e.* 1 = individual, 2 = 2-10 individuals, 3 = 11-100 individuals, 4 = 101-1000 individuals, 5 = >1000). In-house expertise was used to identify invertebrate taxa using available published keys and through reference to the established voucher collections held by WRM. External specialist taxonomic expertise was sub-contracted to assist with Chironomidae (Dr Don Edward, UWA).

4.9 Fish

A number of fish sampling methods were used at each site in order to collect as many species and individuals as possible. Methods included electrofishing, seine nets and gill nets. Electrofishing was conducted with a Smith-Root Model LR24 battery powered backpack electrofisher (Plate 7A). Electrofishing is an extremely useful and efficient sampling tool in rivers with clear, low salinity, slow flow water. All meso-habitats within a maximum 40 m reach were shocked with the intention of recovering as many species/individuals as possible. Shocking was not continuous, but targeted areas of optimum habitat, whereby the operator would shock, move to a new habitat before shocking again, and so prevent fish being driven along in front of the electrical field.

Duplicate 30 m multi-panel gill nets were set at each site where there was sufficient depth of water (Plate 7B). Each net consisted of 6 x 5 m panels, with panels increasing in size from 1" to 6" stretched mesh size. The nets were set perpendicular to the bank, with the smallest mesh set against the bank, and the large mesh positioned into the channel with a float and weight to keep the nets in place. At

[8] Epigean – living or occurring on or near the surface of the ground.

each sampling location, two nets were set for approximately 2.5 hours. Nets were checked frequently to avoid fish deaths. Catch from the duplicate nets were combined to form one replicate sample from each sampling location.

Smaller species and juveniles were sampled by beach seine (10 m net, with a 2 m drop and 6 mm mesh) deployed in shallow areas where there was little vegetation or large woody debris. Typically, two seine hauls were made at each location to maximise the number of individuals caught.

All fish were identified in the field, measured for standard length (SL)[9], and then released alive. Fish nomenclature followed that of Allen *et al.* (2002). Fish measurements provided information on the size structure, breeding and recruitment of fish populations.

Plate 7. Example of electrofishing (left), and setting gill nets at RRU1 (right).

4.10 Data Analysis

Samples were grouped *a priori* into categories according to exposure; potentially exposed sites downgradient of the Jimmawurrada-Robe confluence (RRD) or reference sites upgradient of the Jimmawurrada-Robe confluence (RRU). Water quality and species richness (number of taxa) data were plotted in order to illustrate spatial differences. For comparison of species richness against previous studies, invertebrate taxonomy was standardised across datasets to account for differences in taxonomic resolution and/or advancements in taxonomic knowledge between studies (*i.e.* some taxa were condensed to family or order level to enable comparison). As such, taxa richness may appear lower than was originally reported in each study. Where sufficient numbers of each fish species were measured, length-frequency histograms of current data were plotted.

Univariate analyses (one-way ANOVA) was used to test for statistically significant (p <0.05) differences in water quality variables and micro- and macroinvertebrate species richness between groups (RRD, RRU). The assumptions of normality and homogeneity of sample variances were checked using Shapiro-Wilk and Levene's tests, respectively. Data were $\log_{10}(x+1)$ transformed where appropriate. All univariate analyses were performed using IBM SPSS Statistics (v21) software package.

Multivariate patterns in micro- and macroinvertebrate species assemblages were analysed using procedures from the PRIMER (v7) software package (Clarke and Gorley 2006). Non-metric Multi-Dimensional Scaling (nMDS) ordination plots (Clarke and Warwick 2001) were constructed to visualise differences between sites. nMDS ordinations were based on Bray-Curtis similarity measures for species abundance ($\log_{10}$ class) data. Ordinations were depicted as two-dimensional plots. The Analysis of

[9] Standard length (SL) - measured from the tip of the snout to the posterior end of the last vertebra or to the posterior end of the mid-lateral portion of the hypural plate (*i.e.* this measurement excludes the length of the caudal fin).

Similarity (ANOSIM) routine within PRIMER was used to test for significant ($p < 0.05$) differences in species assemblages between groups (RRD, RRU), based on both abundance (log_{10} class) and presence/absence data. The SIMPER routine within PRIMER was used to determine those species contributing most to the similarity/dissimilarity between significant site groupings identified by ANOSIM.

Too few taxa were recorded from hyporheic samples to warrant ANOVA or PRIMER analyses of these data.

4.11 Survey Limitations

Inherent physical sampling deficiencies are acknowledged as a barrier to sampling aquatic fauna, and in particular fish. For example, fish catch rates may have been hindered by the abundance of aquatic vegetation (macrophytes and algae) which physically obstructed seine and gill nets at some sites. This was somewhat compensated for by the use of a back-pack electrofisher, which generates a pulsed direct electrical current to draw fish out from under such habitat.

This study provides a snapshot of water quality conditions and faunal communities at a single point in time, and is unlikely to fully capture the range of temporal/seasonal variability within the Project area. Prior to sampling, total monthly rainfall at Pannawonica Gauging Station was well below the 45-year average, particularly during February, March and April. As such, there was no surface flow connecting pools along the Robe River, with pools heavily receded and even some fish mortality evident, possibly due to low overnight dissolved oxygen concentrations. The relative lack of rainfall leading up to the survey may also have caused recordings of some other water quality parameters, such as salinity and nutrients, to be higher than would be expected under “average” wet season baseflow conditions, due to evapo-concrentration effects and lack of flushing within the system. Dry conditions may also have affected aquatic faunal communities, particularly hyporheic fauna, which require saturation of the alluvium and strong connectivity between ground and surface waters, and fish, with many speces known to require higher baseflows and connectivity between pools to enable upstream migration and spawning.

5 RESULTS AND DISCUSSION

5.1 Water Quality

5.1.1 General

Raw data for spot measurements of water quality, made in conjunction with aquatic fauna sampling, are provided in Appendix 3. Water quality was highly variable amongst sites (Figures 4 and 5). Salinity levels ranged from fresh[10] (592 µS/cm, RRD5) to brackish (1,700 µS/cm, RRU6), pH from circum-neutral (6.9, RRU3) to slightly alkaline (7.9, RRU1), hardness from 230 mg/L (RRD2) to 520 mg/L (RRU6), total suspended solids from <1 mg/L (RRD4, RRU3, RRU4) to 34 mg/L (RRD5), and dissolved oxygen from hypoxic[11] (14.5%, RRU5) to supersaturated (134.9%, RRD6).

There were no obvious longitudinal gradients upstream or downstream of the Jimmawurrada-Robe confluence. Site RRU6 (located ~1 km upstream of the confluence), together with the downstream sites, tended to have higher salinity (as EC and TDS), alkalinity, hardness and concentrations of associated ions, than sites upstream (Figure 3). Maximum values for most of these parameters (*i.e.* EC, TDS, hardness, Na^+, Cl^+, Ca^{2+}, $S\text{-}SO_4$, Mg^{2+}) and for nitrogen (as N-total, $N\text{-}NO_X$, $N\text{-}NH_3$) were recorded at RRU6. Average concentration of K^+, $S\text{-}SO_4$ and total dissolved sulfur (S) was significantly higher downstream of the Jimmawurrada-Robe confluence (one-way ANOVA, Table 5).

Table 5. Summary results from one-way ANOVAs testing for significant (p <0.05) differences in mean concentrations of water quality parameters, upstream (RRU) and downstream (RRD) of the Jimmawurrada-Robe confluence. Only significant results are shown. Mean (±SE) vales for untransformed data are also provided.

Water quality parameter	ANOVA (df = 1, 11)			Mean (±SE)	
	MS	F	p	RRD (n = 6)	RRU (n = 6)
Fe	0.005	9.52	0.012	0.05 (0.01)	0.12 (0.005)
K	23.24	21.96	0.001	8.4 (0.52)	5.6 (0.29)
S	352.08	35.62	<0.001	25.3 (0.95)	14.5 (1.54)
$S\text{-}SO_4$	2104.10	15.52	0.003	70.2 (4.67)	43.7 (4.83)

The significantly higher concentrations of some ions, most notably $S\text{-}SO_4$, and to a lesser extent Mg (Figure 4), downstream of the Jimmawurrada-Robe confluence, may reflect the influence of dewatering discharge from current mining operations. Some inter-site variability could also be attributed to differences in volume of the remnant pools sampled, and evapoconcentration effects under recessional flows. For example RRU6, where maximum values for a number of parameters were recorded, was the shallowest of the pools sampled (maximum water depth of 0.6 m), and supported extensive organic deposits and abundant macrophyte growth (*Typha* and *Potamogeton*) (Appendix 4). The relative abundance of macrophytes, algae and accumulated organics would also be expected to have varying effect on DO levels, pH and rates of nutrient recycling within each of the pools. The higher level of TSS recorded at Gnieraoora (RRD5) compared to all other sites (Figure 5) was likely due to recent cattle activity, which caused the physical disturbance and suspension of benthic sediments.

At most sites, Na^+ was the dominant cation, with Ca^{2+} sub-dominant, and HCO_{3-} the dominant anion, with Cl^- sub-dominant. The exception was RRU6, where Cl^- was dominant and HCO_{3-} sub-dominant. This suggests groundwater ingress had less influence on the water chemistry of the remnant pool at RRU6

[10] Fresh defined as < 1,500 µS/cm; brackish = 1,500 – 4,500 µS/cm; saline = 4,500 - 50,000 µS/cm; hypersaline > 50,000 µS/cm (DoE 2003). Classifications were presented as TDS (mg/L) in DoE (2003) so a conversion factor of 0.68 was used to convert to conductivity µS/cm as recommended by ANZECC/ARMCANZ (2000).

[11] Dissolved oxygen (DO) levels of zero percent saturation = anoxic; < 20% = defined as hypoxic; 100% = saturated; >100% = super-saturated; more oxygen is dissolved than would be in a state of equilibrium.

than at other pools, which may help to also explain the relatively higher salinity at RRU6 (*i.e*. less groundwater inflow to offset effects of evapoconcentration).

5.1.2 Exceedance of ANZECC/ARMCANZ default TVs

Exceedance of ANZECC/ARMCANZ default 95% TVs was recorded for EC, DO, dissolved zinc, N-total, N-NO_x and N-NH_3 at a number of sites upstream and downstream of the Jimmawurrada-Robe confluence (refer Appendix 3). No exceedance of ANZECC/ARMCANZ (2000) default TVs was recorded for any other parameter. Exceedances are discussed in the following sub-sections.

Electrical Conductivity (EC)

EC values were in exceedance of the ANZECC/ARMCANZ (2000) TV (250 μS/cm) at all sites sampled, although surface waters could still be classified as "fresh" (<1,500 μS/cm) at most sites (Figure 4). The relatively higher EC at RRU6 (1,700 μS/cm) constitutes "brackish" conditions, and was above EC levels reported during long-term monitoring of Robe River pools by Streamtec/UWA and the Proponent (*i.e.* 453 - 1,400 μS/cm). Elevated EC was again considered due to high levels of evapoconcentration in these isolated pools, a process common to surface waters in arid/semi-arid zones (Jolly *et al.* 2008). Although some dilution may occur following wet season rains, salinity can often remain high in arid-zone surface waters due to the variability of flows and flushing of stored salts (Jolly *et al.* 2008). ANZECC/ARMCANZ (2000) acknowledge that the default TV for EC may not be representative of local background levels in all areas of Australia. In such instances, ANZECC/ARMCANZ (2000) recommend developing site-specific trigger values (SSTVs) relevant to local conditions.

Dissolved Oxygen (DO)

Daytime DO saturation was below the ANZECC/ARMCANZ (2000) lower TV (80%) at the majority of sites, and above the upper TV (120%) at RRD6 (134.9%) (Figure 5 andAppendix 3). In aquatic ecosystems, low DO levels are typically considered of greater concern than high levels; however, super-saturated levels (>100%) during the day are often indicative of anoxic or hypoxic conditions at night. Low DO is commonly associated with standing pools (with little physical aeration) that support heavy organic loads (*e.g.* aquatic vegetation, algae, bacteria, *etc.*) (Caraco and Cole 2002). DO saturation is typically lowest in the early morning, following overnight consumption of oxygen through the respiratory processes of aquatic biota (Caraco and Cole 2002, Connolly *et al.* 2004, Flint *et al.* 2014). Sites which exhibited particularly low DO in the current study (*e.g.* RRU3 16.1%, RRU5 14.5%) were sampled early in the morning (*i.e.* between 0700 hrs and 0830 hrs), and also tended to support relatively high abundances of macrophytes and/or algae (Appendix 4). While the oxygen needs of aquatic biota differ between species and life history stages, values less than 50% saturation are associated with chronic responses in fish and macroinvertebrates (Connolly *et al.* 2004, Flint *et al.* 2014).

Super-saturation can occur when net photosynthesis exceeds total oxygen consumption in waterbodies, and is common in areas of high algal and macrophyte growth, particularly if spot measurements are taken later in the day (Caraco and Cole 2002). The organic habitat at RRD6, (134.9% DO) comprised emergent and submerged macrophyte (covering 50% of the site area; Appendix 4), and the spot measurement of DO was taken at 1230 hrs, when photosynthetic processes were likely near their peak. Waterbodies with super-saturated daytime DO are likely to experience overnight hypoxia or anoxia, as respiration by plants, algae, bacteria and other aquatic fauna deplete DO (Caraco and Cole 2002, Connolly *et al.* 2004, Flint *et al.* 2014).

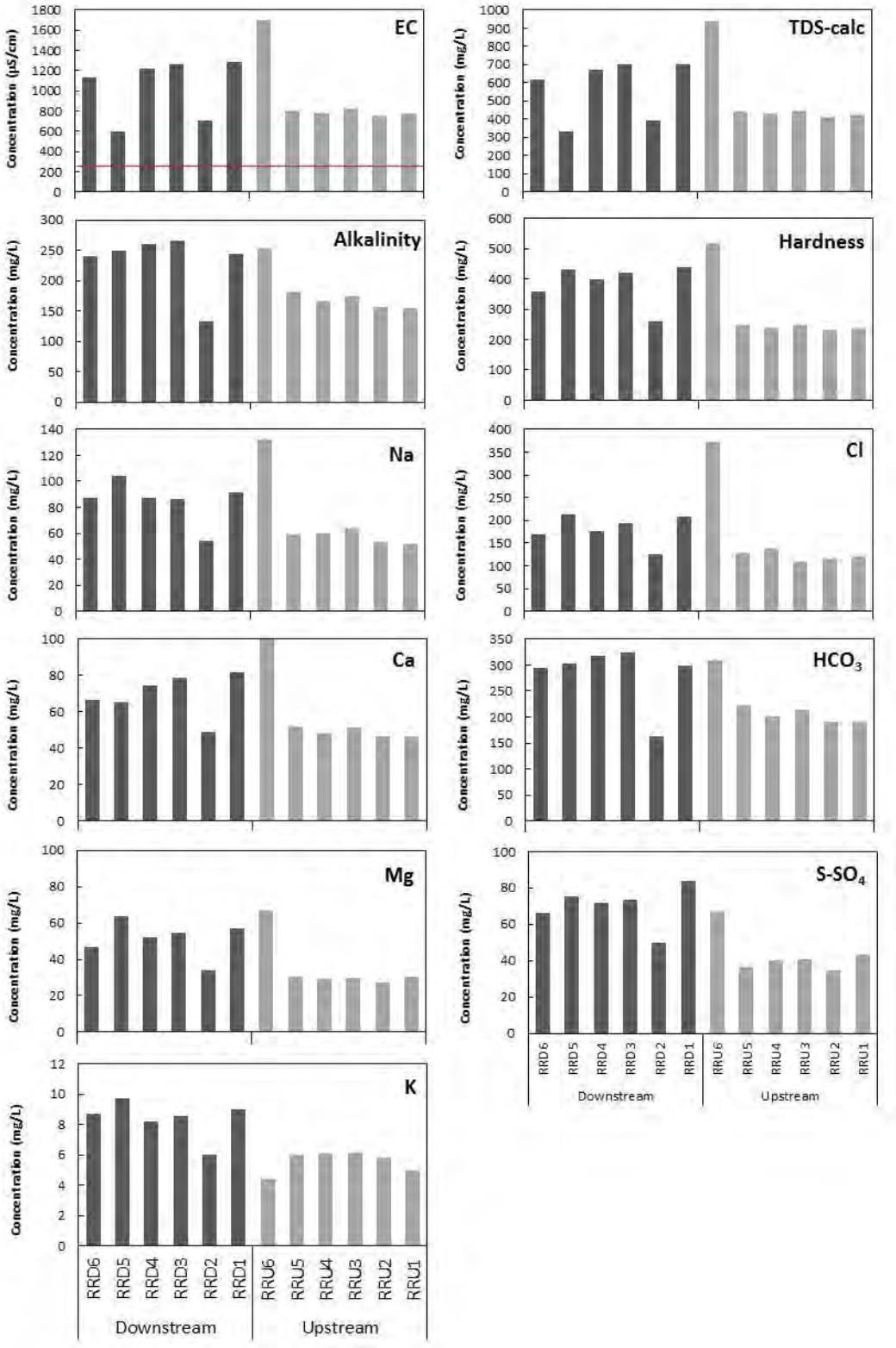


Figure 4. Comparison of EC, alkalinity, hardness and concentration of major ions amongst surface water sampling sites upstream (RRU1 to 6) and downstream (RRD1 to 6) of the Jimmawurrada-Robe confluence. Refer Table 1 for explanation of site codes and Figure 1 for location of sites. ANZECC/ARMCANZ (2000) default 95% species protection level TV (unbroken red line) is indicated for relevant parameters.

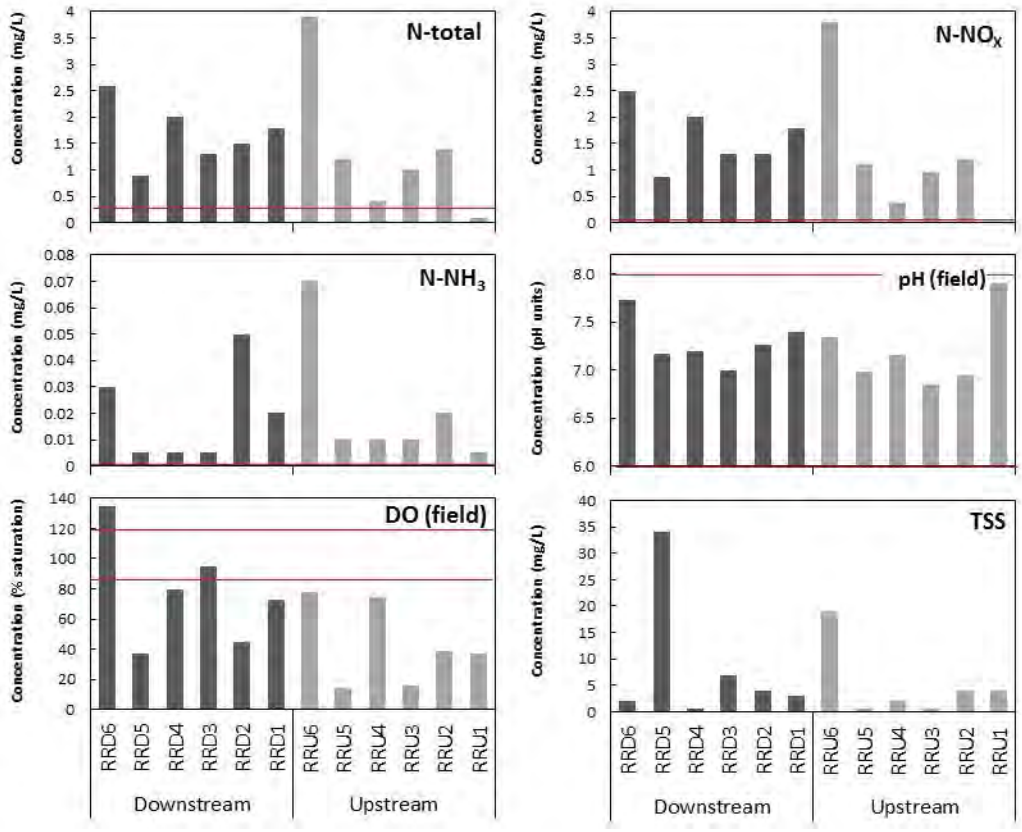


Figure 5. Comparison of N-total, N-NO_X, N-NH_3, pH, DO and TSS amongst surface water sampling sites upstream (RRU1 to 6) and downstream (RRD1 to 6) of the Jimmawurrada-Robe confluence. Refer Table 1 for explanation of site codes and Figure 1 for location of sites. ANZECC/ARMCANZ (2000) default 95% species protection level TV (unbroken red line) is indicated for relevant parameters; upper and lower TVs are shown for pH and DO.

Dissolved zinc

Dissolved zinc (dZn) concentration was in exceedance of ANZECC/ARMCANZ (2000) TVs (0.008 mg/L) at RRU5 (0.012 mg/L) and RRD3 (0.011 mg/L) (Appendix 3). ANZECC/ARMCANZ (2000) provide algorithms to calculate hardness modified TVs (HMTVs), as hardness has an ameliorating effect on the toxicity of a number of metals including cadmium, lead, nickel and zinc[12]. However, once the algorithm was applied, concentrations of dZn at RRU5 and RRD3 still excceded HMTVs. Although elevated, it is unknown what proportion of dZn was labile (bioavailable) or unavailable through processes such as complexing with dissolved organic carbon. Where dissolved levels are elevated, ANZECC/ARMCANZ (2000) recommends testing for labile concentrations/bioavailability to assess if levels are likely to be toxic to aquatic fauna. Given that exceedances of the ANZECC/ARMCANZ (2000) TV were recorded at sites both upstream (reference) and downstream of the Jimmawurrada-Robe confluence, it is unlikely that current Mesa J discharge operations are influencing dZn levels in the Project area.

Nitrogen (N-total, N-NO_X, N-NH_3)

At most sites (except RRU1), N-total, N-NO_X and N-NH_3 exceeded ANZECC/ARMCANZ (2000) default 95% TVs for protection against eutrophication (0.3 mg/L N-total, 0.01 mg/L N-NO_X, 0.01 mg/L N-NH_4[13])

[12] HMTV algorithm for zinc = Default TV*(Hardness/30)^0.85.
[13] Ammonia was analysed as nitrogen-ammonia (N-NH_3), so a conversion factor of 1 was used to convert to nitrogen as ammonium (N-NH_4) for comparison against ANZECC/ARMCANZ (2000) default TV for protection against eutrophication.

(Figure 5 and Appendix 3). N-NO_X levels were greatly in exceedance, *i.e.,* 10 times the default TV at most sites. N-NO_3 constituted nearly all of the measured N-NO_X and N-total (Appendix 3).

In order to compare against the default 95% TV for nitrate as a toxicant (0.7 mg/L NO_3), N-NO_3 concentrations were converted to NO_3 concentration by multiplying by a factor of 4.4. NO_3 exceeded the default 95% TV for nitrate as a toxicant at most sites (except RRU1); however, the default toxicant TV is currently under review as being too conservative. The new ANZECC/ARMCANZ 95% TV for NO_3 as a toxicant is likely to be around 2 - 2.5 mg/L N-NO_3 (~11 mg/L NO_3) (R. van Dam, *eriss*, pers. comm.), and will incorporate most recent data from acute and chronic toxicity testing in New Zealand. Recently published guidelines for Canada also recommend a higher guideline of 2.9 mg/L N-NO_3 (~13 mg/L NO_3) for freshwaters (CCME 2014). In comparison to the proposed ANZECC/ARMCANZ TV of 2 - 2.5 mg/L N-NO_3, only the concentration at RRU6 (3.8 mg/L) was still in exceedance, though the concentration at RRD6 (2.5 mg/L) was close to exceedance. Similar elevated levels of N-NO_3 have been recorded at Medawandy Waters (3.1 mg/L N-NO_3, 3.45 mg/L N-total) during previous monitoring in the Project area (Rio Tinto unpub. data).

Elevated background levels of N-NO_3 and N-NH_3 within the Project area are unsurprising, given that the Robe River catchment is already effected by current and historic pastoral practices (Strategen 2006). Cattle, or evidence of high cattle use were observed at a number of pools during the survey. Elevated N-NO_3 and N-NH_3 in waterbodies caused by livestock disturbance can reduce acid-neutralising capacities of waterbodies, adversely affect the growth, survival and reproduction of aquatic fauna, and most notably stimulate eutrophication and algal blooms (Camargo and Alonso 2006). Another potential anthropogenic source is ammonium nitrate used in mine explosives, though groundwaters in arid zone areas across Australia are often naturally enriched in nitrate, as is the case in the current Project area (Magee 2009).

Significantly higher concentrations of some ions, most notably S-SO_4, and to a lesser extent Mg, as well as elevated N-total and N-NO_x downstream of the Jimmawurrada-Robe confluence (Figures 4 and 5), may also reflect the influence of current mining operations discharges on the water quality of the downstream reach. The elevated S-SO_4 and Mg may indicate presence of geochemical reactions, resulting in the release of these elements downstream of the existing discharge points. The elevated nitrogen levels may indicate discharge of groundwater elevated in nitrates, with groundwaters in the vicinity of current mining operations appearing to be enriched (*e.g.* up to 23.9 mg/L N-NO_3 in bore MB15MEH014) (Rio Tinto unpub. data). The relative contribution of anthropogenic and natural sources to nitrogen enrichment in surface and groundwater of the Project area is unknown, but discharge of nitrogen-enriched groundwater has resulted in elevated nitrate levels in surface waters downstream of other BWT mining operations in the Pilbara.

5.2 Microinvertebrates

5.2.1 Species richness and abundance

A total of 81 microinvertebrate taxa were recorded from the Project area in May 2016, of which 46 were present at potentially exposed sites downstream of the Jimmawurrada-Robe confluence, and 69 were recorded at upstream reference sites (Table 6 and Appendix 5). The list includes groups which could not be identified to species level due to unresolved taxonomy and/or immature specimens. Therefore, the total microinvertebrate species richness is likely to be greater than that reported. Microinvertebrate composition included Protista (protists), Rotifera (rotifers), Copepoda (copepods), Cladocera (water fleas) and Ostracoda (seed shrimp) (Table 6). Generally, Rotifera dominated microinvertebrate taxa at each site, with comparatively few Copepoda, Ostracoda and Cladocera. The microinvertebrate fauna was generally typical of that commonly recorded from tropical/sub-tropical freshwater systems

(*e.g.* Koste and Shiel 1983, Tait *et al.* 1984, Smirnov and De Meester 1996, Segers *et al*. 2004), with Lecanidae dominating within the Rotifera, with Brachionidae and other families less prominent (Appendix 5).

Table 6. Summary of higher-order microinvertebrate taxa composition in the Robe River, upstream (RRU) and downstream (RRD) of the Jimmawurrada-Robe confluence. Refer Appendix 5 for full species list.

Microinvertebrates		Number of Taxa	
Scientific name	Common name	RRD (*n* = 6)	RRU (*n* = 6)
Protista	Protists	7	12
Rotifer	Rotifers	20	33
Micro-crustacea			
Cladocera	Water fleas	5	11
Copepoda	Copepods	9	6
Ostracoda	Seed shrimps	5	7
Total taxa richness		**46**	**69**

Microinvertebrate taxa richness ranged from 33 taxa at RRD6 and RRU5, to just one taxa at RRD5 (Figure 6). There was no significant difference in mean total taxa richness between downstream potentially exposed sites and upstream reference sites (one-way ANOVA, Table 7). Nor were there any significant upstream-downstream differences in taxa richness of major groups of microinvertebrate (rotifers, protists, micro-crustacea) (Table 7).

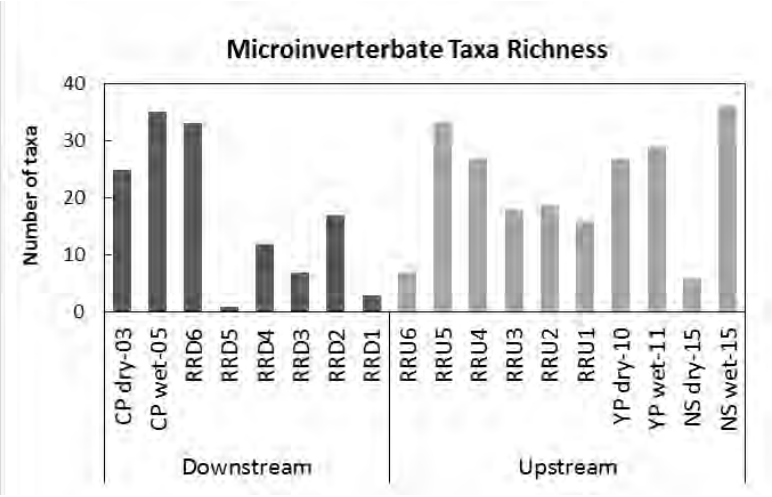


Figure 6. Microinvertebrate taxa richness recorded during the current study, upstream (RRU1 to 6) and downstream (RRD1 to 6) of the Jimmawurrada-Robe confluence, compared with most recent data for nearby Chalyarn Pool (CP; Pinder *et al.* 2010), Yalleen Pool (YP; WRM 2013) and Nyeetbury Spring (NS; WRM 2016). Refer Figure 1 for location of sites.

Table 7. Summary results from one-way ANOVAs testing for significant (p <0.05) differences in taxa richness of major microinvertebrate groups, upstream (RRU) and downstream (RRD) of the Jimmawurrada-Robe confluence. Mean (±SE) vales for untransformed data are also provided.

Microinvertebrate metric	ANOVA (df = 1, 11)			Mean (±SE)	
	MS	F	*p*	RRD (*n* = 6)	RRU (*n* = 6)
Total taxa richness	184.1	1.672	0.225	12.17 (4.81)	20.00 (3.69)
Protista richness	8.333	1.168	0.305	2.33 (0.92)	4.00 (1.24)
Rotifera richness	80.08	2.313	0.159	3.67 (2.46)	8.83 (2.34)
Micro-crustacea richness	3.000	0.183	0.183	6.17 (2.01)	7.17 (1.20)

5.2.2 Comparison against previous surveys

To provide spatial context for microinvertebrate fauna within the Project area, total taxa richness at each site within the Project area was compared against most recent data for nearby pools upstream and downstream of the Project area, *i.e.* Yalleen Pool and Nyeetbury Spring on upper Bungaroo Creek (WRM 2013, 2016), and Chalyarn Pool on Mungarathoona Creek (Pinder *et al.* 2010) (Figure 6). Each of these previous studies used similar microinvertebrate sampling techniques (sweep netting using 50 - 53 μm mesh FBA pond net) and taxonomic resolution to those approaches for the current study.

Some temporal variation was observed between wet and dry season sampling events, with the wet season favouring microinvertebrate taxa richness at Chalyarn Pool, Yalleen Pool and Nyeetbury Spring (Figure 6). At sites upstream of the Jimmawarruda-Robe confluence, taxa richness was spatially variable, with richness at RRU4 and RRU5 similar to that recorded at Yaleen Pool (both seasons) and Nyeetbury Spring in the wet-15 (Figure 6), and slightly higher than that recorded at RRU1, RRU2 and RRU3. Richness was lowest at Nyeetbury Spring in the dry-15, comparable to that recorded at RRU6 in the current study (Figure 6). Within the potentially exposed downstream reach, taxa richness at sites closest to the confluence (RRD1 to RRD5) was generally lower than that recorded at sites further downstream (RRD6 and Chalyarn Pool in both seasons) (Figure 6).

Large spatial (and temporal) variability in species richness and abundance are commonly reported for freshwater systems world-wide. Variation typically depends on factors such as flow regime (with lotic habitat generally favouring taxa richness), pool size, primary production rates and water quality parameters (Miquelis *et al.* 1998, Schiemer *et al*. 2001, Schöll *et al.* 2012). In Pilbara surface waters, microinvertebrate taxa richness is known to fluctuate markedly between sites and seasons (Pinder *et al.* 2010, WRM unpub. data). It is possible that below-average rainfall in the months prior to the current survey may have contributed to the somewhat lower microinvertebrate taxa richness recorded at sites such as RRD1, RRD3, RRD5 and RRU6. Pinder *et al.* (2010) found the wet season (higher rainfall) to generally favour taxa richness during the PBS, as was the case at Chalyarn, Yalleen and Nyteetbury (Figure 6); however, as these studies only provide a snapshot of the microinvertebrate fauna at pools within the Project area, the specific factors driving taxa richness and composition remain unknown.

5.2.3 Spatial variation in species assemblages

Multivariate analysis (ANOSIM) detected no significant difference in microinvertebrate species assemblage composition between upstream reference and downstream potentially exposed sites (Table 8), suggesting there was a high degree of natural variability and overlap amongst assemblages both upstream and downstream of the Jimmawarruda-Robe confluence. Although SIMPER analysis found only a 21% similarity of species assemblages between the upstream and downstream reaches, nMDS plotting displayed no discernible separation of upstream/downstream sites based on Bray-Curtis similarity (Figure 7). SIMPROF analysis did detect some clustering of sites, though with no clear patterns in relation to upstream/downstream location (Figure 7). For example, the upstream sites RRU1, RRU2 and RRU3 clustered with downstream site RRD2, and upstream sites RRU5 and RRU6 clustered with downstream site RRD6, based on similarity of microinvertebrate species assemblages (Figure 7). RRD1 and RRD3 also clustered with a high degree of similarity (Figure 7).

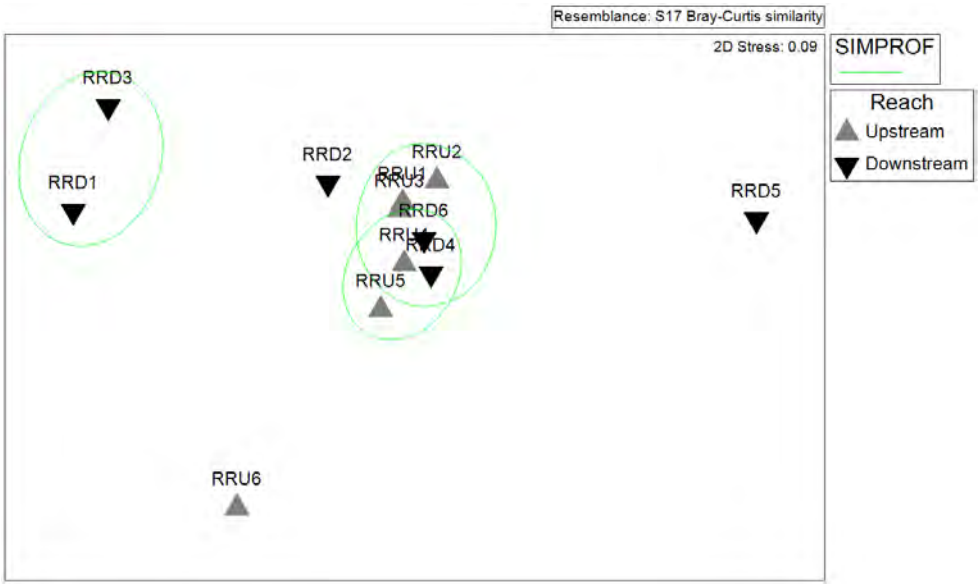


Figure 7. Plot of nMDS ordination on microinvertebrate species assemblages (log_{10} abundance class) upstream (RRU) and downstream (RRD) of the Jimmawurrada-Robe confluence. Ordination based on Bray-Curtis similarity, with SIMPROF analysis as green circles overlain demonstrating significant clustering of sites. Refer Table 1 for explanation of site codes and Figure 1 for location of sites.

Table 8. Summary results from ANOSIM testing for significant (p <0.05) differences in microinvertebrate assemblages (Bray-Curtis similarity) upstream (RRU) and downstream (RRD) of the Jimmawurrada-Robe confluence.

Microinvertebrate assemblage similarity (Bray-Curtis)	ANOSIM	
	R-statistic	*p*
Abundance (log_{10} class)	0.115	0.108
Presence/absence	0.137	0.097

The sampling design allows comparison of change in the similarity (Bray-Curtis) of microinvertebrate assemblages over time between reference and potential exposed sites. The premise being that if the degree of similarity between exposed and reference sites differs significantly over time (compared with pre-mine similarity), this would indicate mine-related response rather than stochastic variability due to factors such as climatic change.

5.2.4 Conservation significance of microinvertebrate fauna of the Project area

The majority of microinvertebrate taxa recorded from the Project area were common, ubiquitous species with Australasian or cosmopolitan distributions; however, the calanoid copepod *Eodiaptomus lumholtzi*, currently listed on the IUCN Red List of Threatened Species as Vulnerable (Reid 1996), was recorded at potentially exposed site RRD6. *E. lumholtzi* was assessed as Vulnerable in 1996 (IUCN ver. 2.3), as it was then known only from a few localities; Lake Woods in Northern Territory, Collinson's Lagoon at Ayr and Saltern Lagoon in the Valley of Lagoons, west of Ingham, Queensland. IUCN (2016) states this assessment requires updating because *E. lumholtzi* has since been recorded from many localities across the Australasian region. *E. lumholtzi* has been recorded previously by the authors at locations across the Pilbara region, including sites along Fortescue River, Coondiner Creek, Kalgan Creek, Weeli Wolli Creek, Koodaideri Springs, Caves Creek, Duck Creek and Cane River (WRM unpub. data). *E. lumholtzi* has also been found in Papua New Guinea, and is considered to have a pan-tropical distribution (Vlaardingerbroek 1989, WRM unpub. data).

Of scientific interest was the collection of an undescribed species of Lecanidae rotifer, *Lecane* n. sp., recorded both upstream and downstream of the Jimmawarruda-Robe confluence (RRU5 and RRD6). Morphologically, this species is similar to the described *Lecane quadridentata*, with the two variants synonymized by Segers (1995); however, the smaller Australian variant recorded in the current study is now recognised as a separate species, and forms part of a wider *L. quadridentata* species complex (Dr Russel Shiel, University of Adelaide, pers. comm.).

5.3 Hyporheic Fauna

5.3.1 Species richness and abundance

A total of 59 taxa were recorded from the hyporheic zone of pools in the Project area (Appendix 6). The majority of these taxa were classified as stygoxene (54%), *i.e.* species that appear in groundwater habitats by accident or seeking refuge during drought, and not specially adapted to subterranean inhabitation. Of these, 8% were classified as stygobitic, *i.e.*, obligate groundwater inhabitants with specialised morphological adaptations to survive in such environments (stygofauna). Of the remaining taxa, 31% were considered occasional hyporheic stygophiles (species that use the hyporheic zone seasonally or during early life history stages), 2% were possible hyporheic taxa, and 5% were unable to be classified (Appendix 6). Although classifications followed those of Boulton (2001), this type of analysis should be treated with some caution, as results are likely affected by available information on life history, taxonomic resolution, and interpretation of classification categories.

Hyporheic taxa richness (combined richness of stygobites, occasional hyporheic stygophiles and possible hyporheic fauna) ranged from two taxa at upstream reference site RRU2, to 12 taxa at potentially exposed downstream site RRD1 (Figure 8). Relatively high hyporheic taxa richness was also recorded at RRU6 (nine taxa), RRU4 and RRD2 (eight taxa), and RRU3 and RRD5 (seven taxa) (Figure 8). The high taxa richness encountered in the hyporheos of these sites, and because surface water was present at these sites despite below average rainfall in the months prior, suggests at least some connectivity between ground- and surface waters (*i.e.* they may be groundwater-supported pools).

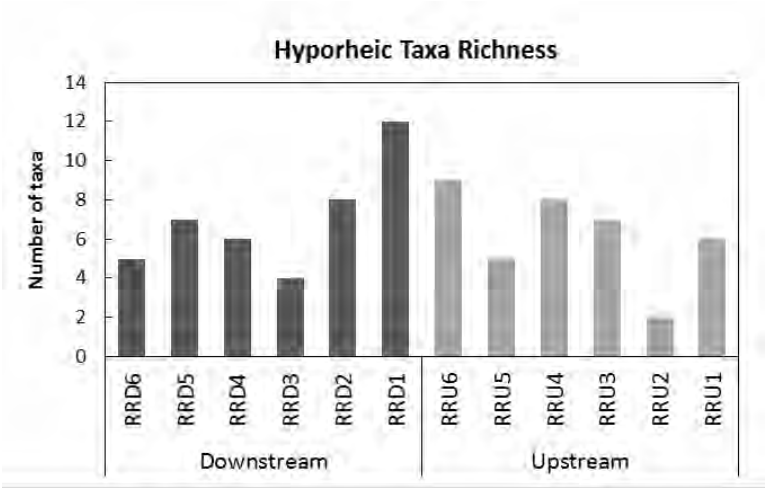


Figure 8. Hyporheic taxa richness (combined richness of stygobites, occasional hyporheic stygophiles and possible hyporheic fauna) of sites upstream (RRU) and downstream (RRD) of the Jimmawurrada-Robe confluence.

5.3.2 Conservation significance of hyporheic fauna of the Project area

Of the fauna collected in hyporheic samples of the Project area, only the amphipod, *Nedsia* sp. is considered likely to be a potential SRE species.

Nedsia sp. (family Melitidae) was recorded from the hyporheic zones of RRU3, RRU4 and RRU6 upstream of the Jimmawurrada-Robe confluence, and RRD1, RRD2, RRD3 and RRD4 downstream of the confluence (Appendix 6). *Nedsia* amphipods were also recorded in the surface water macroinvertebrate samples of RRD3 and RRD4 (Appendix 7). These amphipods could not be confidently identified to species level due to a current lack of taxonomic resolution within the Melitidae amphipods and would require DNA sequencing.

Biota (2006a) recorded four genetically-distinct amphipods of the family Melitidae from bores in the Yarraloola area, downstream (west) of the Project area. A fifth distinct Melitidae lineage was recorded from the Bungaroo Creek area to the southeast (Biota 2006a). Interestingly, based on genetic evidence, each of the four Melitidae lineages from the Yarraloola area have been isolated from one-another for between 2.4 and 6.65 million years, highlighting the extreme degree of amphipod short-range endemism that can occur amongst aquifers in the region despite close geographical proximity (Biota 2006a). Biota (2010) and Bennelongia (2013) also recorded a high abundance of Melitidae amphipods from bores to the south of the current Project area. The majority of these specimens belonged to the genus *Nedsia* (*Nedsia* nr. *hulberti* and *Nedsia* spp.). It is currently unknown whether the *Nedsia* recorded in the current study represent one or more of the *Nedsia* species or Melitidae halotypes recorded by Biota (2006a, 2010) and Bennelongia (2013) or a separate species previously unrecorded.

Although not conservation listed or considered SRE species, the following are stygal species, with their presence indicating some connectivity between ground- and surface-waters. As such, they are of some interest.

The Thermosbaenacean *Halosbaena tulki* was recorded both upstream (RRU3) and downstream (RRD2, RRD3 and RRD4) of the Jimmawurrada-Robe confluence. *Halosbaena tulki* is the single species of Thermosbaenacean known from the Southern Hemisphere, where it appears to be restricted to the Pilbara region (Poore and Humphreys 1992). Thermosbaenacea are a rare order of crustacean, with approximately 16 species known worldwide, all of which are restricted to groundwater environments (Poore and Humphreys 1992). In the vicinity of the Project area, this species was previously collected from seven bores in the Yarraloola area by Biota (2006a).

The ostracod *Candonopsis* cf. *tenuis* is known to occur widely across Australia (DeDeckker 1982, Karanovic and Marmonier 2002), including groundwaters of the Pilbara (Halse *et al.* 2002). WRM has recorded *C.* cf. *tenuis* from the hyporheic zone of a number of sites in the Weeli Wolli Creek catchment, Coondiner Creek, Kalgan Creek, Hamersley Gorge and the Ashburton River (WRM unpub. data). During the current study, *C.* cf. *tenuis* was collected from the hyporheic zone of upstream reference site RRU6 (Appendix 6).

Vestalenula marmonieri is a stygal ostracod species known only from Western Australia and New Caledonia (Schön *et al.* 2010). This species is relatively widespread across the Pilbara region (being collected from over 50 locations by Pinder *et al.* (2010) during the PBS), though due to its preference for phreatic[14] environments, is most commonly associated with groundwater-fed systems such as Weeli Wolli Creek (WRM unpub. data). In the current study, *V. marmonieri* was recorded from potentially exposed downstream sites RRD1 and RRD5, and upstream reference site RRU1 (Appendix 6). *V.*

[14] Groundwater environments.

marmonieri was also collected in microinvertebrate samples of RRU1, RRU2, RRU3, RRU6, RRD2, RRD4 and RRD5 (Appendix 5).

5.4 Macroinvertebrates

5.4.1 Species richness and abundance

A total of 148 macroinvertebrate taxa were recorded from the Project area, of which 116 were present at sites downstream of the Jimmawurrada-Robe confluence, and 117 at upstream reference sites (Table 9, Appendix 7). In this context, "taxa" includes groups which could not be identified to species level, due to unresolved taxonomy and/or immaturity of specimens. Therefore, the total macroinvertebrate taxa richness at each site is likely greater than reported herein. The macroinvertebrate fauna comprised Cnidaria (freshwater hydra), Mollusca (freshwater snails and bivalves), Oligochaeta (aquatic segmented worms), Crustacea (amphipods and freshwater shrimp), Acarina (water mites), Collembolla (springtails), Odonata (dragonflies and damselflies), Ephemeroptera (mayflies), Hemiptera (true bugs), Coleoptera (aquatic beetles), Diptera (two-winged or "true" fly larvae), Trichoptera (caddisflies) and Lepidoptera (aquatic moth larvae; Table 9). Macroinvertebrate composition was typical of freshwater systems throughout the world (Hynes 1970), being dominated by Insecta (comprising 89% of all taxa), with Diptera (29%) and Coleoptera (32%) most prominent within this class. There were 46 singleton taxa recorded (*i.e.* those recorded from only one site), and 12 taxa were considered common taxa, *i.e.* they were present at over 80% of sites. These included the snail *Melanoides* spp., segmented worms (Oligochaeata spp.), the freshwater shrimp *Caridina indistincta*, the mayflies Baetidae spp. and *Cloeon* sp. Red Stripe, the pygmy backswimmer *Paraplea* spp., and the midge larvae/pupae Ceratopogonidae spp., Dasyheleinae spp., Chironomidae spp., *Polypedilum* sp. 1, *Larsia albiceps* and *Paramerina* sp. (Appendix 7).

Table 9. Summary of higher-order microinvertebrate taxa composition in the Robe River, upstream (RRU) and downstream (RRD) of the Jimmawurrada-Robe confluence. Refer Appendix 7 for full species list.

Macroinvertebrates		Number of Taxa	
Scientific name	Common name	RRD (*n* = 6)	RRU (*n* = 6)
Cnidaria	Freshwater hydra	1	0
Oligochaeta	Aquatic worms	1+	1+
Gastropoda	Freshwater snails	4	5+
Bivalvia	Freshwater bivalves	0	1
Amphipoda	Stygal amphipods	2	0
Decapoda	Freshwater shrimps	1+	1+
Acarina	Water mites	1+	1+
Ephemeroptera	Mayflies	6	5
Odonata	Dragonflies and damselflies	14	14
Hemiptera	True bugs	18	16
Coleoptera	Aquatic beetles	30	35
Diptera	Two-winged flies	30	31
Trichoptera	Caddisflies	7	4
Lepidoptera	Aquatic moth larvae	2	2
	Total taxa richness	**116**	**117**

+ indicates a taxa could only be identified to genus/family/order level (not species level), and as such more than one species is likely to be present within this taxonomic group.

Macroinvertebrate taxa richness at upstream sites ranged from 34 taxa at RRU3 and RRU5, to 72 taxa at RRU1 (Figure 9). Richness at sites downstream of the Jimmawarruda-Robe confluence ranged from 38 taxa at RRD3 and RRD5, to 56 taxa at RRD2 (Figure 9). There was no significant difference in total

taxa richness between downstream potentially exposed sites and upstream reference sites (one-way ANOVA, Table 10). Nor were there any significant upstream-downstream differences in taxa richness of most major macroinvertebrate groups (Table 10). The exception was Ephemeroptera (mayflies), where mean richness was significantly higher at sites downstream of the confluence (4.3) compared to those upstream (2.5) (Table 10). This was largely due to the lower richness/absence of *Tasmanocoenis* sp. P/*arcuata* (Caenidae) and *Cloeon fluviatile* (Baetidae) at upstream sites, particularly RRU4 to 6 closest to the confluence.

Table 10. Summary results from ANOVAs testing for significant (p <0.05) differences in taxa richness of major macroinvertebrate groups (indicated by *), upstream (RRU) and downstream (RRD) of the Jimmawurrada-Robe confluence. Mean (±SE) vales for untransformed data are also provided.

Macroinvertebrate metric	ANOVA			Mean (±SE)	
	MS	F	p	RRD (n = 6)	RRU (n = 6)
Total taxa richness	0.083	0.001	0.982	46.2 (3.5)	46.3 (6.1)
Diptera richness	0.000	0.000	1.000	14.0 (1.8)	14.0 (4.6)
Coleoptera richness	18.75	0.587	0.461	8.5 (2.4)	11.0 (2.2)
Hemiptera richness	0.333	0.035	0.855	6.3 (1.1)	6.0 (1.4)
Odonata richness	1.333	0.377	0.553	5.33 (0.6)	6.0 (0.9)
Trichoptera richness	1.333	1.429	0.260	1.7 (0.4)	1.0 (0.4)
Ephemeroptera richness	10.08	6.798	0.026*	4.3 (0.5)	2.5 (0.5)
Mollusca richness	0.083	0.068	0.799	2.7 (0.4)	2.8 (0.5)
Crustacea richness	0.750	-0.738	0.411	2.7 (0.5)	2.2 (0.3)

5.4.2 Comparison against previous studies

To provide spatial context for macroinvertebrate fauna within the Project area, total taxa richness at each site was compared against most recent data for nearby pools upstream and downstream, *i.e.* Yalleen Pool and Nyeetbury Pool on upper Bungaroo Creek (WRM 2013, 2016), and Chalyarn Pool on Mungarathoona Creek (Pinder *et al.* 2010) (Figure 9). Each of these previous studies used similar macroinvertebrate sampling techniques (kick-sweep netting using 250 µm mesh FBA pond net) and taxonomic resolution to those of the current study.

Taxa richness within the Project area (34 – 72 taxa) was generally comparable to that previously recorded for Yalleen Pool (39 – 45), Nyeetbury Spring (51 – 52) and Chalyarn Pool (49 – 77) (Figure 9). The lack of spatial variability in macroinvertebrate taxa richness between studies probably reflects the similar hydrological nature and size of these pools (*i.e.* all are either permanent/semi-permanent riverine pools, flowing only after heavy rainfall) because they are all within relatively close geographical proximity to one-another (*i.e.* within 20 – 30 km, and all part of the Robe River catchment). Pinder *et al.* (2010) noted riverine pools of the Pilbara (particularly those of the same catchment) generally display a high degree of homogeneity, in terms of macroinvertebrate species richness and composition, in comparison to similarly sized turbid wetlands and claypans.

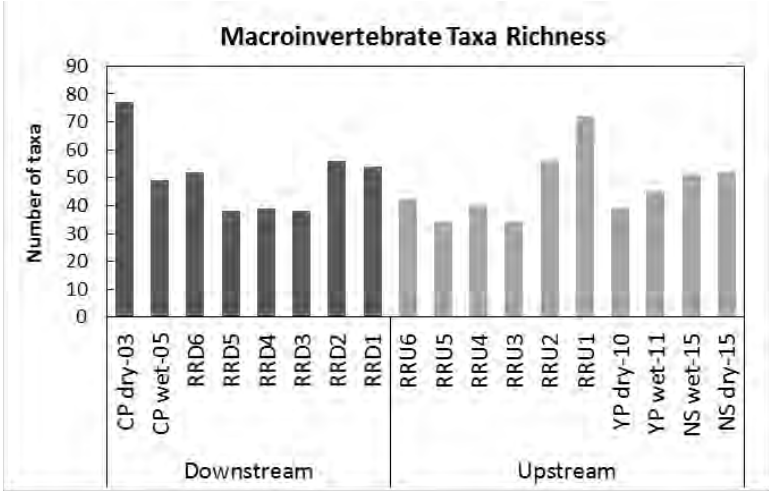


Figure 9. Macroinvertebrate taxa richness recorded during the current study, upstream (RRU1 to 6) and downstream (RRD1 to 6) of the Jimmawurrada-Robe confluence, together with most recent data for nearby Chalyarn Pool (CP; Pinder *et al.* 2010), Yalleen Pool (YP; WRM 2013) and Nyeetbury Spring (NS; WRM 2016). Refer Figure 1 for location of sites.

To provide temporal/seasonal context for macroinvertebrate taxa richness in the current Project area, April/May (wet season) 2016 figures were compared against historic mean dry season taxa richness recorded at Robe River pools by Streamtec/UWA between 2002 and 2011[15]. Again, both studies utilised the same macroinvertebrate sampling technique (sweep netting using a 250 µm mesh FBA pond net), and taxonomy was standardised across datasets to account for inherent variation/advancements in taxonomic knowledge between studies (*i.e.* some taxa were condensed to family or order level to enable comparison). As such, taxa richness may appear lower than was originally reported in each study.

At the reach upstream of the Jimmawarruda-Robe confluence, mean dry season richness at Medawandy Waters (22) and Pannawonica Hill (23) were generally comparable to wet season taxa richness recorded at RRU3 (22), RRU4 (30), RRU5 (20) and RRU6 (26), but slightly lower than taxa richness recorded at RRU1 (54) and RRU2 (38) (Figure 10). Downstream of the confluence, mean dry season richness recorded at Gnieroora, Martangkuna, Pulari, Japanese Pool and Yarramudda (20 – 27 taxa) was also similar to wet season richness recorded at RRD1, RRD3, RRD4 and RRD5 (21 – 33 taxa), and only slightly lower than that recorded at RRD6 (41 taxa) and RRD2 (38 taxa). The apparent lack of seasonal variability in taxa richness likely reflects the capacity for pools of the Project area to hold water year-round (*i.e.* they are either permanent/semi-permanent), acting as refuge pools for migratory macroinvertebrates during the dry season, and generally favouring both temporary and permanent resident macroinvertebrate species over more ephemeral waterbodies (Sponseller *et al.* 2001, Pinder *et al.* 2010). Furthermore, Pinder *et al.* (2010) found there to be little seasonal variation in macroinvertebrate assemblages at permanent/semi-permanent riverine pools of the Pilbara region in comparison to more ephemeral waterbodies, particularly when flooding had not occurred prior to wet season sampling (as was the case in the current study). It must be noted that the current study provides only a snapshot of the macroinvertebrate fauna of the Project area and taxa richness could still vary considerably between time periods.

[15] The most recent round of macroinvertebrate data (2013) was not included in analysis, as Streamtec (2014) did not feature a raw species list. Earlier species lists (1996 & 1998) were not included in the analysis due to the vast improvements in taxonomic knowledge and microscope technology since those studies.

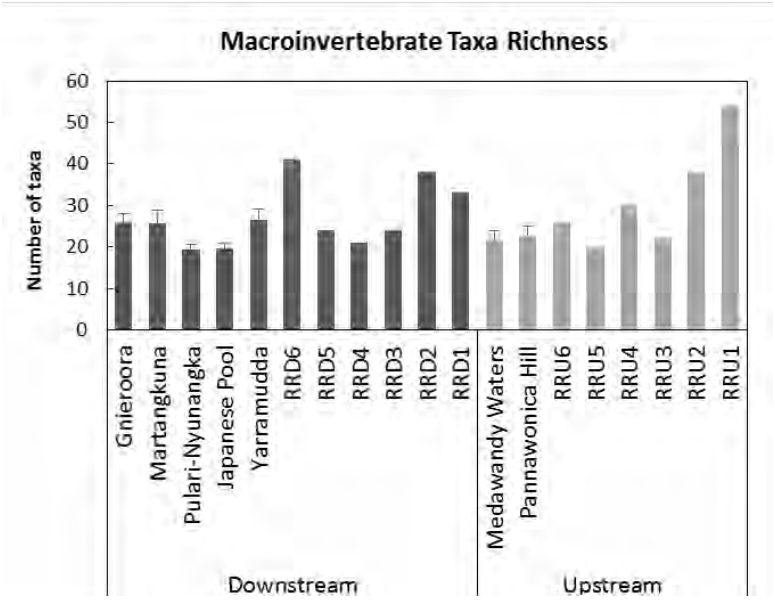


Figure 10. Comparison of standardised macroinvertebrate taxa richness recorded during the current study, with that recorded by Streamtec/UWA during long-term monitoring of Robe River pools. Refer Figure 1 for location of sites.

5.4.3 Spatial variation in species assemblages

Multivariate analysis (ANOSIM) detected no significant difference in macroinvertebrate species assemblage composition between upstream reference and downstream potentially exposed sites (Table 11), suggesting there was a high degree of natural variability and overlap amongst upstream/downstream sites. Although SIMPER analysis found only a 45% similarity of species assemblages between upstream and downstream sites, nMDS plotting displayed no distinguishable separation of upstream/downstream sites based on Bray-Curtis similarity (Figure 11), with SIMPROF analysis (not shown) detecting no clustering of these groups. One site (RRU3) was separate from all other sites, which is attributed to the low overall taxa richness (34) recorded at this site compared to others. As with taxa richness, the lack of variability in upstream/downstream macroinvertebrate assemblages likely reflects the relatively similar hydrological nature (permanent/semi-permanent) of pools in the Project area.

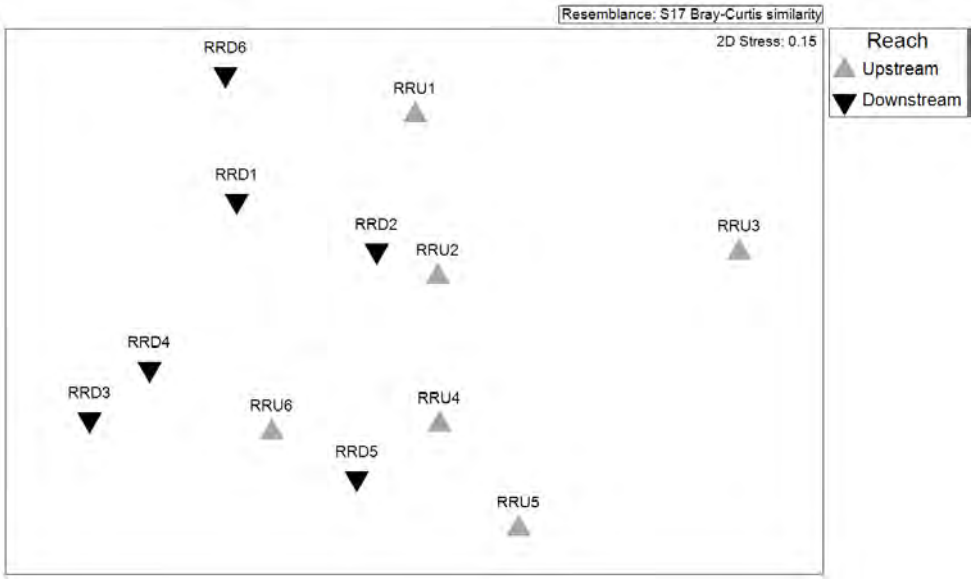


Figure 11. Plot of nMDS ordination on macroinvertebrate species assemblages (log_{10} abundance class) upstream (RRU) and downstream (RRD) of the Jimmawurrada-Robe confluence. Ordination based on Bray-Curtis similarity. Refer Table 1 for explanation of site codes and Figure 1 for location of sites.

Table 11. Summary results from ANOSIM testing for significant (p <0.05) differences in macroinvertebrate assemblages (Bray-Curtis similarity) upstream (RRU) and downstream (RRD) of the Jimmawurrada-Robe confluence.

Macroinvertebrate assemblage similarity (Bray-Curtis)	ANOSIM	
	R-statistic	*p*
Abundance (log_{10} class)	0.154	0.106
Presence/absence	0.111	0.186

5.4.4 Conservation significance of macroinvertebrate fauna of the Project area

The Pilbara pin damselfly, *Eurysticta coolawanyah* (family Isostictidae), is endemic to the Pilbara region, and is currently listed as Near Threatened on the IUCN Red List of Threatened Species (IUCN 2016). *Eurysticta coolawnyah* was recorded from two sites in the current study; RRD3 and RRD4, both downstream of the Jimmawarruda-Robe confluence (Appendix 7). *E. coolawanyah* is known from over 40 locations across the Pilbara (Pinder *et al.* 2010), and has been recorded by WRM from a number of riverine pools and springs along the Fortescue River, DeGrey River, Coondiner Creek, Kalgan Creek and Weeli Wolli Creek (WRM unpub. data). Along the Robe River, this species has been recorded consistently by Streamtec/UWA, as well as from Bungaroo Creek (WRM 2013) and Mugarathoona Creek (Pinder *et al.* 2010).

It is likely that both RRD3 and RRD4 are important refuge pools for *E. coolawanyah* in the area, as both are persistent waterbodies which support relatively high densities of emergent macrophyte (see Appendix 4). Damselflies (such as *E. coolawanyah*) are known to actively select sites with greater concentrations of emergent macrophyte, which are used for perching, mating and oviposition (egg-laying) (D'Amico *et al.* 2004, Rouquette and Thomson 2004, Ward and Mill 2005, Remsburg and Turner 2009).

Although the following species are not listed for conservation significance, they are endemic to the Pilbara region and therefore of some scientific interest. The Pilbara tiger dragonfly, *Ictinogomphus dobsoni* (family Lindeniidae), was collected at reference site RRU3, and potentially exposed sites RRD1, RRD4 and RRD6 (Appendix 7). This species appears to be relatively common across the Robe River

catchment, having been recorded from Chalyarn Pool, Red Hill Creek (Pinder *et al*. 2010) and a number of permanent/semi-permanent Robe River pools (Streamtec/UWA). Elsewhere, *I. dobsoni* has been recorded from many of the other major river systems of the Pilbara, including the Fortescue, Ashburton, Yule, DeGrey and Sherlock rivers (DEC 2009, Pinder *et al*. 2010, CSIRO 2015). Large pools within the Project area epitomise ideal refuge habitats for *I. dobsoni*, which is known to prefer still or sluggish permanent riverine waterbodies (Watson 1991).

The Pilbara endemic dytiscid beetle *Tiporus tambreyi* was recorded at reference sites RRU3, RRU4 and RRU6, and potentially exposed site RRD1 (Appendix 7). This species is common and ubiquitous across the region, and in the vicinity of the Project area, has been recorded from Robe River pools (Streamtec/UWA), Chalyarn Pool (Pinder *et al.* 2010) and Red Hill Creek (WRM 2009, Pinder *et al.* 2010).

The haliplid beetle *Haliplus pilbaraensis,* recorded from reference site RRU1 (Appendix 7), is endemic to the Pilbara region and relatively new to science (Watts and McRae 2010). This species appears to occur fairly widely throughout the Pilbara, and has been recorded at localities such as Glen Ross Creek, Coondiner Pool, the Fortescue Marsh, Moreton Pool, Paradise Pool, Munreemya Billabong, Wackilina Creek Pool, West Peawah Creek Pool, Harding River Pool, and an un-named creek in Millstream (Watts and McRae 2010). Closer to the Project area, *H. pilbaraensis* was previously recorded from Red Hill Creek (WRM 2009).

5.5 Fish

5.5.1 Species composition and abundance

A total of 3,515 individual fish were caught, measured and released in the Project area; 1,578 from upstream reference sites (RRU1 - 6), and 1,937 from sites downstream of the Jimmawarruda-Robe confluence (RRD1 - 6). Seven true freshwater taxa were recorded, including the western rainbowfish, spangled perch, Pilbara tandan (eel-tailed catfish), Fortescue grunter, barred grunter, bony bream, and a hybridised form of Terapontidae (grunter) (Table 12). Four species captured were of estuarine/marine origin, including milkfish, tarpon (ox-eye herring) (Plate 8), mullet and banded scat (striped butterfish) (Plate 8) (Table 12). Each of the freshwater species, with the exception of bony bream, was recorded both upstream and downstream of the Jimmawarruda-Robe confluence (bony bream were only recorded upstream of the confluence) (Table 12). The marine vagrant tarpon and mullet were also recorded both upstream and downstream of the confluence; however, milkfish and banded scat were only recorded from the downstream reach (Table 12). Each of these species, except milkfish, was previously recorded from the Robe River by Morgan and Gill (2004) and Streamtec/UWA.

Table 12. Summary of freshwater and estuarine/marine vagrant fish species recorded in the Project area, including scientific and common names. ✓ = fish species was present.

Origin	Species	Common name	Downstream						Upstream					
			RRD6	RRD5	RRD4	RRD3	RRD2	RRD1	RRU6	RRU5	RRU4	RRU3	RRU2	RRU1
Freshwater	*Melanotaenia australis*	Western rainbowfish	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Neosilurus sp.	Pilbara tandan			✓	✓	✓			✓		✓	✓	✓
	Leipotherapon unicolor	Spangled perch	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Leipotherapon aheneus	Fortescue grunter	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Amniataba percoides	Barred grunter	✓		✓	✓		✓	✓	✓				
	Terapontidae sp.	Grunter hybrid		✓			✓		✓	✓		✓		✓
	Nematalosa erebi	Bony bream											✓	
Estuarine/ marine	*Chanos chanos*	Milkfish	✓		✓									
	Megalops cyprinoides	Tarpon/ox-eye herring	✓	✓		✓	✓	✓		✓	✓		✓	
	Mugil sp.	Mullet		✓				✓			✓		✓	
	Selenotoca multifasciata	Banded scat/striped butterfish	✓	✓	✓	✓	✓	✓						

There was no significant difference in mean abundance of fish upstream and downstream of the Jimmawarruda-Robe confluence (one-way ANVOA, $p = 0.433$), nor was there any significant difference in mean abundance of any of the individual species between the upstream and downstream reaches (one-way ANOVA, $p < 0.05$). There was a significant difference in mean species richness between upstream and downstream sites, with mean richness significantly higher downstream of the Jimmawarruda-Robe confluence (one-way ANVOA, $p = 0.008$). This was mainly due to the greater presence of estuarine species such as banded scat, milkfish and tarpon at the downstream reach (Table 12).

Western rainbowfish were the most abundant fish of the Project area, with a total of 2,401 individuals captured. Western rainbowfish were present at all sites, with 1,019 recorded from upstream reference sites (42%), and 1,382 recorded from downstream sites (48%) (Figure 12). Fortescue grunter (685 individuals) and spangled perch (203 individuals) were the second and third most abundant species of the Project area, respectively. Fortescue grunter were collected from all sites, with similar numbers captured both upstream (320 individuals; 47%) and downstream (365 individuals; 53%) of the Jimmawarruda-Robe confluence (Figure 12). Spangled perch were also present at all sites, with the majority recorded at upstream sites (145 individuals; 71%) (Figure 12). Of the remaining freshwater species, Pilbara tandan (34 individuals) were recorded at upstream sites RRU1, RRU2, RRU3, RRU5, and downstream sites RRD2, RRD3 and RRD4; barred grunter (47 individuals) were recorded at upstream sites RRU5 and RRU6, and at downstream sites RRD3, RRD4 and RRD5. Terapontidae hybrids (12 individuals) were recorded at upstream sites RRU1, RRU3, RRU5 and RRU6, and downstream sites RRD2 and RRD5 (Figure 12). Bony bream (5 individuals) were only recorded at upstream site RRU2.

Of the estuarine/marine fish species, tarpon (39 individuals) (Plate 8) were recorded at upstream sites RRU2, RRU4 and RRU5, and all sites downstream of the Jimmawarruda-Robe confluence (Figure 12). Mullet (33 individuals) were recorded at upstream sites RRU2 and RRU4, and downstream sites RRD1 and RRD5 (Figure 12). Banded scat (53 individuals) (Plate 8) were only recorded downstream of the confluence, but were present at all sites within that reach (Figure 12). Milkfish (7 individuals) were only recorded from downstream sites RRD4 and RRD6 (Figure 12).

Plate 8. The banded scat *Selenotoca multifaciata* (left) and the tarpon *Megalops cyprinoides* (right), captured downstream of the Jimmawarruda-Robe confluence.

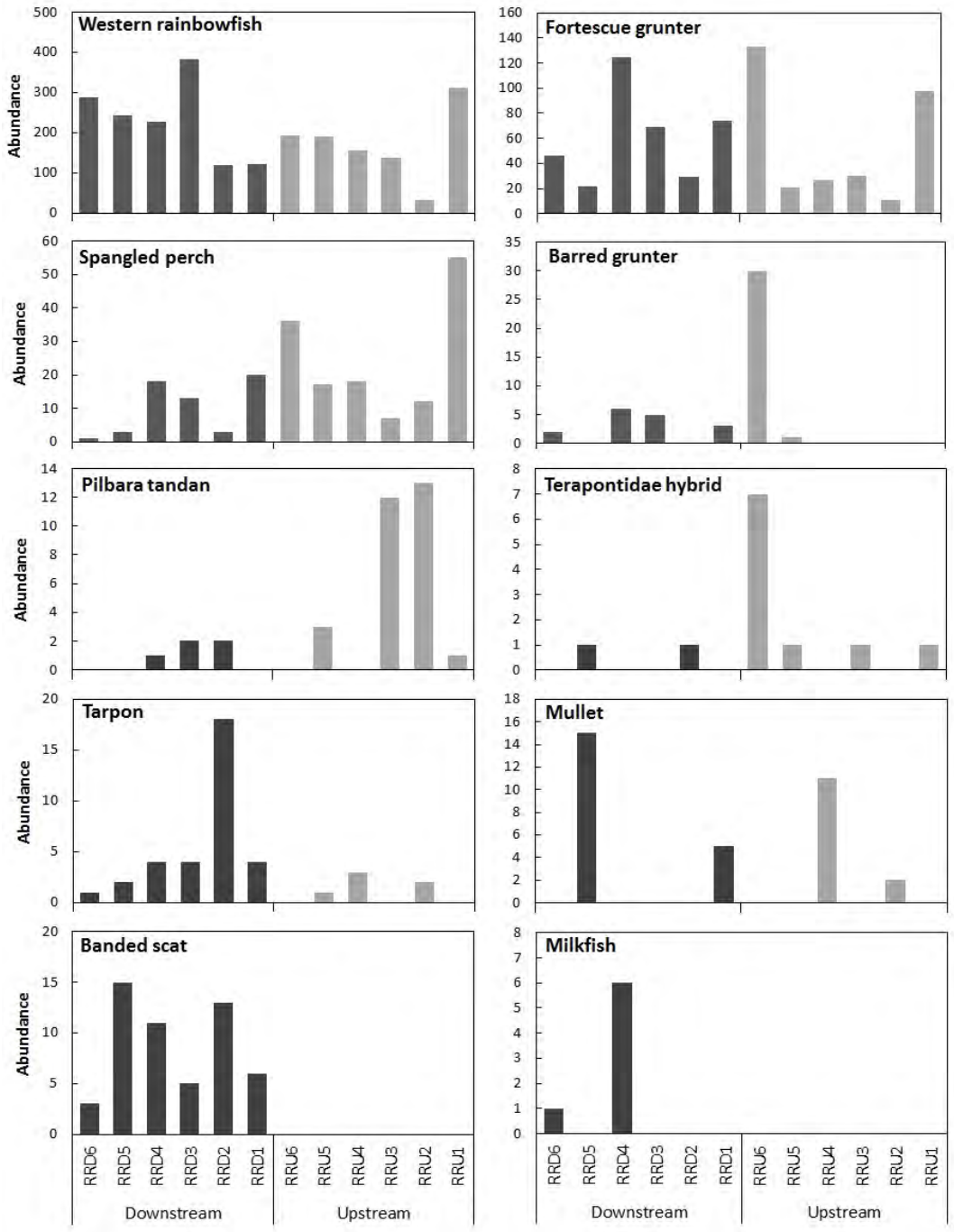


Figure 12. Abundance of each fish species recorded from upstream (RRU1 to 6) and downstream (RRD1 to 6) of the Jimmawurrada-Robe confluence. Note: bony bream (*Nematalosa erebi*) were also recorded from the Project area, but were not plotted due to low overall abundance of this species.

5.5.2 Conservation significance of fish species

One conservation listed freshwater fish species was recorded from the Project area; the Pilbara endemic Fortescue grunter (*Leipotherapon aheneus*). Currently, the Fortescue grunter is listed on the IUCN Red List of Threatened Species as Lower Risk/Near Threatened (IUCN 2016), and as a Priority 4 (P4) species on the Department of Parks and Wildlife (Parks and Wildlife) Priority Fauna List (Parks and Wildlife 2016). This species is only known from the Fortescue, Robe and Ashburton River systems (Allen *et al*. 2002, Morgan and Gill 2004); however, it is considered to be common within this range, as is evidenced

by the ubiquitousness of this species across the current Project area, being the second most abundant fish collected (685 individuals) and occurring at all sites both upstream and downstream of the Jimmawarruda-Robe confluence (Table 12 and Figure 12).

The following species are not listed for conservation significance, but are of some scientific interest:

Individuals which appeared to be hybridised forms of two of the three co-occurring Robe River Terapontidae species (spangled perch, barred grunter and/or Fortescue grunter; Plate 9) were recorded from RRU1, RRU3, RRU5, RRU6, RRD2 and RRD5 (Table 12 and Figure 12). Hybridised grunters have been recorded from other Pilbara systems by the authors and others, including the Fortescue, Murchison and Ashburton rivers (Morgan and Gill 2006, Morgan *et al.* 2009, WRM 2016, WRM unpub. data). Morgan and Gill (2006) propose hybridisation between closely related fish species is not uncommon; however, the hybridisation of grunters in Pilbara river systems is not fully understood, and is of some interest, particularly if hybridisation results in the loss of species through replacement with reproductively unviable individuals, or if there is evidence of incipient speciation (the formation of a new species). Loss or replacement of a species is especially important in the case of the Fortescue grunter, as it is a nationally and internationally listed species of conservation significance.

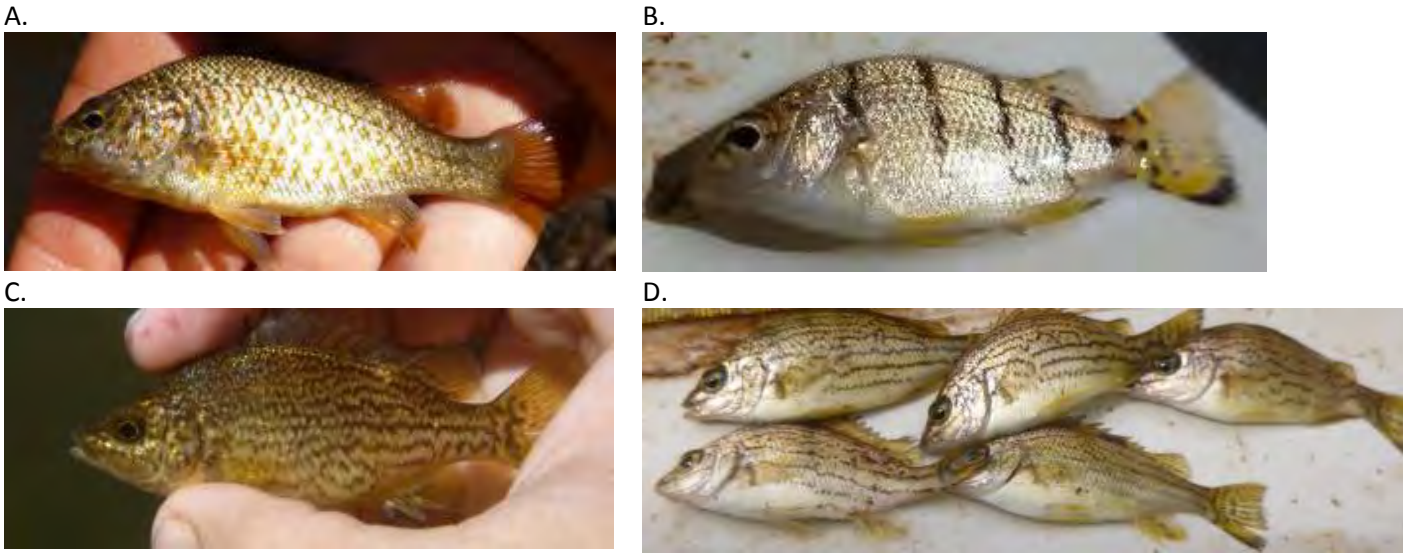


Plate 9. Terapontid hybridisation, illustrating (A) Spangled perch *Leiopotherapon unicolor,* (B) barred grunter *Amniataba percoides*, (C) Fortescue grunter *Leiopotherapon aheneus*, and (D) Terapontidae hybrids from RRU6, possibly sharing the features of barred and Fortescue grunter. Photographs by Chris Hofmeester (A, B and C)/WRM (D) ©.

None of the estuarine/marine fish species recorded in the Project area are endemic to the Pilbara region or currently listed for conservation significance. Milkfish (*Chanos chanos*) were not reported from the freshwater reaches of the Robe River by either Streamtec/UWA, Morgan and Gill (2004) or Antao and Braimbridge (2010). As such, collection of this species during the current study (along with its collection from further downstream) likely establishes a new record for the system. *Chanos chanos* is widely distributed across tropical and sub-tropical climes of the Indo-West Pacific region (Bagarinao 1994, Swanson 1998, Allen *et al.* 2002). This species is known to utilise fresh, brackish, oceanic and hypersaline lagoon environments (*i.e.* are euryhaline), being extremely efficient at osmoregulation during all life-history stages (Swanson 1998, Lin *et al.* 2003). In Australian waters, adult milkfish are pelagic schooling fish, inhabiting shallow, off-shore marine habitats. Spawning typically takes place offshore, following which juveniles migrate to sheltered estuaries. Sub-adult milkfish occasionally penetrate further upstream into freshwater reaches, before returning to the ocean to undergo sexual maturation and spawning (Bagarinao 1994, Allen *et al.* 2002).

5.5.3 Fish population structure

The reproductive strategies of freshwater fish species in the Pilbara are 'opportunistic' and 'periodic', reflecting the seasonal yet unpredictable nature of rainfall and streamflow in the region (Beesley 2006). Breeding of many species occurs during the wet season and during this time, multiple spawning events are known to occur (Beesley 2006). Further, the volume, hydrological regime and habitat complexity of Pilbara waterbodies can have a marked influence on fish population structure, with larger pools and more complex habitat considered generally advantageous for fish communities (Allen *et al.* 2002, Morgan *et al.* 2002, Morgan *et al.* 2009). Therefore, anthropogenically-induced alterations to streamflow patterns, water levels and water quality can have a discernible impact on life-history strategies and assemblage composition of local fish populations (Allen *et al.* 2002). Analysing population structure provides one means of characterising the health of fish assemblages at each site, and by extension the ecological processes driving aquatic communities within the waterbody. The presence of newly recruited and juvenile fish, for example, indicates recent spawning activity (and conditions conducive to such). Conversely, the presence of only sub-adult and adult (larger) fish may indicate a higher amount of predatory pressure on juvenile fish, and/or that conditions in pools are not conducive to spawning.

In order to examine population structures of the most ubiquitous freshwater fish of the Pilbara region (western rainbowfish, spangled perch and Pilbara tandan), length-frequency data for age-classes were estimated from published literature (*i.e.* Lake 1971, Bishop *et al.* 2001, Allen *et al.* 2002, Morgan *et al*. 2002, Beesley 2006; Table 13).

Table 13. Age-classes used in length-frequency analysis of Western rainbowfish, spangled perch and Pilbara tandan from the Project area. Age-classes are adapted from Lake (1971), Bishop *et al.* (2001), Allen *et al.* (2002), Morgan *et al*. (2002) and Beesley (2006).

Species	Age-class	Size mm SL
Western rainbowfish	New recruit	< 30
(*Melanotaenia australis*)	Juvenile	31-40
	Sub-adult	41-50
	Adult	> 51
Spangled perch	New recruit	< 30
(*Leiopotherapon unicolor*)	Juvenile	31-50
	Sub-adult	51-70
	Adult	> 71
Pilbara tandan	New recruit	< 30
(*Neosilurus* sp.)	Juvenile	31-70
	Sub-adult	71-90
	Adult	> 91

Western rainbowfish

Western rainbowfish breed throughout the year, with multiple spawning bouts that take full advantage of the region's intermittent rainfall and streamflow (Beesley 2006). Rainbowfish of the family Melanotaeniidae are usually sexually mature by the end of their first year (Allen *et al.* 2002). The size at sexual maturity can vary between river systems (typically around 50 mm SL), though western rainbowfish generally attain a maximum size of 110 mm total length (TL) (Allen *et al.* 2002).

The population structure of western rainbowfish at most upstream and downstream sites appeared to be healthy, with a variety of age-classes (new recruits, juveniles, sub-adults and adults) represented at RRU1, RRU4, RRU5, and RRD2 – RRD6 (Figure 13). New recruits and juveniles were particularly abundant at upstream site RRU4, and downstream sites RRD2, RRD4 and RRD6 (Figure 13), indicating spawning activity and good recruitment at these waterbodies. No western rainbowfish new recruits were recorded at RRD1, where sub-adults and adults (50 – 90 mm SL) dominated the population (Figure 13). Relatively low numbers of new recruits and juveniles (and low western rainbowfish numbers in general) were also recorded at RRU2 (Figure 13). Low recruitment of rainbowfish at RRD1 was possibly due to the small size of this pool, which also contained piscivorous species such as spangled perch, Fortescue grunter and barred grunter. Reduced depth and volume of small pools such as RRD1 inherently increases the risk of juvenile fishes to teleost (fish) and avian predation (Morgan *et al.* 2009). Conversely, low western rainbowfish abundance (and concurrent low abundance of new recruits and juveniles) recorded at RRU2 may have been related to the large size and volume of this pool, which would enable fish to avoid capture in seine and gill nets. Relatively low abundances of all fish species were recorded at RRU2, with the exception of Pilbara tandan, which are more commonly caught while electrofishing, rather than in seine and gill nets.

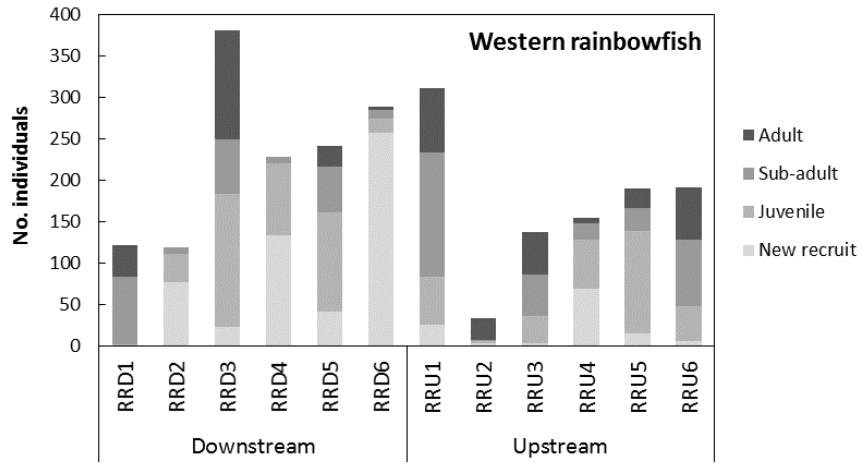


Figure 13. Abundance of western rainbowfish (*Melanotaenia australis*) age-classes recorded from each pool in the Project area.

Spangled Perch

Spangled perch are known to take advantage of wet season flooding to migrate upstream and breed (Bishop *et al.* 1995, Bishop *et al.* 2001, Pusey *et al.* 2004, Marsden and Power 2007). During this time, multiple spawning events are known to occur (Beesley 2006). In the Fitzroy River, Morgan *et al.* (2002) collected mature specimens at the beginning of the wet season, and larvae at the end of the wet season, indicating that spawning coincided with the flooding of the river. Spangled perch mature in their first year, at approximately 58 mm TL for males and 78 mm TL for females, and can reach a maximum size of 300 mm TL (Allen *et al.* 2002, Beesley 2006).

Spangled perch recruitment in the Project area appeared to be low, with new recruits (< 30 mm SL) only recorded at RRU1 and RRU2 upstream of the Jimmawarruda-Robe confluence, and RRD3 and RRD4 downstream of the confluence (Figure 14). Juveniles (31 - 60 mm SL) were also absent or recorded in low numbers at most sites (Figure 14). This reflects the high degree of variability in streamflow in the Project area, with low rainfall and streamflow leading up to the survey likely restricting spangled perch spawning activity. The exception was downstream site RRD3, where the spangled perch population comprised mainly juveniles (227 juveniles) (Figure 14). This suggests spangled perch may have spawned in or upstream of this pool recently following a flood event, with juveniles becoming isolated as waters

receded. RRD3 supported the highest abundance of spangled perch in the Project area (382 individuals), constituting 67% of all spangled perch caught during the survey; however, given the ubiquitousness of this species across the Pilbara, it is likely that larger populations reside at larger pools within the Project area. Catch per unit effort is likely reduced in these pools, such as RRU2, RRU4, RRU5, RRD4, RRD5 and RRD6, due to their size and depth, and presence of submerged debris (*e.g.* logs, branches, snags), which hinders seine and gill netting.

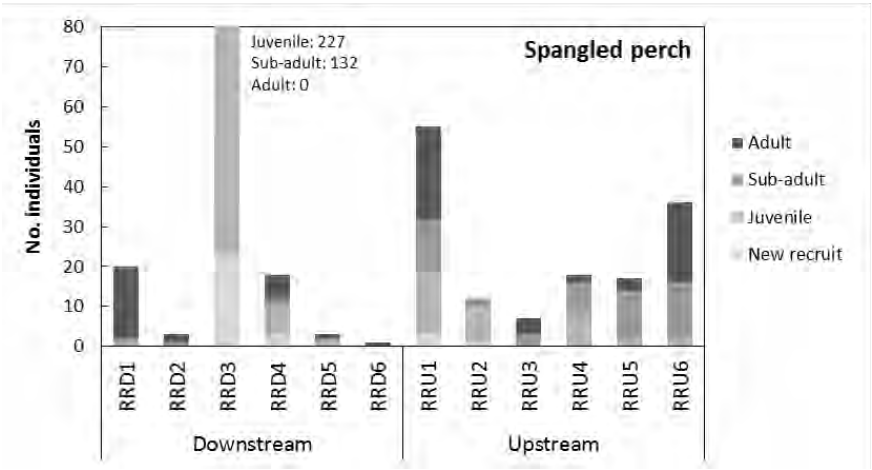


Figure 14. Abundance of spangled perch (*Leipotherapon unicolor*) age-classes recorded from each pool in the Project area. Note: column representing RRD3 is only partially displayed; the remainder of age-classes are given as text (new recruits are still displayed).

Pilbara tandan

Very little is known of the breeding ecology of the Pilbara tandan. Species of *Neosilurus* catfish usually attain a maximum size of only 200 mm SL, whereas similar species, such as *N. hyrtlii* and *N. ater*, can reach up to 400 mm TL (Lake 1971, Bishop *et al.* 2001). Breeding is thought to occur in the early wet season, where adults (> 91 mm SL) build their nests under large cobbles in flowing riffle zones (Bishop *et al*. 2001, Morgan *et al.* 2002). It is at this time when flooding increases the area and diversity of aquatic habitat available, while also initiating increases in plankton and other food sources (Bishop *et al.* 2001).

Pilbara tandan were collected in relatively low abundance throughout the Project area, with no new recruits (< 30 mm SL) recorded (Figure 15). Juvenile Pilbara tandan (31 – 70 mm SL) were only recorded at RRD2, RRU1 and RRU2 (Figure 15). Similar to spangled perch, low Pilbara tandan recruitment likely reflects the lack of streamflow in the Project area prior to the survey. Further, low overall catch rates of Pilbara tandan was likely due to the inherent difficulties in sampling this species. Like most other catfish, the Pilbara tandan is a benthic feeder, with techniques such as gill and seine netting generally limited in their ability to collect specimens due to the bottom-dwelling nature of these fish.

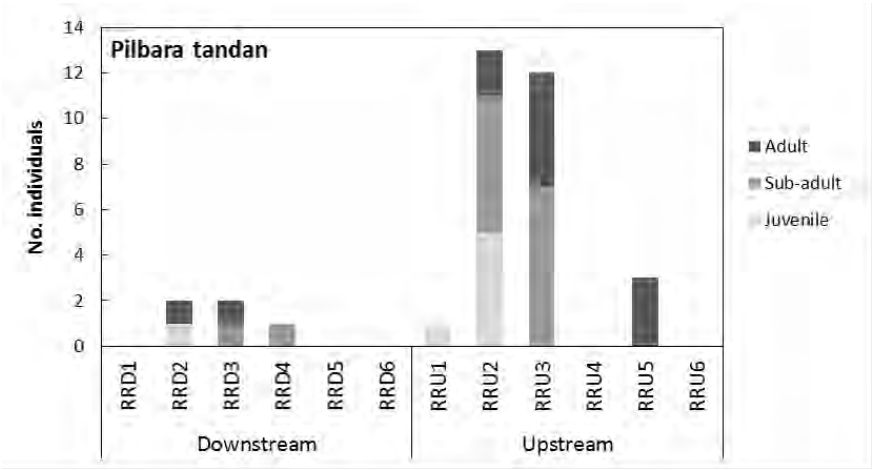


Figure 15. Abundance of Pilbara tandan (*Neosilurus* sp.) age-classes recorded from each pool in the Project area.

5.6 Other Fauna

No frogs or tadpoles were observed at any site in the current study. Although it is expected that some frogs do utilise pools within the Project area, the presence of large predatory fish, waterbirds and other predators (*e.g.* snakes) at these waterbodies would likely reduce survival rates of tadpoles in remnant pools.

No turtles were captured or observed in the Project area. EPA (1991) noted the native flat-shelled turtle, *Chelodina steindachneri,* was present at Gnieraoora and Martangkuna, but do not state the source of the records, which was possibly the 1991 survey by Streamtec/UWA for the Mesa J Project area.

6 SUMMARY AND CONCLUSIONS

This report summarises the results of wet season baseline sampling of aquatic ecosystems of the Robe River, both upstream and downstream of the proposed Mesa H development. The aim of the sampling program was to document the current ecological condition of the Robe River prior to the Mesa H development, which will require mine dewatering and surplus water discharge and may result in a surface discharge footprint along the Robe River. The current sampling program documents "current" ecological condition, moreso than "natural" condition due to the existing mine operations. In general, both water quality and aquatic fauna (microinvertebrate, hyporheic invertebrate, macroinvertebrate and fish) data indicated little ecological difference between "reference" sites upstream of the proposed development, and downstream sites that may be potentially exposed to dewatering discharge.

Water quality was highly variable amongst sites, with salinity levels ranging from fresh (592 µS/cm) to brackish (1,700 µS/cm), pH from circum-neutral (6.9) to slightly alkaline (7.9) and dissolved oxygen from hypoxic (14.5%) to supersaturated (134.9%). There were no obvious longitudinal gradients upstream or downstream of the Jimmawurrada-Robe confluence. Site RRU6, (~1 km upstream of the confluence) and the downstream sites, tended to have higher salinity (as EC and TDS), alkalinity, hardness and concentrations of associated ions, than sites upstream. This inter-site variability was attributed to differences in volume of the remnant pools sampled and evapoconcentration effects under recessional flows.

Exceedances of ANZECC/ARMCANZ default 95% TVs were recorded for nitrogen nutrients (N-total, N-NO_x and N-NH_3) at most sites upstream and downstream of the Jimmawurrada-Robe confluence. Elevated background levels of N-NO_3 and N-NH_3 within the Project area are unsurprising, given that the Robe River catchment is already effected by current and historic pastoral practices, with groundwaters also appearing to be enriched. Cattle, or evidence of high cattle use, were observed at a number of pools. Elevated N-total and N-NO_x downstream of the Jimmawurrada-Robe confluence may also reflect discharge of nitrogen-enriched groundwater from existing mine operations, though the relative contribution of anthropogenic and natural sources to nitrogen enrichment in surface waters of the Project area is unknown. With the exception of dissolved zinc at RRU5 and RRD3, no heavy metal analyte exceeded ANZECC/ARMCANZ default 95% TVs in the Project area.

A total of 81 microinvertebrate taxa were recorded from the Project area, of which 46 were present at potentially exposed sites downstream of the Jimmawurrada-Robe confluence, and 69 were recorded at upstream reference sites. The microinvertebrate fauna was generally typical of that commonly recorded from tropical/sub-tropical freshwater systems, comprising protists, rotifers, copepods, cladocerans (water fleas) and ostracods (seed shrimp), with Lecanidae dominating within the Rotifera. There were no significant differences in total mean microinvertebrate taxa richness between reference and potentially exposed sites, nor was there any significant difference in richness of any of the major microinvertebrate groups (protists, rotifers, micro-crustaceans) between these reaches.

Hyporheic sampling collected 59 taxa in total, the majority of which were species not specially adapted to groundwater environments (stygoxene); however, 8% were considered stygobitic (obligate groundwater inhabitants), 31% occasional hyporheic stygophiles (species that use the hyporheic zone seasonally or during early life history stages), and 2% possible hyporheic taxa. There were no obvious longitudinal gradients or patterns in hyporheic taxa richness between reference and potentially exposed sites, though hyporheic taxa richness was relatively high at RRD1, RRU6, RRD2 and RRU4, suggesting strong connectivity between ground- and surface- waters at these sites.

A total of 148 macroinvertebrate taxa were recorded from surface waters, with composition typical of freshwater systems throughout the world, being dominated by Insecta, in particular Diptera (true flies) and Coleoptera (aquatic beetles). There were no clear upstream/downstream gradients in

macroinvertebrate richness within the Project area, with no significant difference in mean total taxa richness, and mean richness of most major macroinvertebrate groups, between reference and potentially exposed sites. Similarly, multivariate analysis detected no distinguishable separation of reference or potentially exposed sites based on macroinvertebrate species assemblage structure.

3,515 individual fish, representing 11 species, were captured, measured and released in the Project area. True freshwater species included western rainbowfish, spangled perch, Pilbara tandan (eel-tailed catfish), Fortescue grunter, barred grunter, Terapontidae (grunter) hybrids and bony bream. Estuarine/marine vagrant fish species included milkfish, tarpon/ox-eye herring, mullet and banded scat/striped butterfish, the majority of which were recorded at downstream sites. The conservation listed Fortescue grunter (*Leipotherapon aheneus*; IUCN Lower Risk/Near Threatened; Parks and Wildlife Priority 4) was the second most abundant fish species of the Project area, recorded at all upstream and downstream sites. Similar to other fauna indices, there was no significant difference in mean total abundance of fish between upstream and downstream sites, nor was there any significant difference in mean abundance of each individual species between the reaches. Healthy (breeding) populations of western rainbowfish, the most abundant fish species of the Project area, were recorded from both the upstream and downstream reaches; however, spangled perch and Pilbara tandan recruitment appeared to be low throughout the Project area.

Including the Fortescue grunter, four species of conservation significance were recorded in the Project area, all of which were present at sites potentially exposed to dewatering discharge. These are summarised in Table 14 below:

Table 14. Summary of aquatic species of conservation significance (conservation listed or short range endemic) recorded from the Project area.

Species	Common name	Conservation significance	Occurrence within the Project area	Occurrence elsewhere
Microinvertebrates				
Eodiaptomus lumholtzi	Calanoid copepod	IUCN Vulnerable	RRD6	Koodaderi Spring, Homestead Trib., Mindy Mindy Ck., Cane R., NT & QLD.
Stygal / SRE invertebrates				
Nedsia spp.	Stygal amphipod	Potential short range endemic (data deficient)	RRD1 – 4, RRU3, RRU4 and RRU5	Uncertain, possibly bores within the Yarraloola Area
Macroinvertebrates				
Eurysticta coolawanyah	Pilbara pin damselfly	IUCN Near Threatened, Pilbara endemic	RRD3 and RRD4	Widespread throughout the Pilbara, though infrequently collected
Fish				
Leipotherapon aheneus	Fortescue grunter	IUCN Near Threatened, Parks and Wildlife Priority 4, Pilbara endemic	All sites	Robe R. catchment, Fortescue R. (below Fortescue Marsh); Ashburton R.

Current results indicate little ecological difference between "reference" sites upstream of the proposed Mesa H development, and downstream sites that may be potentially exposed to dewatering discharge operations. As such, these results provide a good starting point to enable the detection of potential ecological changes downstream of the Mesa H development caused by an altered abstraction and dewatering discharge regime. Data collected from reference sites upstream of Mesa H serve as the "control" for potentially exposed sites, while April/May 2016 data provide a snapshot of the "before"

condition, against which any future changes following mine development can be assessed. The premise being that if the degree of similarity between exposed and reference sites differs significantly over time (compared with pre-mine similarity), this would indicate mine-related response rather than stochastic variability due to factors such as climatic change.

7 REFERENCES

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8 APPENDICES

Appendix 1. Photographs of sampled sites

Potential impact sites downstream of the Jimmawurrada-Robe confluence in April-May 2016.

RRD1

RRD2

RRD3

RRD4

RRD5

RRD6

Reference sites upstream of the Jimmawurrada-Robe confluence in April-May 2016

RRU1

RRU2

RRU3

RRU4

RRU5

RRU6

Appendix 2. ANZECC/ARMCANZ (2000) trigger values

Table A2-1. ANZECC/ARMCANZ (2000) default trigger values for some physical and chemical stressors for tropical Australia for slightly disturbed ecosystems (TP = total phosphorus; FRP = filterable reactive phosphorus; TN = total nitrogen; NOx = total nitrates/nitrites; NH4+ = ammonium). Data derived from trigger values supplied by Australian states and territories, for the Northern Territory and regions north of Carnarvon in the west and Rockhampton in the east.

	TP ($\mu g\ L^{-1}$)	*FRP ($\mu g\ L^{-1}$)*	*TN ($\mu g\ L^{-1}$)*	*NOx ($\mu g\ L^{-1}$)*	*NH_4^+ ($\mu g\ L^{-1}$)*	*DO % saturation[f]*	*pH*
Aquatic Ecosystem							
Upland River[e]	10	5	150	30	6	90-120	6.0-7.5
Lowland River[e]	10	4	200-300[h]	10[b]	10	85-120	6.0-8.0
Lakes & Reservoirs	10	5	350[c]	10[b]	10	90-120	6.0-8.0
Wetlands[3]	10-50[g]	5-25[g]	350-1200[g]	10	10	90[b]-120[b]	6.0-8.0

b = Northern Territory values are 5µgL-1 for NOx, and <80 (lower limit) and >110% saturation (upper limit) for DO;
c = this value represents turbid lakes only. Clear lakes have much lower values;
e = no data available for tropical WA estuaries or rivers. A precautionary approach should be adopted when applying default trigger values to these systems;
f = dissolved oxygen values were derived from daytime measurements. Dissolved oxygen concentrations may vary diurnally and with depth. Monitoring programs should assess this potential variability;
g = higher values are indicative of tropical WA river pools;
h = lower values from rivers draining rainforest catchments.

Table A2-2. ANZECC/ARMCANZ (2000) Default trigger values for salinity and turbidity for the protection of aquatic ecosystems, applicable to tropical systems in Australia.

Aquatic Ecosystem		*Comments*
Salinity	***(µs/cm)***	
Upland & lowland rivers	20-250	Conductivity in upland streams will vary depending on catchment geology. The fist flush may result in temporarily high values
Lakes, reservoirs & wetlands	90-900	Higher conductivities will occur during summer when water levels are reduced due to evaporation
Turbidity	***(NTU)***	
Upland & lowland rivers	2-15	Can depend on degree of catchment modification and seasonal rainfall runoff
Lakes, reservoirs & wetlands	2-200	Most deep lakes have low turbidity. However, shallow lakes have higher turbidity naturally due to wind-induced re-suspension of sediments. Wetlands vary greatly in turbidity depending on the general condition of the catchment, recent flow events and the water level in the wetland.

Table A2-3. ANZECC/ARMCANZ (2000) default trigger values for toxicants at alternative levels of protection (µg/L).

	Trigger values for freshwater Level of protection (% species)			
Compound	***99%***	***95%***	***90%***	***80%***
METALS & METALLOIDS				
Aluminium pH > 6.5	27	55	80	150
Aluminium pH < 6.5	ID	ID	ID	ID
Arsenic (As III)	1	24	94	360
Arsenic (As IV)	0.9	13	42	140
Boron	90	370	680	1300
Cadmium	0.06	0.2	0.4	0.8
Cobalt	ID	ID	ID	ID
Chromium (Cr III)	ID	ID	ID	ID
Chromium (Cr VI)	0.01	1	6	40
Copper	1	1.4	1.8	2.5
Iron	ID	ID	ID	ID
Manganese	1200	1900	2500	3600
Molybdenum	ID	ID	ID	ID
Nickel	8	11	13	17
Lead	1	3.4	5.6	9.4
Selenium (Se total)	5	11	18	34
Selenium (Se IV)	ID	ID	ID	ID
Uranium	ID	ID	ID	ID
Vanadium	ID	ID	ID	ID
Zinc	2.4	8	15	31
NON-METALLIC INORGANICS				
Ammonia	320	900	1430	2300
Chlorine	0.4	3	6	13
Nitrate	17	700	3400	17000

Appendix 3. Water quality data

Results from spot measurement of surface water quality taken in conjunction with aquatic fauna sampling. ANZECC/ARMCANZ (2000) default TV for protection of 95% of freshwater species is also provided for comparison; ☐ ≥ default TV, ☐ ≥ 2x default TV, ☐ ≥ 10x default TV; note, for DO, values highlighted are less than the lower default TV.

Water Quality Parameter	Method Code	*LOR*	Units	ANZECC TV	RRD1 30-04-16 0815hr	RRD2 30-04-16 1345hr	RRD3 30-04-16 1530hr	RRD4 29-04-16 1415hr	RRD5 29-04-16 1200hr	RRD6 30-04-16 1230hr	RRU1 05-05-16 0845hr	RRU2 28-04-16 1130hr	RRU3 28-04-16 0830hr	RRU4 28-04-16 1500hr	RRU5 29-04-16 0715hr	RRU6 07-05-16 1015hr
Al	iMET1WCICP	*0.005*	mg/L	0.055	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Alkalinity	iALK1WATI	*1*	mg/L	NP	245	133	266	260	249	241	155	156	175	166	183	253
As	iMET1WCMS	*0.001*	mg/L	0.013[A]	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
B	iMET1WCICP	*0.02*	mg/L	0.37	0.29	0.18	0.2	0.28	0.36	0.28	0.19	0.19	0.22	0.2	0.21	0.33
Ba	iMET1WCICP	*0.002*	mg/L	NP	0.051	0.035	0.039	0.04	0.058	0.046	0.043	0.044	0.055	0.039	0.044	0.05
CO_3	iALK1WATI	*1*	mg/L	NP	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Ca	iMET1WCICP	*0.1*	mg/L	NP	81.5	48.9	78.5	74.2	65.6	66.8	46.5	46.3	51.1	48.4	51.8	100
Cd	iMET1WCMS	*0.0001*	mg/L	0.0002	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Cl	iCO1WCDA	*1*	mg/L	NP	209	126	193	176	213	169	120	115	109	138	128	372
Co	iMET1WCMS	*0.0001*	mg/L	ID	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0002	<0.0001	<0.0001	<0.0001
Cr	iMET1WCMS	*0.0005*	mg/L	0.001	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Cu	iMET1WCMS	*0.0001*	mg/L	0.0014	0.0002	0.0002	0.0002	0.0002	0.0002	0.0007	0.0003	0.0002	0.0002	0.0002	0.0002	0.0003
DO (field)	TPS WP-82Y logger	*0.01*	% sat.	90 - 120	72.7	44.6	94.6	79.2	37.4	134.9	37.2	38.5	16.1	74.1	14.5	77.8
DO (field)	TPS WP-82Y logger	*0.01*	mg/L	NP	5.8	3.6	8.0	5.8	2.7	8.4	2.4	2.9	1.2	5.8	0.9	5.3
EC	iEC1WZSE	*2*	µS/cm	250	1280	711	1260	1220	592	1130	772	748	824	782	802	1700
Fe	iMET1WCICP	*0.005*	mg/L	0.3*	0.007	0.013	<0.005	<0.005	0.012	0.036	0.058	0.022	0.099	0.059	0.061	0.018
HCO_3	iALK1WATI	*1*	mg/L	NP	299	162	324	317	303	294	190	191	214	202	223	309
Hardness	iHTOT2WACA	*1*	mg/L	NP	440	260	420	400	430	360	240	230	250	240	250	520
K	iMET1WCICP	*0.1*	mg/L	NP	9	6	8.6	8.2	9.7	8.7	5	5.8	6.2	6.1	6	4.4
Mg	iMET1WCICP	*0.1*	mg/L	NP	57.2	33.7	54.3	52.4	63.6	46.7	30.3	27	29.7	29.3	30.3	66.5
Mn	iMET1WCICP	*0.001*	mg/L	1.9	<0.001	0.002	<0.001	<0.001	0.003	0.004	0.002	0.009	0.099	0.002	0.004	0.004
Mo	iMET1WCMS	*0.001*	mg/L	ID	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001
N-NH_3	iAMMN1WFIA	*0.01*	mg/L	0.01[N]	0.02	0.05	<0.01	<0.01	<0.01	0.03	<0.01	0.02	0.01	0.01	0.01	0.07
N-NO_2	iNTRN1WFIA	*0.01*	mg/L	NP	<0.01	0.02	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.04
N-NO_3	iNTAN1WCALC	*0.01*	mg/L	NP	1.8	1.3	1.3	2	0.86	2.5	<0.01	1.2	0.95	0.38	1.1	3.7

Water Quality Parameter	Method Code	*LOR*	Units	ANZECC TV	RRD1 30-04-16 0815hr	RRD2 30-04-16 1345hr	RRD3 30-04-16 1530hr	RRD4 29-04-16 1415hr	RRD5 29-04-16 1200hr	RRD6 30-04-16 1230hr	RRU1 05-05-16 0845hr	RRU2 28-04-16 1130hr	RRU3 28-04-16 0830hr	RRU4 28-04-16 1500hr	RRU5 29-04-16 0715hr	RRU6 07-05-16 1015hr
N-NO_X	iNTAN1WFIA	*0.01*	mg/L	0.01	1.8	1.3	1.3	2	0.87	2.5	<0.01	1.2	0.96	0.38	1.1	3.8
N-total	iNP1WTFIA	*0.01*	mg/L	0.3	1.8	1.5	1.3	2	0.88	2.6	0.09	1.4	1	0.41	1.2	3.9
Na	iMET1WCICP	*0.1*	mg/L	NP	91.4	53.9	86.4	87.1	104	87.2	51.6	53.3	64.7	60.1	58.9	132
Ni	iMET1WCMS	*0.001*	mg/L	0.011	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
OH	iALK1WATI	*1*	mg/L	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
P-total	iPP1WTFIA	*0.005*	mg/L	0.01	0.011	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	0.011
Pb	iMET1WCMS	*0.0001*	mg/L	0.034	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
pH (field)	WTW pH330i field meter	*0.1*	[H+]	6.0 - 8.0	7.4	7.3	7.0	7.2	7.2	7.7	7.9	7.0	6.9	7.2	7.0	7.4
pH (lab)	iPH1WASE	*0.1*	[H+]	6.0 - 8.0	7.9	7.8	7.7	7.9	7.8	8	8	7.7	7.6	7.9	7.7	7.8
Redox (field)	WTW pH330i field meter	*-1999*	mV	NP	-27.2	-19.3	-3.8	-15.6	-13.5	-46.1	-56.8	-1.1	2.6	-19.4	-3.3	-22.9
S	iMET1WCICP	*0.1*	mg/L	NP	28	28	25	24	25	22	14	12	14	13	12	22
S-SO_4	iMET1WCICP	*0.1*	mg/L	NP	84	50	73.6	72	75.3	66.3	43.3	34.8	40.5	40	36.6	67.1
Se	iMET1WCMS	*0.001*	mg/L	0.011	0.002	<0.001	<0.001	0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.003
TDS-calc	iSOL1WDCA	*5*	mg/L	NP	700	390	700	670	330	620	420	410	450	430	440	940
Temp (field)	TPS WP-82Y logger	*-5*	°C	NP	27.4	25.0	30.1	30.7	27.4	28.2	24.8	29.6	26.6	28.6	28.2	27.7
TSS	iSOL1WPGR	*1*	mg/L	NP	3	4	7	<1	34	2	4	4	<1	2	<1	19
U	iMET1WCMS	*0.0001*	mg/L	ID	0.0009	0.0004	0.0004	0.0004	0.001	0.0008	0.0002	0.0002	0.0001	0.0004	0.0003	0.0016
V	iMET1WCMS	*0.0001*	mg/L	ID	0.0017	0.0012	0.0008	0.0016	0.0015	0.0031	0.0019	0.0011	0.0003	0.0013	0.001	0.0027
Zn	iMET1WCMS	*0.001*	mg/L	0.008[H]	0.004	0.002	0.011	0.003	0.003	0.007	0.004	0.004	0.001	0.003	0.012	0.004

* ANZECC/ARMCANZ (2000) provide only a low reliability TV for iron (Fe);

[A] Default TV shown is for AsV, as no default TV is provided for total arsenic;

[B] For bioaccumulating chemicals, ANZECC/ARMCANZ (2000) recommend using the default 99% species protection level TV;

[H] Default TV should be modified for water hardness using algorithms provided in Table 3.4.3 of ANZECC/ARMCANZ (2000);

[N] Default TV shown is for ammonium nitrogen, as N-NH_4^+, for protection against eutrophication. Default TV for protection against toxic effects of ammonia, as N-NH_3, is 0.9 mg/L.

Appendix 4. Habitat data

Site	RRD1	RRD2	RRD3	RRD4	RRD5	RRD6	RRU1	RRU2	RRU3	RRU4	RRU5	RRU6
Date	30-04-16	30-04-16	30-04-16	29-04-16	29-04-16	30-04-16	05-05-16	28-04-16	28-04-16	28-04-16	29-04-16	07-05-16
Canopy cover (%)	0	25	5	15	35	5	2	20	2	5	50	5
Bedrock %	0	5	2	0	0	5	5	0	0	0	0	2
Boulders %	0	2	5	0	2	2	2	2	1	5	0	2
Cobbles %	10	3	5	5	10	3	10	10	19	15	5	35
Pebbles %	30	15	35	35	23	25	36	50	60	40	65	25
Gravel %	30	55	35	55	45	35	40	32	15	38	23	15
Sand %	5	20	13	5	15	5	5	3	3	2	5	0
Silt %	15	0	5	0	5	10	0	1	2	0	0	21
Clay %	10	0	0	0	0	15	2	2	0	0	2	0
Mineral %	45	41	41	36	49	5	5	49	53	12	10	20
Emergent veg %	10	10	20	35	20	20	5	25	0	60	43	40
Submergent veg %	0	30	15	5	15	30	25	15	0	10	20	5
Floating veg %	0	0	0	0	0	0	55	3	0	10	0	0
Algae %	5	2	10	5	10	3	5	2	15	5	10	3
Detritus %	40	10	10	15	2	38	0	2	5	2	5	30
Trailing veg %	0	5	2	2	2	2	0	3	0	0	5	0
LWD %	0	2	2	2	2	2	3	1	2	1	5	2
Other %	0	0	0	0	0	0	2	0	25	0	2	0
Max Pool Depth (m)	0.8	0.7	1	2	4	1.2	1.20	3	1	1	1.2	0.6
Pool Length (m)	7	12	25	150	45	20	100	60	3	120	40	40
Ave Pool Width (m)	3	6	5	20	25	30	20	10	5	20	10	12
Bed compaction*	2	3	3	2	3	1	3	2	2	2	3	3
Habitat diversity	4	7	7	7	7	7	7	8	5	7	8	6
Mean substrate size (phi)	-0.575	-1.750	-2.465	-2.900	-2.140	-0.025	-2.960	-3.405	-4.135	-3.945	-3.420	-2.515
Substrate diversity**	6	6	7	4	6	8	7	6	5	5	5	6

* Bed compaction categories range from 1 = loose, to 5 = armoured.

** Total number of substrate types present.

Appendix 5. Microinvertebrate data

Values are total abundance.

Phylum/Class/Order	Family	Lowest Taxon	RRU1	RRU2	RRU3	RRU4	RRU5	RRU6	RRD1	RRD2	RRD3	RRD4	RRD5	RRD6
PROTISTA														
CILIOPHORA	**Stentoridae**	*Stentor* sp.	0	0	0	4	*	0	0	0	0	0	0	0
RHIZOPODA	**Arcellidae**	*Arcella discoides* Ehrenberg, 1843	*	0	13	3	0	0	0	1	0	1	0	1
		Arcella hemisphaerica Perty 1852	0	0	25	0	0	0	0	2	0	0	0	0
		Arcella megastoma Penard, 1902	0	0	0	2	0	0	0	0	0	0	0	0
		Arcella [sm]	*	0	0	0	0	0	0	0	0	0	0	0
	Centropyxidae	*Centropyxis aculeata* (Ehrenberg, 1838)	0	0	0	0	1	0	0	0	0	0	0	0
		Centropyxis cf. *aculeata* (Ehrenberg, 1838) [v. sm]	0	0	0	1	1	0	0	0	0	0	0	0
		Centropyxis ecornis (Ehrenberg, 1841)	0	*	0	5	11	0	0	1	0	1	2	2
	Difflugiidae	*Difflugia globulosa* Dujardin, 1837	*	1	1	6	2	0	0	3	0	0	0	3
		Difflugia gramen Penard, 1902	0	0	0	0	0	0	0	0	0	0	0	2
		Difflugia sp. [sm, pyriform]	0	0	0	1	4	0	0	0	0	0	0	*
	Lesquereusiidae	*Lesquereusia spiralis* (Ehrenberg, 1840)	0	0	1	0	3	0	0	0	1	0	0	2
	Trigonopyxidae	*Cyclopyxis* sp.	0	0	0	1	0	0	0	0	0	0	0	0
ANIMALIA														
ROTIFERA														
Bdelloidea		indet. bdell. [lg, bidentate]	0	0	0	0	20	4	0	0	0	0	0	4
		indet. bdell. [sm, likely more than one sp.]	0	1	8	4	14	2	0	0	0	0	0	4
		indet. bdell. [tiny]	0	0	0	0	*	0	0	0	0	1	0	0
Monogononta	**Asplanchnidae**	*Asplanchnopus hyalinus* (Harring, 1913)	0	0	0	0	0	0	0	0	0	0	0	*
	Brachionidae	*Brachionus angularis* Gosse, 1851	*	0	0	0	0	0	0	0	0	0	0	0
		Keratella procurva (Thorpe, 1912)	0	0	0	0	0	0	0	0	0	*	0	0
		Plationus patulus (Müller, 1786)	0	1	0	0	0	0	0	0	0	0	0	2
		Platyias quadricornis (Ehrenberg, 1832)	0	*	0	0	0	0	0	0	0	0	0	0
	Dicranophoridae	*Dicranophoroides caudatus* (Ehrenberg, 1834)	0	0	0	0	1	0	0	1	0	0	0	0
	Euchlanidae	*Euchlanis dilatata* Ehrenberg, 1832	0	*	0	0	0	0	0	0	0	0	0	1
		Tripleuchlanis plicata (Levander, 1894)	0	0	0	2	1	0	0	0	0	0	0	*
	Flosculariidae	*Sinantherina* sp. [solitary]	*	*	0	0	0	0	0	0	0	0	0	0
	Gastropodidae	*Ascomorpha* sp.	0	0	1	0	0	0	0	0	0	1	0	3
	Lecanidae	*Lecane bulla* (Gosse, 1851)	0	0	1	7	2	0	0	0	0	0	0	4
		Lecane curvicornis (Murray, 1913)	0	0	0	0	9	0	0	0	0	0	0	0
		Lecane hamata (Stokes, 1896)	0	0	1	0	0	0	0	0	0	0	0	1

Phylum/Class/Order	Family	Lowest Taxon	RRU1	RRU2	RRU3	RRU4	RRU5	RRU6	RRD1	RRD2	RRD3	RRD4	RRD5	RRD6
		Lecane ludwigii (Eckstein, 1883)	0	0	0	0	0	0	0	0	0	1	0	0
		Lecane **n. sp.**	0	0	0	0	1	0	0	0	0	0	0	2
		Lecane stenroosi (Meissner, 1908)	2	0	0	0	0	1	0	0	0	1	0	0
		Lecane thalera(Harring & Myers, 1926)	0	0	0	11	9	0	0	0	0	1	0	1
		Lecane (s. str.) a	0	0	0	0	12	0	0	0	0	0	0	0
		Lecane (s. str.) b [v. sm]	0	0	0	0	1	0	0	0	0	0	0	0
		Lecane (*M.*) sp. a	0	0	0	1	4	0	0	0	0	0	0	0
		Lecane (*M.*) sp. b	0	0	0	0	3	0	0	0	0	0	0	0
		Lecane (*M.*) sp. c	0	0	0	0	1	1	0	0	0	0	0	0
	Lepadellidae	*Colurella* sp. [tiny]	0	0	0	0	2	0	0	0	0	0	0	0
		Lepadella cf. *rhomboides* (Gosse, 1886)	0	0	0	0	1	0	0	0	0	0	0	0
		Lepadella sp.	0	0	1	1	2	0	0	0	0	0	0	0
		Squatinella rostrum (Schmarda, 1846)	0	0	0	0	1	0	0	0	0	0	0	1
	Lindiidae	*Lindia* sp.	0	0	0	0	3	0	0	0	0	0	0	0
	Notommatidae	*Cephalodella gibba* (Ehrenberg, 1830)	0	0	1	0	0	0	0	0	0	0	0	0
		Cephalodella sp.	*	0	0	0	0	0	0	0	0	0	0	0
		notommatid, indet.	0	0	0	0	0	0	0	0	0	0	0	1
	Proalidae	*Proales* sp.	0	0	0	1	0	0	0	0	0	0	0	3
	Scaridiidae	*Scaridium* sp.	0	0	0	0	1	0	0	0	0	0	0	0
	Synchaetidae	*Polyarthra* sp.	5	145	6	0	0	0	0	0	0	0	0	39
		indet. contr. blob	*	0	3	2	0	0	0	0	0	0	0	0
		maybe rotifer	0	0	0	1	0	0	0	0	0	0	0	0
ARTHROPODA														
CLADOCERA	**Bosminidae**	*Bosmina meriodionalis* Sars, 1904	0	0	0	2	0	0	0	0	0	0	0	0
	Chydoridae	*Anthalona harti* Van Damme, Sinev & Dumont, 2011	0	0	0	0	0	0	0	1	0	0	0	0
		Chydorus sp.	0	0	0	1	0	0	0	0	0	0	0	0
		Dunhevedia crassa King, 1853	0	*	0	0	0	0	0	0	0	0	0	0
		Ephemeroporus barroisi (Richard, 1894)	0	0	0	2	0	0	0	1	2	0	0	0
		Karualona karua (King, 1853)	0	0	0	1	0	0	0	4	0	0	0	0
		indet. alonine	*	0	*	0	0	0	0	1	1	0	0	0
	Daphnidae	*Ceriodaphnia cornuta* Sars, 1885	*	0	0	0	0	0	0	0	0	0	0	0
		Ceriodaphnia sp.	0	*	0	0	0	0	0	0	0	0	0	0
	Ilyocryptidae	*Ilyocryptus* sp. [juv.]	0	0	0	0	0	1	0	0	0	0	0	0
	Moinidae	*Moina micrura*	0	*	0	0	0	0	0	0	0	0	0	0
	Sididae	*Diaphanosoma excisum* Sars, 1885	0	*	0	0	0	0	0	0	0	0	0	*
COPEPODA	**Calanoida**	*Eodiaptomus lumholtzi* (Sars, 1889)	0	0	0	0	0	0	0	0	0	0	0	1
		calanoid copepodite	0	0	0	0	0	0	0	0	0	0	0	1

Phylum/Class/Order	Family	Lowest Taxon	RRU1	RRU2	RRU3	RRU4	RRU5	RRU6	RRD1	RRD2	RRD3	RRD4	RRD5	RRD6
		calanoid nauplii	0	0	0	0	0	0	0	0	0	0	0	3
	Cyclopoida	*Mesocyclops darwini* Dussart & Fernando, 1988	0	0	0	1	0	0	0	0	1	0	0	*
		Mesocyclops sp. [other]	0	0	0	0	*		0	0	0	0	0	0
		Tropocyclops cf. *prasinus* (Fischer, 1860)	0	0	0	0	0	0	0	0	0	9	0	3
		indet. cyclopoid sp. [3-seg. P1-4]	0	0	0	0	0	0	0	2	0	0	0	0
		indet. cyclopoid lg	*	*	0	0	0	0	0	0	0	0	0	0
		indet. cyclopoid sm	*	2	1	0	0	0	0	8	0	0	0	0
		cyclopoid copepodites	11	2	35	14	5	1	2	76	0	21	0	26
		cyclopoid nauplii	184	56	106	93	97	2	0	13	0	168	0	85
OSTRACODA	**Cyprididae**	*Cypretta* sp.	*	*	0	1	0	0	0	3	0	0	0	*
		cf. *Cypridopsis* sp.	0	0	*	1	0	valves	0	0	0	*	0	0
		Heterocypris sp.	0	*	0	0	0	0	0	0	0	0	0	0
		Sarscypridopsis sp.	0	0	0	0	0	0	0	0	0	0	0	0
	Darwinulidae	*Vestalenula marmonieri*	0	*	0	1	3	valves	2	70	13	0	0	*
	Limnocytheridae	*Limnocythere* sp.	0	0	0	0	*	0	valves	2	2	0	0	*
	Notodromadidae	indet. juv.	0	0	0	0	2	0	1	3	1	0	0	3
		Taxa Richness	**16**	**19**	**18**	**27**	**33**	**7**	**3**	**17**	**7**	**12**	**1**	**33**

*found after initial count of ~200 cells

Appendix 6. Hyporheic invertebrate data

Values are log_{10} abundance categories, where 1= 1 individual, 2 = 2-10 individuals, 3 = 11-100, 4 = 101-1000, and so on. Hyporheic fauna classifications (Class) followed those of Boulton (2001), where: X = stygoxene, O = occasional hyporheic stygophile, P = possible hyporheic taxa, S = stygobite and U = Unclassified.

Phylum/Class/Order	Family	Lowest Taxon	Class	RRD1	RRD2	RRD3	RRD4	RRD5	RRD6	RRU1	RRU2	RRU3	RRU4	RRU5	RRU6
PLATYHELMINTHES															
TURBELLARIA		Turbellaria spp.	X	0	0	0	0	1	1	0	0	0	0	0	2
NEMATODA		Nematoda spp.	O	0	0	0	0	3	2	2	0	0	1	0	0
MOLLUSCA															
GASTROPODA															
Cerithimorpha	**Thiaridae**	*Melanoides* spp.	X	2	0	0	3	2	0	0	0	0	0	0	0
Hygrophila	**Planorbidae**	*Gyraulus* spp.	X	0	0	0	2	0	0	0	0	0	0	0	0
ANNELIDA															
OLIGOCHAETA		Oligochaeta spp. (imm./dam.)	U	0	0	2	0	2	0	0	0	2	2	0	0
Tubificida	**Naididae**	Naididae spp. (imm./dam.)	O	1	3	0	0	3	0	0	0	0	2	2	0
		Allonais pectinata	O	0	0	0	0	0	0	0	0	0	1	0	0
		Branchiura sowerbyi	O	0	2	0	0	0	0	0	0	0	3	0	0
		Pristina aequiseta	O	0	3	0	0	0	0	0	0	0	0	0	0
		Pristina leidyi	O	0	0	0	0	0	0	0	0	0	0	2	0
		Pristina longiseta	O	1	0	2	0	1	3	0	0	0	1	0	1
	Phreodrilidae	Phreodrilidae spp.	O	0	0	0	2	0	0	0	0	1	0	0	0
ARTHROPODA															
CRUSTACEA															
MALACOSTRACA															
Amphipoda		Amphipoda spp. (stygofauna)	S	3	2	3	0	0	0	1	0	2	0	2	3
	Eriopisidae	*Nedsia* spp.	S	3	2	1	1	0	0	0	0	2	1	0	3

Phylum/Class/Order	Family	Lowest Taxon	Class	RRD1	RRD2	RRD3	RRD4	RRD5	RRD6	RRU1	RRU2	RRU3	RRU4	RRU5	RRU6
Thermosbaenacea	**Halosbaenidae**	*Halosbaena tulki*	S	0	2	2	1	0	0	0	0	2	0	0	0
MAXILLIPODA															
Cyclopoida		cyclopoid copepodites	U	2	3	1	0	1	3	2	0	3	0	2	3
	Cyclopidae	*Halicyclops calm*	O	0	0	0	0	0	0	1	1	0	0	0	0
		Mesocyclops darwini	O	0	0	0	0	0	0	0	0	2	0	0	0
		Microcyclops varicans	O	1	0	0	0	0	2	0	0	0	0	0	2
OSTRACODA															
	Candonidae	*Candonopsis* cf. *tenuis*	S	0	0	0	0	0	0	0	0	0	0	0	1
	Cyprididae	*Cypridopsis* sp.	O	2	0	0	1	0	0	0	0	0	0	0	0
		Cyprinotus cingalensis	O	1	0	0	0	0	0	0	0	0	0	0	0
		Stenocypris major	X	0	0	0	1	0	0	0	0	0	0	0	0
	Darwinulidae	*Vestalenula marmonieri*	S	3	0	0	0	1	0	2	0	0	0	0	0
ARACHNIDA		Acarina spp.	P	2	3	0	2	2	3	2	0	2	2	1	2
HEXAPODA															
ENTOGNATHA															
Entomobryomorpha		Entomobryoidea spp.	O	2	1	0	0	3	1	0	1	2	2	2	3
Poduromorpha		Poduroidea spp.	O	1	0	0	2	0	0	0	0	0	0	0	0
Symphypleona		Symphypleona spp.	O	0	0	0	0	0	0	2	0	0	0	0	1
INSECTA															
Ephemeroptera	**Caenidae**	*Tasmanocoenis* sp. P/*arcuata*	X	0	0	0	0	0	0	0	0	1	0	0	0
Coleoptera		Coleoptera spp. (L)	U	0	2	0	0	0	0	0	0	0	2	0	2
	Carabidae	Carabidae sp.	X	0	0	0	0	0	0	0	0	0	1	0	0
	Dytiscidae	Bidessini sp. (L)	X	0	0	0	0	0	0	0	0	0	1	0	0
	Elmidae	*Austrolimnius* spp. (L)	X	2	0	2	0	0	0	0	0	0	0	0	0
	Hydraenidae	Hydraenidae sp. (L)	O	0	0	0	0	1	0	0	0	0	0	0	1
		Hydraena spp.	O	2	0	0	0	0	0	0	0	0	0	0	0
	Hydrophilidae	Hydrophilidae spp. (L)	X	0	0	1	0	0	0	0	0	0	0	1	0

Phylum/Class/Order	Family	Lowest Taxon	Class	RRD1	RRD2	RRD3	RRD4	RRD5	RRD6	RRU1	RRU2	RRU3	RRU4	RRU5	RRU6
		Chaetarthria nigerrima (L)	X	0	0	0	0	2	0	0	0	0	0	0	0
		Enochrus sp. (L)	X	0	0	0	0	1	0	0	0	0	0	0	0
		Helochares sp. (L)	X	0	0	0	0	0	0	1	0	0	0	0	0
	Ptiliidae	Ptiliidae sp.	X	0	0	1	0	0	0	0	0	0	0	0	0
	Scirtidae	Scirtidae spp. (L)	X	2	1	0	0	0	1	0	0	0	1	2	2
	Staphylinidae	Staphylinidae sp.	X	0	1	0	0	0	0	0	0	0	0	0	0
Diptera	**Ceratopogonidae**	Ceratopogonidae spp. (P)	X	1	2	0	0	2	0	3	0	0	2	1	2
		Ceratopogoninae spp.	X	3	3	3	2	4	3	0	3	3	4	2	4
		Dasyheleinae spp.	X	0	3	3	2	3	1	3	2	1	2	0	0
		Forcipomyiinae spp.	X	0	0	0	0	2	0	0	0	0	0	0	0
	Chironomidae	Chironomidae sp. (P)	X	0	1	0	0	0	0	0	0	0	0	0	0
	Chironominae														
	Chironomini	*Paratendipes* sp. K1	X	0	1	0	0	3	0	0	0	0	0	0	0
		Polypedilum sp. 1	X	0	0	0	0	0	0	0	0	0	2	0	0
	Tanytarsini	*Cladotanytarsus* sp. (WWTS4)	X	0	0	0	0	1	0	0	0	0	0	0	0
		Tanytarsus sp. (WWTS1)	X	1	1	0	0	1	0	2	0	1	1	0	0
		Paratanytarsus sp. (WWTS2)	X	1	2	0	0	2	0	2	0	0	0	0	0
	Orthocladiinae	Orthocladiinae sp. (WWO7)	X	0	2	0	0	0	0	0	0	0	0	0	0
		Orthocladiinae sp. (WWO8)	X	0	0	2	0	0	2	0	0	2	0	0	2
	Tanypodinae	*Paramerina* sp. (WWT1)	X	2	0	0	0	0	0	0	0	1	0	0	0
	Dolichopodidae	Dolichopodidae spp.	X	0	2	2	0	0	0	0	1	0	0	0	0
	Empididae	Empididae spp.	X	0	0	2	0	0	0	0	0	0	0	0	0
	Tabanidae	Tabanidae sp.	X	0	0	0	0	0	0	1	0	0	0	0	0
	Tipulidae	Tipulidae spp.	X	0	1	0	0	3	0	2	1	0	0	0	0
		Taxa richness		**21**	**22**	**14**	**11**	**22**	**11**	**14**	**6**	**15**	**18**	**10**	**16**

(imm./dam) = taxa were too immature / damaged to be accurately identified to a lower taxonomic level.

(P) = taxa were in pupal form.

(L) = taxa were in larval form.

NB: some chironomid taxa are followed by their unique morphotype code (in parentheses).

Appendix 7. Macroinvertebrate data

Values are $\log_{10}$ abundance categories, where 1= 1 individual, 2 = 2-10 individuals, 3 = 11-100, 4 = 101-1000, and so on.

Phylum/Class/Order	Family	Lowest Taxon	RRD1	RRD2	RRD3	RRD4	RRD5	RRD6	RRU1	RRU2	RRU3	RRU4	RRU5	RRU6
CNIDARIA														
HYDROZOA														
Anthoathecata	**Hydridae**	*Hydra* sp.	1	0	0	0	0	0	0	0	0	0	0	0
MOLLUSCA														
GASTROPODA		Gastropoda spp. (imm./dam.)	0	0	0	0	0	0	0	0	0	0	2	0
Cerithimorpha	**Thiaridae**	*Melanoides* spp.	3	0	3	3	2	3	4	4	2	2	3	4
Hygrophila	**Lymnaeidae**	*Bullastra vinosa*	2	2	0	0	3	3	2	2	1	0	0	0
	Planorbidae	*Amerianna* spp.	0	0	0	0	0	0	0	2	0	0	0	0
		Ferrissia petterdi	2	2	0	0	0	0	0	0	0	0	2	0
		Gyraulus spp.	3	3	0	3	2	3	4	3	0	0	2	2
BIVALVIA														
Unionoida	**Hyriidae**	*Velesunio* spp.	0	0	0	0	0	0	0	0	0	0	0	2
ANNELIDA														
OLIGOCHAETA		Oligochaeta spp.	3	3	3	3	3	0	3	3	3	3	4	2
ARTHROPODA														
CRUSTACEA														
MALACOSTRACA														
Amphipoda		Amphipoda spp. (stygofauna)	0	0	3	2	0	0	0	0	0	0	0	0
	Eriopisidae	*Nedsia* spp.	0	0	2	3	0	0	0	0	0	0	0	0
Decapoda	**Atyidae**	Atyidae spp. (imm./dam.)	2	0	2	0	0	0	0	0	0	0	2	2
		Caridina indistincta	3	3	3	2	3	3	3	4	3	2	3	1
CHELICERATA														
ARACHNIDA		Acarina spp.	3	3	0	2	2	0	4	3	3	0	3	2
HEXAPODA														
ENTOGNATHA														
Entomobryomorpha		Entomobryoidea spp.	2	2	0	0	0	0	2	0	0	0	0	0
Symphypleona		Symphypleona sp.	0	0	0	0	0	0	1	0	0	0	0	0
INSECTA														
Odonata														
Anisoptera		Anisoptera spp. (imm./dam.)	2	2	2	0	1	2	2	3	2	2	0	0
	Aeshnidae	*Hemianax papuensis*	0	0	0	0	0	1	0	0	0	0	0	0
	Libellulidae	*Crocothemis nigrifrons*	0	2	0	0	0	0	1	0	0	0	1	0

Phylum/Class/Order	Family	Lowest Taxon	RRD1	RRD2	RRD3	RRD4	RRD5	RRD6	RRU1	RRU2	RRU3	RRU4	RRU5	RRU6
		Diplacodes bipunctata	0	0	0	0	0	1	0	0	2	2	0	1
		Diplacodes haematodes	0	0	0	0	0	0	1	0	0	1	0	0
		Orthetrum caledonicum	2	0	0	1	0	1	1	0	0	0	0	0
		Rhodothemis lieftincki	0	0	0	0	1	0	0	2	2	3	2	0
		Rhyothemis graphiptera	0	0	1	2	1	0	0	0	0	0	0	0
		Zyxomma elgneri	0	0	1	0	0	0	0	1	2	0	1	0
	Lindeniidae	*Ictinogomphus dobsoni*	1	0	0	1	0	2	0	0	1	0	0	0
Zygoptera		Zygoptera spp. (imm./dam.)	1	2	1	2	0	2	2	2	0	3	0	3
	Coenagrionidae	*Argiocnemis rubescens*	2	2	0	0	0	0	2	0	2	0	1	0
		Ischnura aurora	0	2	0	0	2	2	3	2	0	2	0	2
		Ischnura heterosticta	0	0	0	0	0	0	0	0	0	2	0	0
		Pseudagrion aureofrons	0	0	0	0	0	0	2	1	0	1	0	0
		Pseudagrion microcephalum	0	0	0	0	0	1	0	0	0	2	0	0
	Isostictidae	*Eurysticta coolawanyah*	0	0	1	2	0	0	0	0	0	0	0	0
Ephemeroptera	**Baetidae**	Baetidae spp. (imm./dam.)	2	3	3	3	2	3	1	3	0	2	0	2
		Cloeon fluviatile	0	3	2	2	2	0	3	0	0	0	0	0
		Cloeon sp. Red Stripe	2	4	3	3	2	2	3	3	1	3	2	3
	Caenidae	Caenidae spp. (imm./dam.)	0	3	3	2	0	2	1	0	2	0	0	0
		Tasmanocoenis sp. M	0	0	2	0	0	0	0	0	0	0	0	0
		Tasmanocoenis sp. P/*arcuata*	2	3	2	2	0	2	1	0	0	0	1	0
Hemiptera	**Belostomatidae**	Belostomatidae spp. (imm./dam.)	0	2	0	0	0	2	3	2	0	2	2	2
		Diplonychus spp.	0	2	1	0	1	0	0	2	0	0	2	1
		Lethocerus distinctifemur	0	0	0	0	0	0	0	0	1	0	0	0
	Corixidae/Micronectidae	Corixidae/Micronectidae spp. (imm./dam.)	0	2	0	2	0	2	2	3	0	0	0	0
	Gelastocoridae	*Nerthra* spp. (imm./dam.)	0	0	0	1	0	0	1	0	0	0	0	0
	Gerridae	Gerridae spp. (imm./dam.)	0	2	0	0	0	0	2	2	0	0	1	0
		Limnogonus fossarum gilguy	0	2	0	0	2	0	2	1	0	2	0	0
	Hebridae	Hebridae spp. (imm./dam.)	1	1	0	0	2	2	0	2	0	0	1	2
		Hebrus axillaris	0	0	0	0	0	2	0	0	0	0	0	0

Phylum/Class/Order	Family	Lowest Taxon	RRD1	RRD2	RRD3	RRD4	RRD5	RRD6	RRU1	RRU2	RRU3	RRU4	RRU5	RRU6
		Merragata hackeri	0	0	0	0	0	0	0	2	0	0	2	0
	Hydrometridae	*Hydrometra papuana*	0	0	0	0	0	0	0	0	0	0	1	0
	Mesoveliidae	Mesoveliidae spp. (imm./dam.)	2	3	0	0	1	2	3	0	0	2	0	2
		Mesovelia spp. (imm./dam.)	0	0	0	2	0	0	0	0	0	0	0	0
		Mesovelia hackeri	0	1	0	0	0	2	0	0	0	0	0	0
		Mesovelia hungerfordi	0	0	0	2	0	0	0	0	0	0	0	0
		Mesovelia vittigera	0	2	0	2	0	0	2	0	0	0	1	0
	Micronectidae	*Micronecta* spp. (imm./dam.)	0	0	0	0	0	0	0	2	0	0	0	0
		Micronecta paragoga	0	0	0	0	0	2	0	0	0	0	0	0
	Nepidae	Nepidae spp. (imm./dam.)	1	0	0	0	0	0	0	0	0	0	0	0
		Laccotrephes tristis	0	0	1	0	0	0	0	1	0	0	0	0
		Ranatra diminuta	1	2	0	0	0	0	1	0	0	0	0	0
	Pleidae	*Paraplea* spp.	3	2	1	2	2	3	4	3	0	3	0	3
Coleoptera		Coleoptera spp. (L)	2	0	0	0	0	0	0	0	0	0	0	0
		Unknown spp. (L)	0	0	0	0	0	0	2	0	0	0	0	0
	Dytiscidae	*Allodessus bistrigatus*	0	0	0	0	0	2	0	0	0	0	0	0
		Bidessini spp. (L)	0	0	0	0	0	0	1	0	0	2	1	0
		Copelatus nigrolineatus	0	0	0	0	0	0	1	0	0	0	0	1
		Cybister tripunctatus	0	0	0	0	0	1	0	0	1	0	0	0
		Hydaticus consanguineus	0	2	0	0	0	0	0	0	0	0	0	0
		Hydaticus daemeli	0	0	0	0	0	0	0	1	0	0	0	0
		Hydroglyphus godeffroyi	0	0	0	0	0	2	0	1	0	0	0	0
		Hydroglyphus grammopterus	0	0	0	0	0	2	0	0	0	0	0	0
		Hydroglyphus leai	0	0	0	0	0	0	2	0	0	0	0	0
		Hydroglyphus orthogrammus	0	0	0	0	0	2	2	2	0	0	0	0
		Hydrovatus spp. (L)	2	0	0	0	0	0	4	0	2	0	1	0
		Hydrovatus opacus	2	0	0	0	0	0	2	0	2	0	0	0
		Hyphydrus lyratus	0	1	0	0	0	2	0	2	0	0	0	1
		Laccophilus sharpi	0	0	0	0	0	0	0	2	0	0	0	0
		Limbodessus compactus	2	1	0	0	0	2	2	0	0	1	0	0

Phylum/Class/Order	Family	Lowest Taxon	RRD1	RRD2	RRD3	RRD4	RRD5	RRD6	RRU1	RRU2	RRU3	RRU4	RRU5	RRU6
		Necterosoma darwini	0	0	0	0	0	0	0	0	0	0	0	1
		Necterosoma regulare	0	0	0	0	0	0	0	0	0	0	0	2
		Onychohydrus atratus	1	0	0	0	0	0	0	0	2	0	0	0
		Platynectes decempunctatus var. *decempunc.*	0	0	0	0	0	2	0	1	2	0	0	1
		Rhantaticus congestus	0	1	0	0	0	0	1	0	0	0	0	0
		Tiporus tambreyi	2	0	0	0	0	0	0	0	2	2	0	3
	Elmidae	*Austrolimnius* spp. (L)	2	0	2	0	0	0	0	0	0	0	0	0
	Haliplidae	*Haliplus pilbaraensis*	0	0	0	0	0	0	2	0	0	0	0	0
	Hydraenidae	*Hydraena* spp.	2	0	0	0	0	2	4	3	0	0	0	0
		Limnebius spp.	0	0	0	0	0	2	0	2	0	0	0	0
	Hydrochidae	*Hydrochus* spp.	3	2	0	2	0	3	3	1	2	1	0	3
	Hydrophilidae	Hydrophilidae spp. (L)	0	0	0	0	0	0	3	0	0	0	0	0
		Anacaena horni	2	2	0	0	0	0	0	0	0	0	0	0
		Berosus dallasae	0	0	0	0	0	2	0	1	0	0	0	2
		Enochrus deserticola	0	1	0	0	0	1	3	2	2	0	0	0
		Helochares spp. (L)	0	2	0	2	2	2	3	0	0	3	0	2
		Helochares tatei	0	0	0	0	1	1	1	0	0	0	0	0
		Laccobius sp.	0	0	0	0	0	0	0	0	0	1	0	0
		Paracymus spenceri	0	2	0	0	0	0	3	2	0	2	0	0
		Regimbartia attenuata	1	0	0	0	0	2	2	0	0	0	0	0
		Regimbartia attenuata (L)	0	0	0	0	0	0	0	1	0	0	0	0
		Sternolophus marginicollis	2	3	1	0	0	0	0	3	3	0	1	0
	Noteridae	*Neohydrocoptus subfasciatus* (L)	2	1	0	0	0	0	0	0	0	0	0	0
	Scirtidae	Scirtidae spp. (L)	0	0	0	0	2	0	1	0	1	0	1	0
Diptera	**Ceratopogonidae**	Ceratopogonidae spp. (P)	0	2	2	2	2	0	2	0	0	3	0	2
		Ceratopogoninae spp.	2	0	3	2	1	2	3	2	1	2	3	3
		Dasyheleinae spp.	2	3	3	2	3	1	4	3	0	3	3	2
		Forcipomyiinae spp.	0	1	0	0	0	0	3	0	0	0	0	0
	Chironomidae	Chironomidae spp. (P)	2	2	2	2	2	2	3	2	0	1	2	0
	Chironominae													

Phylum/Class/Order	Family	Lowest Taxon	RRD1	RRD2	RRD3	RRD4	RRD5	RRD6	RRU1	RRU2	RRU3	RRU4	RRU5	RRU6
	Chironomini	*Chironomus* sp. (WWC3)	0	2	0	0	3	0	0	2	3	3	2	0
		Cladopelma curtivalva	3	2	3	2	0	3	2	0	0	0	0	0
		Cryptochironomus griseidorsum	2	0	0	0	0	0	0	0	0	0	0	0
		Dicrotendipes sp. (WWC17)	0	0	0	2	0	0	0	0	0	0	0	0
		Dicrotendipes sp. 1	0	0	2	2	0	0	0	0	0	0	0	0
		Dicrotendipes sp. 2	3	0	3	0	0	1	3	3	2	0	0	0
		Kiefferulus intertinctus	0	0	0	2	2	0	0	2	3	0	0	0
		Parachironomus sp. K2	0	0	0	0	0	0	2	0	0	0	0	0
		Paratendipes sp. K1	3	2	0	0	0	0	0	0	0	0	0	0
		Polypedilum (Pentapedilum) leei	2	0	0	0	0	3	2	0	0	0	0	2
		Polypedilum sp. 1	3	3	0	2	2	2	0	3	2	3	3	3
		Polypedilum sp. 2	0	0	0	0	2	0	0	0	0	0	0	2
		Skusella subvittata	2	0	0	0	0	0	0	0	0	0	0	0
	Tanytarsini	*Cladotanytarsus* sp. (WWTS4)	3	2	3	3	0	1	2	3	0	0	0	3
		Paratanytarsus sp. (WWTS2)	0	0	2	0	0	0	0	0	0	2	3	2
		Tanytarsus sp. (WWTS1)	0	3	2	0	3	0	3	3	3	3	3	2
	Orthocladiinae	*Nanocladius* sp. (WWO6)	0	0	0	0	0	0	3	0	0	0	0	0
	Tanypodinae	*Ablabesmyia hilli*	0	0	0	2	2	0	0	2	0	2	0	0
		Fittkauimyia disparipes	0	0	0	0	0	0	0	0	2	0	0	0
		Larsia albiceps	4	3	3	3	3	3	3	4	2	3	3	3
		Paramerina sp. (WWT1)	3	3	2	2	2	0	3	3	3	2	0	3
		Procladius sp. (WWT5)	3	0	3	3	3	0	0	0	0	2	0	3
	Culicidae	Culicidae spp. (P)	0	0	0	0	0	0	3	1	0	0	0	0
		Anopheles spp.	0	2	0	0	2	0	3	3	0	2	2	2
		Culex spp.	0	2	0	0	0	0	4	2	0	0	0	2
	Dolichopodidae	Dolichopodidae sp.	1	0	0	0	0	0	0	0	0	0	0	0
	Ephydridae	Ephydridae spp.	0	0	0	0	0	0	0	0	0	0	0	2
	Sciomyzidae	Sciomyzidae spp.	0	0	0	0	0	0	2	0	0	0	0	0
	Stratiomyidae	Stratiomyidae spp.	2	0	0	0	0	2	3	0	0	1	0	0
		Stratiomyidae sp. (P)	0	0	0	0	1	0	0	0	0	0	0	0

Phylum/Class/Order	Family	Lowest Taxon	RRD1	RRD2	RRD3	RRD4	RRD5	RRD6	RRU1	RRU2	RRU3	RRU4	RRU5	RRU6
	Tabanidae	Tabanidae spp.	0	2	0	0	0	1	3	0	0	0	0	0
	Thaumaleidae	Thaumaleidae spp.	0	0	0	0	0	0	0	0	0	0	0	2
	Tipulidae	Tipulidae sp. (P)	0	0	0	0	0	0	1	0	0	0	0	0
Trichoptera	**Ecnomidae**	*Ecnomus* spp.	1	0	2	0	1	0	0	0	0	0	0	0
	Hydroptilidae	*Hellyethira* spp.	0	0	2	0	0	0	0	0	0	0	0	0
	Leptoceridae	Leptoceridae spp. (imm./dam.)	0	0	0	0	2	0	0	0	1	0	0	0
		Leptocerus souta	0	0	0	0	0	0	2	0	0	0	0	0
		Oecetis sp.	1	0	0	0	0	0	0	0	0	0	0	0
		Triplectides ciuskus seductus	0	0	2	0	0	0	0	0	0	0	0	0
Lepidoptera	**Crambidae**	*Acentropinae* spp.	0	2	0	0	0	0	0	1	0	0	0	0
		Parapoynx spp.	0	1	0	0	0	2	2	2	0	2	0	0
		Taxa richness	**54**	**56**	**38**	**39**	**38**	**52**	**72**	**56**	**34**	**40**	**34**	**42**

(imm./dam) = taxa were too immature / damaged to be accurately identified to a lower taxonomic level.

(P) = taxa were in pupal form.

(L) = taxa were in larval form.

NB: some chironomid taxa are followed by their unique morphotype code (in parentheses)

Mesa H
Desktop Mesa Façade Assessment
October 2017

Prepared for
Robe River Mining Co. Pty Ltd

astron

Report Reference: 14289-17-BISR-1Rev0_180209

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Mesa H
Desktop Mesa Façade Assessment

Prepared for
Robe River Mining Co. Pty Ltd

Job Number: 14289-17

Reference: 14289-17-BISR-1Rev0_180209

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Approval

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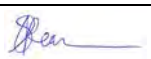
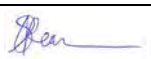
			Name	**Signature**
A	13/10/2017	M. Brand	S. Pearse	
B	20/11/2017	M. Brand	S. Pearse	
0	09/02/2018	M. Brand	S. Pearse	

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Abbreviations

Abbreviation	Definition
EIA	Environmental Impact Assessment
EPA	Environmental Protection Authority
ha	Hectares
MNES	Matters of National Environmental Significance
P	Priority
PEC	Priority Ecological Community
SD	Standard deviation
SRE	Short Range Endemic
TEC	Threatened Ecological Community

Executive Summary

Astron was engaged to undertake a desktop mesa façade ecological value assessment for the potential development of the Mesa H deposit. The purpose of the mesa façade assessment was to assist in determining which mesa façades should be prioritised for retention/avoidance if the Proposal proceeds. The Mesa H survey area is located adjacent to the existing Mesa J Operation, south-west of Pannawonica, Western Australia and is 4,930 hectares.

The mesa façade assessment area was 446.8 hectares and consisted of 48 assessment sites of approximately 500 metre long sections. The desktop assessment utilised the field data and literature already gathered and compiled during Level 2 flora, vegetation and fauna surveys completed by Astron and aligns with the Environmental Protection Authority's guideline for landforms. Each mesa section was scored for a number of ecological factors (flora and vegetation, vertebrate fauna and invertebrate fauna) and the total scores were used to determine the priority for retention rating. The priority for retention rating scales of high, moderate and low were determined using the mean and standard deviation of all mesa assessment sites.

Twenty per cent (91.2 ha) of the total area of mesa façades within the survey area were rated as high priority for retention, 56% (250.2 ha) as moderate priority for retention and 24% (105.4 ha) as low priority for retention. Ten of the 48 assessment sites were rated as high priority for retention (21%), 25 were rated as moderate priority (52%) and 13 were rated as low priority (27%). The 10 sites rated as high were found along the western façade near the Robe River and a small section along the northern façade that passes close to the Robe River within the Mesa H survey area. The western façade along the Robe River is characterised by structurally diverse habitats with high moisture retention, providing refuge and shelter sites for Matters of National Environmental Significance species such as the Ghost Bat, Northern Quoll and Pilbara Olive Python. In addition, vegetation analogous to the Priority 3 Priority Ecological Community '*Triodia sp. Robe River assemblages of mesas of the West* Pilbara' was present in these areas.

In accordance with the Environmental Protection Authority guideline on landforms, the mesa landforms within the survey area were assessed for their significance – rarity, variety, integrity and ecological importance. The mesas within the survey area are associated with the Robe land system, represented by only 0.7% of all land systems within the Pilbara bioregion; however, the survey area comprises only 0.3% of the land system occurrence within the Pilbara bioregion. Similar mesa landforms are common within the Robe Valley; although, a number of these are already approved or are proposed for mining, so the potential for cumulative impacts are increased. However, large sections of mesa façade are being retained along these mesas (currently approved or proposed for mining) to maintain the landscape geodiversity, important habitats, heritage values and visual amenity. The mesas do not appear to support any endemic or highly restricted terrestrial flora or fauna. The Robe land system is generally not susceptible to vegetation degradation or erosion as the mesa landforms are robust. Hence, if the façade is retained, while the mesa is mined, its condition and ecological function should be preserved.

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Appendix A: Mesa Façade Assessment Criteria
Appendix B: Mesa Façade Assessment Results

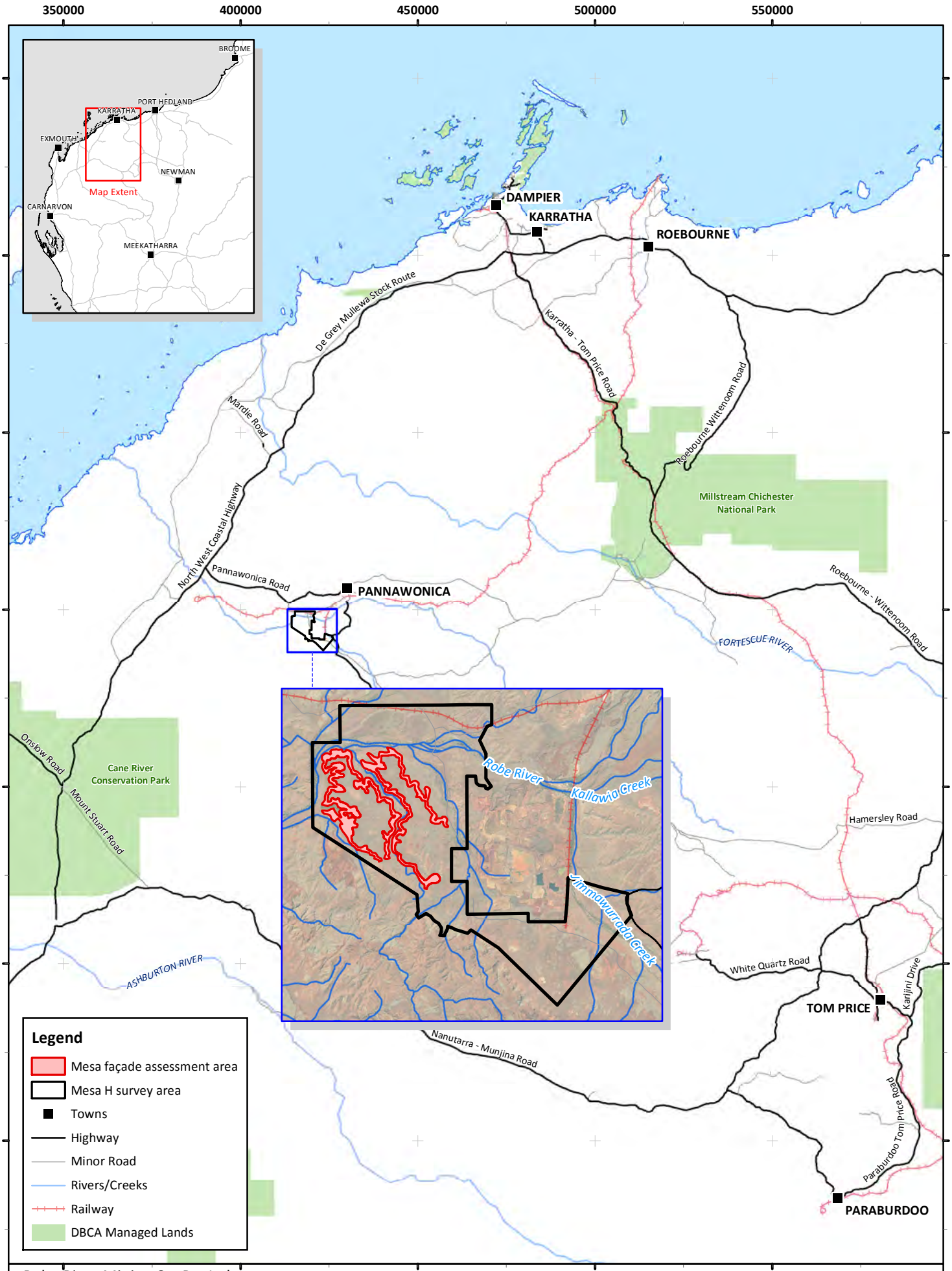
1 Introduction

1.1 Project Background

Rio Tinto, on behalf of Robe River Mining Co. Pty. Ltd (the Proponent), engaged Astron to undertake a mesa façade ecological value assessment for the potential development of the Mesa H deposit (the Proposal), located adjacent to the existing Mesa J Operation, south-west of Pannawonica, Western Australia. The assessment is required to provide data on the ecological value of the mesa façades to assist in determining which mesa façades (or sections of mesa façades) should be retained if the Proposal proceeds. The Mesa H survey area is 4,930 ha and the mesa façade assessment area is 446.8 ha (Figure 1).

1.2 Scope and Objectives

The objective of the assessment was to undertake a mesa façade ecological value assessment to assist in determining which mesa façades to be prioritised for retention/avoidance if the Proposal proceeds. The specific scope of work was to undertake a desktop assessment using the field data and literature already gathered and compiled during the Level 2 flora, vegetation and fauna surveys completed by Astron (Astron Environmental Services 2017a, 2017c, 2017b, 2017d) and align it with the Environmental Protection Authority's (EPA) *Environmental Factor Guideline – Landforms* (Environmental Protection Authority 2016).



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Mesa H – Desktop Mesa Façade Assessment, October 2017

Figure 1: Survey area location

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Author: J. Johnston	Date: 12-10-2017	Datum: GDA 1994 - Projection: MGA Zone 50
Drawn: T. Pedersen	Figure Ref: 14289-17-ENVDR-1RevA_171012_Fig01	0 10 20 30 40 50 Km

N

2 Methods

The EPA has recently released a bulletin detailing how a landform is considered in the Environmental Impact Assessment (EIA) processes (Environmental Protection Authority 2016). This guidance document will inform proponents as to the value a certain type of landform will have within an EIA process. A landform was described as 'a distinctive, recognisable physical feature of the earth's surface having a characteristic shape produced by natural processes' (Environmental Protection Authority 2016). In this case, the mesas of the survey area represent a distinct type of landform, although Mesa H is not as distinct as other mesas in the Robe Valley (John Cleary Planning 2005). Mesa H was described by John Cleary Planning (2005) as:

- a discrete mesa, although tends to blend into the adjacent landform in the south-east
- moderate-sized escarpment on the river/west side
- has a second tier in places
- shallow valleys and rounded tops on the south side
- long valley separates the two forms
- highly eroded with small mesas in the south-east
- eroded with rounded forms in the east
- stronger mesa formation in the north-east.

The mesa façades that were to be assessed within the survey area were defined and provided by Rio Tinto. The survey area provided captures 50 m of the mesa crest, breakaway and slope habitats, so the survey area does contain some areas that do not necessarily reflect just the high quality habitat. The mesa façade areas were divided into approximately 500 m sections of mesa façade for individual assessment (Figure 2). This assessment was only undertaken as a desktop assessment, and no specific field assessments beyond the field survey work for the Level 2 fauna and vegetation and flora surveys were conducted to assess the mesa façade within the Mesa H survey area.

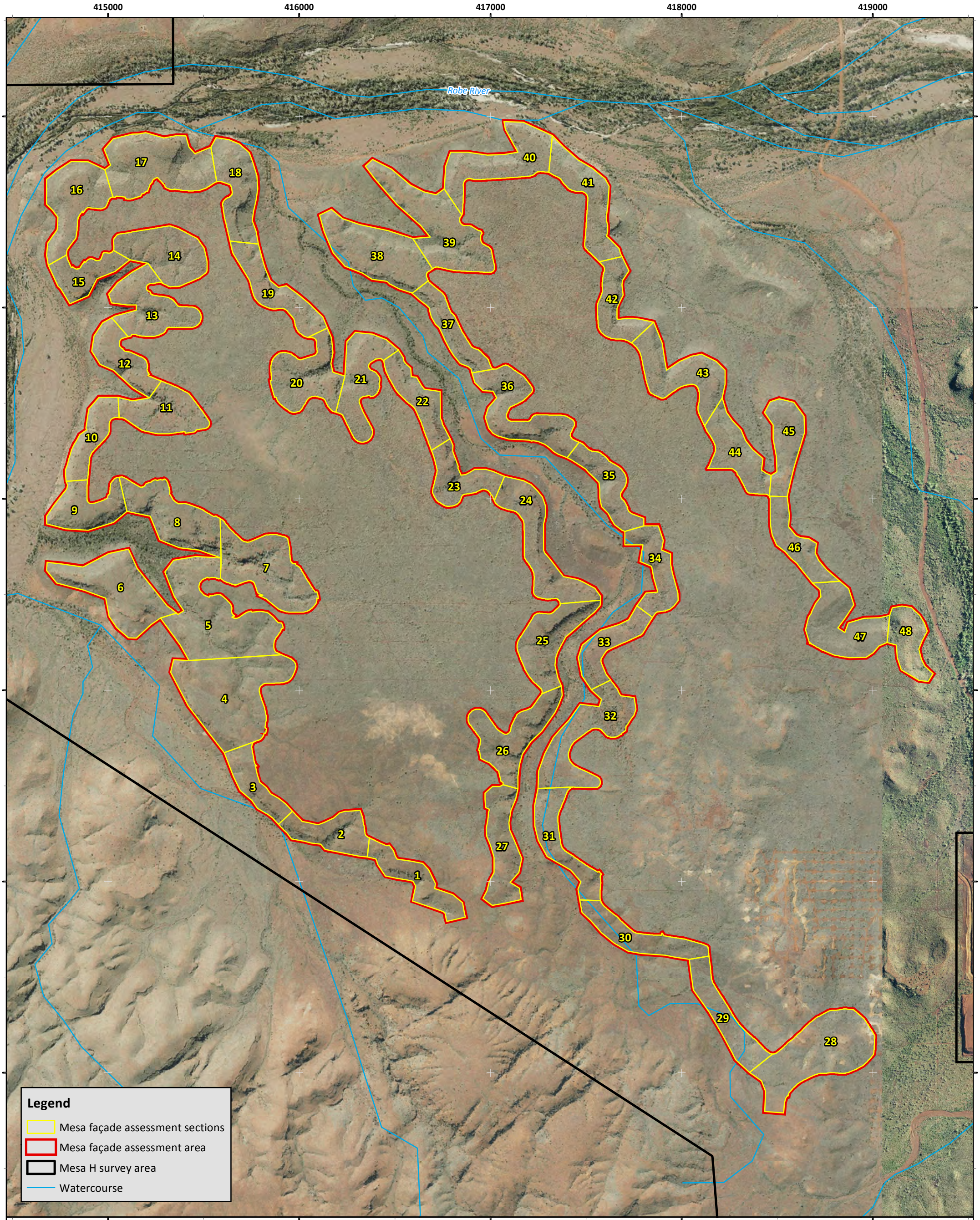
A desktop assessment was undertaken to assess whether any listed flora and fauna species, introduced species, Short Range Endemic (SRE) invertebrate species, Priority Ecological Communities (PEC), Threatened Ecological Communities (TEC) or SRE communities have been recorded within the survey area and specifically on the mesas of the survey area. Background information (including database searches) and field data already gathered and compiled by Level 2 flora, vegetation and fauna surveys were used in the assessment. Specifically, all data previously compiled and collected from the following reports were used:

- Mesa H Level 2 Fauna Assessment – May 2016 (Astron Environmental Services 2017b)
- Mesa H Level 2 Vegetation and Flora Assessment – May 2016 (Astron Environmental Services 2017c)
- Mesa H Ghost Bat, *Macroderma gigas*, Contextual Study – September 2017 (Astron Environmental Services 2017a)
- Mesa H Riparian Community Assessment – June 2016 (Astron Environmental Services 2017d)

Each mesa section was scored for each ecological factor with a rating of 0 to 4 being applied as per the criteria in Table A.1 (Appendix A). The higher the value, the higher the ecological value was for that particular factor. Each mesa section assessed received a total score for the following factors:

- flora and vegetation ecological value (seven factors)
- vertebrate fauna ecological value (11 factors)
- invertebrate fauna ecological value (four factors)
- overall ecological value (22 factors).

The overall score of the mesa section determined the ecological façade rating as either a high, moderate or low priority for retention. The priority rating scales for high, moderate and low was determined by calculating the mean and standard deviation for all mesa assessment sites. One standard deviation (1SD) either side of the mean was considered to be the upper and lower bounds of a moderate rating. All scores 1SD above the mean received a high rating and all scores 1SD below the mean received a low rating. Overall scores for each mesa assessment site were checked manually to ensure sites with one or two highly significant attributes (e.g. Pilbara Olive Python den) were not rated as a lesser priority due to low scores for other attributes. The rating scales are summarised in Table A.2 (Appendix A).



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Mesa H – Desktop Mesa Façade Assessment, October 2017

Figure 2: Mesa façade assessment sections

Author: J. Johnston	Date: 13-11-2017	Coordinate System: GDA 1994 MGA Zone 50
Drawn: T. Pedersen	Figure Ref: 14289-17-BIDR-1RevB_171113_Fig02	0 200 400 600 800 1,000 Metres; N

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3 Results

3.1 Mesa Assessment Sites

Forty-eight mesa façade assessments were undertaken by Astron, 27 assessments on the western side and 21 assessments on the eastern side of Mesa H (Figure 2 and Table B.1; Appendix B).

3.2 Flora and Vegetation

Vegetation considered to be analogous to the Priority (P) 3 PEC '*Triodia sp. Robe River assemblages of mesas of the West Pilbara*' was recorded in association with tops, breakaways and gullies of mesa landforms in the survey area (Astron Environmental Services 2017c). In addition, two conservation significant flora species were recorded within the mesa façade sections (Astron Environmental Services 2017c). *Triodia* sp. Robe River (M.E. Trudgen et al. MET 12367) P3 was recorded across a number of mesa assessment sites in association with mesas, low hills and ranges, particularly favouring rocky ledges and breakaways in these habitats (Figure B.1; Appendix B). *Rhynchosia bungarensis* P4 was recorded in locations along the Robe River and was only recorded within mesa assessment site 7 (Figure B.1, Appendix B).

Seven mesa assessment sites (15, 24, 25, 26, 32, 33 and 34) were rated as high priority for flora and vegetation (Table B.1; Appendix B). This was primarily due to the inferred (not confirmed) presence of the P3 PEC '*Triodia sp. Robe River assemblages of mesas of the West Pilbara*', as well as the number of other Priority flora species recorded at these sites and the lack of weed species present (Figure B.1; Appendix B).

Mesa assessment sites 3, 4, 6, 28 and 30 were rated as low priority for flora and vegetation, mainly due to the lack of priority flora records as well as the presence of weed species. Mesa assessment site 28 was the only site that contained a weed species (Table B.1; Appendix B).

3.3 Vertebrate Fauna

Eleven mesa assessment sites (6, 7, 8, 9, 10, 11, 12, 13, 15, 16, and 40) were rated as high priority for vertebrate fauna (Table B.1; Appendix B). The high rating was generally due to records of species of Matters of National Environmental Significance (MNES), particularly the Ghost Bat, or contained a number of caves suitable for Ghost Bats and Pilbara Leaf-nosed Bats (Table B.1; Appendix B). A number of the assessments within the Mesa H survey area have focussed on roost habitat, specifically the presence of potential maternal and diurnal roosts, for conservation significant bat species, particularly the Ghost Bat (Astron Environmental Services 2017a, 2017b).

Mesa assessment sites 39 and 40 contained Pilbara Olive Python records (Figure B.1; Appendix B), but mesa assessment site 39 was only rated as moderate due to a lack of other MNES species records, significant caves and gorges/gullies. Given suitable habitat and its cryptic nature, it is likely that this species occurs more widely within the mesa assessment sites.

Twelve mesa assessment sites were rated as low priority for vertebrate fauna and were generally found along the eastern most façade of the mesa (sites 43 to 48), as well as mesa façade sections within the south of the Mesa H survey area (sites 1, 23, 27 to 30).

3.4 Invertebrate Fauna

Mesa assessment sites rated as high priority for SRE invertebrate fauna were generally the same sites as those for vertebrate fauna. Six assessment sites (5, 7, 8, 11, 12 and 13) were rated as high priority for invertebrate fauna (Table B.1; Appendix B) and were associated with two main gorges on

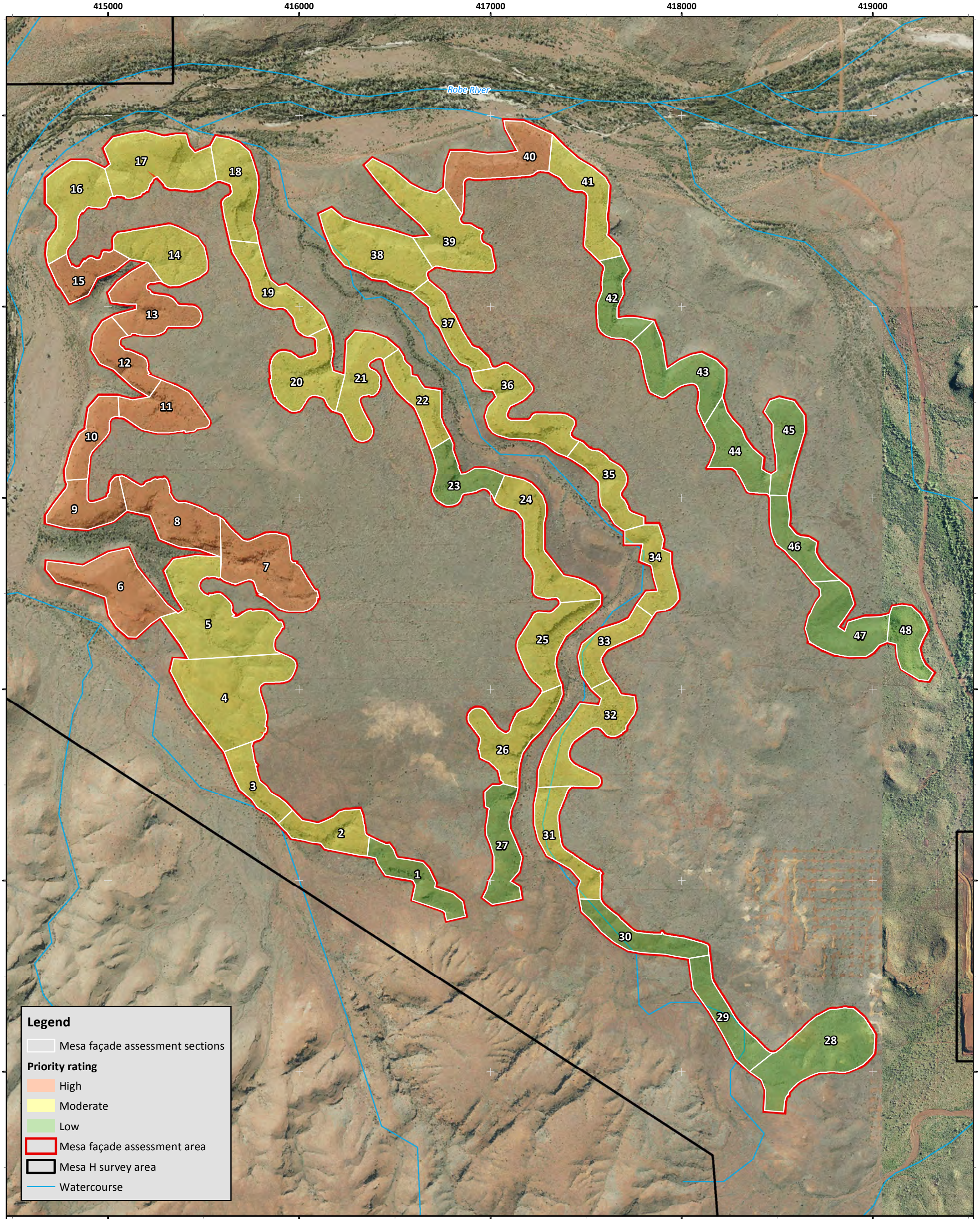
the western façade of the Mesa H survey area along the Robe River. This was due to the record of the potential SRE species *Buddelundia* '61' at site 7 (Figure B.1; Appendix B) and the presence of structurally diverse habitats with high moisture retention on south facing façades.

Fifteen mesa assessment sites were rated as low priority for invertebrate fauna and included most of the assessment sites along the eastern most façade of the mesa (sites 41 to 48) as well as mesa façade sections within the south of the Mesa H survey area.

3.5 Overall Ecological Value

Of the mesa façade assessments within the Mesa H survey area, 10 were rated as high priority for retention (21%), 25 were rated as moderate priority (52%) and 13 were rated as low priority (27%; Figure 3). The 10 sites rated as high were found within the two main gorges on the western façade along the Robe River (sites 6 to 13 and 15) and a small section of façade (site 40) along the northern section near the Robe River (Figure 3 and Table A.1; Appendix A). The 13 sites rated as low priority for retention were generally found along the eastern façades of both mesa façades (sites 23 and 27 to 30 and sites 42 to 48) as well as mesa assessment site 1 (Figure 3). Three of the mesa assessment sites (sites 5, 16 and 32) rated as moderate priority for retention had high overall rating scores of 41 and were close to being ranked as high priority for retention. These sites were generally found adjacent to those sites rated as high priority for retention (Figure 3).

Twenty per cent (91.2 ha) of the total area of mesa façades within the survey area were rated as high priority for retention, 56% (250.2 ha) as moderate priority for retention and 24% (105.4 ha) as low priority for retention (Figure 3 and Table B.1; Appendix B).



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Mesa H – Desktop Mesa Façade Assessment, October 2017

Figure 3: Mesa façade sections classified according to priority for retention based on overall ecological value

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Author: J. Johnston	Date: 13-11-2017
Drawn: T. Pedersen	Figure Ref: 14289-17-BIDR-1RevB_171113_Fig03

Coordinate System: GDA 1994 MGA Zone 50

0 200 400 600 800 1,000 Metres

N

4 Conclusions

In accordance with the guidance statement (Environmental Protection Authority 2016), the criteria for assessing the significance of the mesa landforms within the survey area are detailed below. The criterion of Scientific and Social Importance is not discussed as this could not be addressed within the scope of this mesa façade assessment.

Rarity

The mesas within the survey area are all associated with the Robe land system (van Vreeswyk et al. 2004). The Robe land system represents only 0.7% of all land systems within the Pilbara bioregion (van Vreeswyk et al. 2004). However, the survey area comprises only 0.3% of the Robe land system occurrence within the Pilbara bioregion.

Variety

All the mesas occur within the Robe land system, and given that the survey area represents 0.3% of this land system within the Pilbara, similar landforms exist outside the survey area. The mesas found within the Mesa H survey area are not considered to represent a particularly good or important example of their type and other similar intact mesas currently exist outside the survey area.

Integrity

The Robe land system is not generally susceptible to vegetation degradation or erosion. Mesas are robust and have resisted a large amount of erosion and natural degradation process over time. Less resistant surrounding formations are eroded away on the surface into valleys, where they collect water drainage from the surrounding area, while the more resistant layers are left standing out and elevated in the landscape resulting in a mesa formation. Hence, if the façade is retained, while the mesa is mined, its condition and ecological function should be preserved.

The mesas within the Mesa H survey area were considered to still be intact and in good condition, although they are not in pristine condition (John Cleary Planning 2005). The Robe land system has been the target of considerable mining activity due to its geology (van Vreeswyk et al. 2004). A number of the mesas within the Robe Valley have been approved for, or are proposed for, mining, indicating that the potential for cumulative impacts on the mesa formations within the immediate area is relatively high. However, the majority of the mesa façades are being retained within these mesas (currently approved or proposed for mining) to maintain the landscape geodiversity, important habitats, heritage values and visual amenity.

Ecological Importance

Fifty-six per cent (250.2 ha) and 24% (105.4 ha) of the total area of mesa façades were rated as moderate and low priority for retention, respectively. Twenty per cent (91.2 ha) of the total area of mesa façades within the survey area were rated as high priority for retention.

The areas of mesa façades rated as high priority for retention were located along the western façade near the Robe River and a small section along the northern façade that passes close to the Robe River within the survey area. These areas are characterised by structurally diverse habitats with high moisture retention, providing refuge and shelter sites for MNES species such as the Ghost Bat, Pilbara Olive Python and Northern Quoll. In addition, vegetation analogous to the P3 PEC '*Triodia sp. Robe River assemblages of mesas of the West Pilbara*' was present in these areas. The mesas do not appear to support any endemic or highly restricted flora or fauna. The potential SRE species recorded within the mesa façade site 7 has also been collected from multiple habitats that extend far beyond the survey area.

5 References

Astron Environmental Services 2017a, *Mesa H Ghost Bat, Macroderma gigas, Contextual Study September 2017*, unpublished report prepared for Robe River Mining Co. Pty Ltd.

Astron Environmental Services 2017b, *Mesa H Level 2 Fauna Assessment - May 2016*, unpublished report for Robe River MIning Co. Pty Ltd, Perth.

Astron Environmental Services 2017c, *Mesa H Level 2 Vegetation and Flora Assessment - May 2016*, unpublished report for Robe River MIning Co. Pty Ltd, Perth.

Astron Environmental Services 2017d, *Mesa H Riparian Community Assessment - June 2016*, unpublished report for Robe River Mining Co. Pty Ltd.

Environmental Protection Authority 2016, *Environmental Factor Guideline: Landforms*, Environmental Protection Authority, Perth.

John Cleary Planning 2005, *Mesa A - Warramboo Robe River. Landscape and Geodiversity Assessment Study*, prepared for Robe River Iron Associates.

van Vreeswyk, AME, Payne, AL, Leighton, KA & Hennig, P 2004, *An inventory and condition survey of the Pilbara region, Western Australia. Technical Bulletin No. 92*, Department of Agriculture and Food, Perth.

Appendix A: Mesa Façade Assessment Criteria

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Table A.1: Criteria for rating ecological factors for the mesa façade assessment.

Ecological factor	Rating score				
	(4)	(3)	(2)	(1)	(0)
Flora and vegetation					
Threatened ecological communities (Matters of National Environmental Significance (MNES))	Confirmed as present	Inferred as present	Potential habitat	Low likelihood of occurrence	Not present
Priority Ecological Communities	Confirmed as present	Inferred as present / analogous community present	Potential habitat	Low likelihood of occurrence	Not present
Threatened flora (MNES)	Recorded	Likely occurrence – suitable habitat and close proximity of previous records	Potential occurrence – suitable habitat or close proximity of previous records	Unlikely occurrence – no suitable habitat	Not recorded
Priority flora (P1 to P2)	Recorded	Likely occurrence – suitable habitat and close proximity of previous records	Potential occurrence – suitable habitat or close proximity of previous records	Unlikely occurrence – no suitable habitat	Not recorded
Other Priority flora or vegetation of conservation significance including undescribed taxa and groundwater dependent ecosystems	Confirmed as present	Inferred as present	Potential habitat	Low likelihood of occurrence	Not present
Vegetation condition	Excellent	Very Good	Good	Poor/Very Poor	Degraded
Weed species	Not present	Suitable weed habitat (disturbances, close proximity of tracks, etc.)	Confirmed as present – non-invasive (not declared) species	Confirmed as present – invasive (not declared) species	Confirmed as present – declared pests

Ecological factor		Rating score				
		(4)	(3)	(2)	(1)	(0)
Vertebrate fauna						
MNES fauna habitat suitability	**Pilbara Olive Python**	Recorded	**Potential shelter and foraging habitat**	**Suitable foraging and dispersal habitat**	**Limited foraging and dispersal habitat**	No suitable habitat
	Pilbara Leaf-nosed Bat	Recorded	**Potential shelter and foraging habitat**	**Suitable foraging and dispersal habitat**	**Limited foraging and dispersal habitat**	No suitable habitat
	Ghost Bat	Recorded	**Potential shelter and foraging habitat**	**Suitable foraging and dispersal habitat**	**Limited foraging and dispersal habitat**	No suitable habitat
	Northern Quoll	Recorded	**Potential shelter and foraging habitat**	**Suitable foraging and dispersal habitat**	**Limited foraging and dispersal habitat**	No suitable habitat
Threatened fauna		Recorded	Likely occurrence – suitable habitat and close proximity of previous records	Potential occurrence – suitable habitat or close proximity of previous records	Unlikely occurrence – no suitable habitat	Not present

Ecological factor	Rating score				
	(4)	(3)	(2)	(1)	(0)
Priority (or migratory) fauna	Recorded	Likely occurrence – suitable habitat and close proximity of previous records	Potential occurrence – suitable habitat or close proximity of previous records	Unlikely occurrence – no suitable habitat	Not present
Roosts/caves present	1 or more maternal roosts	1 or more diurnal roosts	>3 other caves(e.g. nocturnal feeding shelters)	1-2 other caves (e.g. nocturnal feeding shelters)	None present
Breakaway habitat present	Predominantly mapped as and south-facing	Predominantly mapped as breakaway but not south-facing	Partly mapped as breakaway and south-facing	Partly mapped as breakaway but not south-facing	Limited or no breakaway habitat mapped
Gorge/gullies present	>10	10 – 5	5 – 2	1	0
Permanent pools	≥2 within 500 m	1 within 500 m	≥2 within 1 km	1 within 1 km	None within 1 km
Distance to riverine habitat (i.e. Robe River)	<100 m	<250 m	<500 m	<1 km	>1 km
Invertebrate fauna					
Threatened and listed invertebrate fauna	Recorded	Likely occurrence based on proximity of previous records	Potential occurrence based on proximity of previous records	Unlikely occurrence – no or very few previous records	Not present
SRE fauna	Recorded	Likely occurrence based on proximity of previous records	Potential occurrence based on proximity of previous records	Unlikely occurrence – no or very few previous records	Not present

Ecological factor	Rating score				
	(4)	(3)	(2)	(1)	(0)
Relictual habitats	Structurally diverse habitats with high moisture retention ubiquitous (i.e. many deeply incised gullies and shaded runoffs)	Structurally diverse habitats with high moisture retention widespread but not ubiquitous (i.e. incised gorge present)	Less diverse habitat (one or two types) and limited moisture-holding capacity (i.e. shallow gullies)	Limited habitat suitability (i.e. flat and exposed, no moisture-holding capacity and limited ground cover)	No relictual habitats
Specialist habitats	Specialist habitats ubiquitous (i.e. rocky outcrops, fringing woodlands)	Specialist habitats widespread (i.e. rocky outcrops, fringing woodlands)	Specialist habitats present but not widespread or few types	Specialist habitats rare; area generally exposed and little diverse	No specialist habitats

Table A.2: Rating scale for the priority of retention for mesas or mesa sections.

Priority rating for retention	Flora and vegetation	Vertebrate fauna	Invertebrate fauna	Overall
High	≥13	≥24	≥7	≥42
Moderate	11-12	10-23	4-6	26-41
Low	≤10	≤9	≤3	≤25

Appendix B: Mesa Façade Assessment Results

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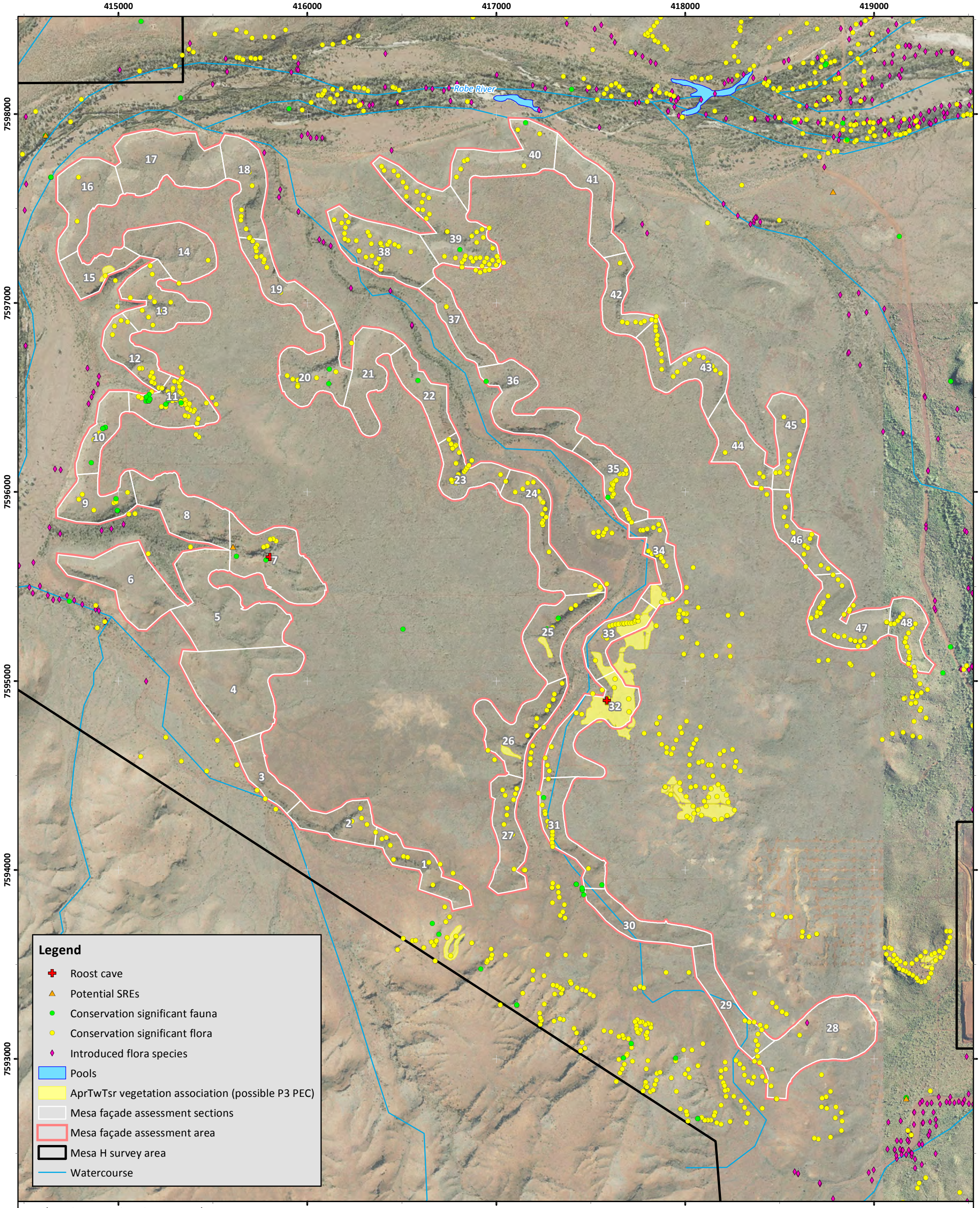
Table B.1: Mesa façade assessment site scores.

Mesa façade sections	Area (ha)	FLORA AND VEGETATION								VERTEBRATE FAUNA										INVERTEBRATE FAUNA				Flora and vegetation total	Vertebrate fauna total	Invertebrate fauna total	TOTAL
		TECs	PECs	Threatened flora (MNES)	Priority flora (P1 to P2)	Other Priority flora or vegetation of conservation significance	Vegetation condition	Weed species	Pilbara Olive Python habitat	Pilbara Leaf-nosed Bat habitat	Ghost Bat habitat	Northern Quoll habitat	Threatened fauna	Priority (or migratory) fauna	Roosts/caves present	Breakaway habitat present	Gorges/gullies present	Distance to riverine habitat (i.e. Robe River)	Permanent pools	Threatened and listed invertebrate fauna	SRE fauna	Relictual habitats	Specialist habitats				
1	6.68	0	0	0	0	4	4	4	1	1	1	1	2	2	0	0	0	0	0	0	1	1	1	**12**	**8**	**3**	**23 (low)**
2	6.86	0	0	0	0	4	4	4	3	1	1	3	2	2	0	4	0	0	0	0	1	2	2	**12**	**16**	**5**	**33 (moderate)**
3	5.26	0	0	0	0	2	4	4	3	2	2	2	2	2	0	2	0	0	0	0	1	2	2	**10**	**15**	**5**	**30 (moderate)**
4	19.90	0	0	0	0	2	4	4	3	2	2	3	2	2	0	2	0	0	0	0	1	2	2	**10**	**16**	**5**	**31 (moderate)**
5	19.23	0	0	0	0	3	4	4	3	3	3	3	3	2	0	3	1	1	1	0	1	3	3	**11**	**23**	**7**	**41 (moderate)**
6	13.62	0	0	0	0	3	4	3	3	3	2	3	3	2	0	4	1	2	3	0	1	3	2	**10**	**26**	**6**	**42 (high)**
7	13.50	0	0	0	0	4	4	4	3	3	4	3	4	2	3	4	1	0	1	0	4	3	3	**12**	**28**	**10**	**50 (high)**
8	11.08	0	0	0	0	3	4	4	3	3	3	3	3	2	0	4	1	2	1	0	1	3	3	**11**	**25**	**7**	**43 (high)**
9	7.17	0	0	0	0	4	4	3	3	3	3	3	4	2	1	4	0	2	3	0	1	2	2	**11**	**28**	**5**	**44 (high)**
10	5.55	0	0	0	0	4	4	3	3	3	4	4	4	4	0	3	1	2	3	0	1	3	2	**11**	**31**	**6**	**48 (high)**
11	8.30	0	0	0	0	4	4	4	3	3	4	4	4	4	2	3	1	2	2	0	1	3	3	**12**	**32**	**7**	**51 (high)**
12	6.22	0	0	0	0	4	4	4	3	2	2	3	3	2	0	4	1	2	2	0	1	3	3	**12**	**24**	**7**	**43 (high)**
13	9.50	0	0	0	0	4	4	4	3	3	3	3	3	2	0	4	1	1	2	0	1	3	3	**12**	**25**	**7**	**44 (high)**
14	10.11	0	0	0	0	4	4	4	1	1	1	1	3	2	0	0	0	2	2	0	1	1	1	**12**	**13**	**3**	**28 (moderate)**
15	5.31	0	3	0	0	4	4	4	3	2	2	3	3	2	0	4	0	3	3	0	1	3	2	**15**	**25**	**6**	**46 (high)**
16	10.24	0	0	0	0	4	4	4	3	2	2	3	3	2	0	3	0	3	3	0	1	2	2	**12**	**24**	**5**	**41 (moderate)**
17	14.82	0	0	0	0	3	4	4	3	2	2	3	3	2	0	3	0	4	1	0	1	2	2	**11**	**23**	**5**	**39 (moderate)**
18	8.99	0	0	0	0	4	4	3	3	2	2	3	2	2	0	3	0	3	0	0	1	2	2	**11**	**20**	**5**	**36 (moderate)**
19	7.74	0	0	0	0	4	4	4	3	2	2	3	2	2	0	3	0	1	0	0	1	2	2	**12**	**18**	**5**	**35 (moderate)**
20	9.88	0	0	0	0	4	4	4	3	2	2	4	4	4	0	1	0	1	0	0	1	2	2	**12**	**21**	**5**	**38 (moderate)**
21	8.82	0	0	0	0	3	4	4	3	2	2	3	3	2	0	3	0	0	0	0	1	2	2	**11**	**18**	**5**	**34 (moderate)**
22	6.33	0	0	0	0	4	4	4	3	2	2	3	4	2	1	3	0	0	0	0	1	2	2	**12**	**20**	**5**	**37 (moderate)**
23	6.29	0	0	0	0	4	4	4	1	1	1	1	2	2	0	1	0	0	0	0	1	2	1	**12**	**9**	**4**	**25 (low)**
24	11.20	0	3	0	0	4	4	4	3	2	2	3	2	2	0	3	0	0	0	0	1	2	2	**15**	**17**	**5**	**37 (moderate)**
25	9.42	0	3	0	0	4	3	4	3	2	2	3	4	2	1	1	0	0	0	0	1	2	2	**14**	**18**	**5**	**37 (moderate)**
26	9.90	0	3	0	0	4	3	4	3	2	2	3	2	2	0	3	0	0	0	0	1	2	2	**14**	**17**	**5**	**36 (moderate)**
27	8.54	0	0	0	0	4	3	4	1	1	1	1	2	2	0	0	0	0	0	0	1	1	1	**11**	**8**	**3**	**22 (low)**
28	16.89	0	0	0	0	4	4	1	1	1	1	1	2	2	0	0	0	0	0	0	1	1	1	**9**	**8**	**3**	**20 (low)**
29	7.40	0	0	0	0	4	4	4	1	1	1	1	2	2	0	0	0	0	0	0	1	1	1	**12**	**8**	**3**	**23 (low)**
30	7.24	0	0	0	0	2	4	4	1	1	1	1	2	2	0	0	0	0	0	0	1	1	1	**10**	**8**	**3**	**21 (low)**

Mesa façade sections	Area (ha)	FLORA AND VEGETATION								VERTEBRATE FAUNA										INVERTEBRATE FAUNA				Flora and vegetation total	Vertebrate fauna total	Invertebrate fauna total	TOTAL
		TECs	PECs	Threatened flora (MNES)	Priority flora (P1 to P2)	Other Priority flora or vegetation of conservation significance	Vegetation condition	Weed species	Pilbara Olive Python habitat	Pilbara Leaf-nosed Bat habitat	Ghost Bat habitat	Northern Quoll habitat	Threatened fauna	Priority (or migratory) fauna	Roosts/caves present	Breakaway habitat present	Gorges/gullies present	Distance to riverine habitat (i.e. Robe River)	Permanent pools	Threatened and listed invertebrate fauna	SRE fauna	Relictual habitats	Specialist habitats				
31	7.35	0	0	0	0	4	4	4	3	2	2	3	4	4	1	1	0	0	0	0	1	2	2	**12**	**20**	**5**	**37 (moderate)**
32	11.75	0	3	0	0	4	3	4	3	2	2	3	4	2	3	3	0	0	0	0	1	2	2	**14**	**22**	**5**	**41 (moderate)**
33	5.85	0	3	0	0	4	3	4	3	2	2	3	2	2	0	3	0	0	0	0	1	2	2	**14**	**17**	**5**	**36 (moderate)**
34	6.52	0	3	0	0	4	4	4	1	2	2	3	2	2	0	1	0	0	0	0	1	2	2	**15**	**13**	**5**	**33 (moderate)**
35	6.35	0	0	0	0	4	4	4	3	1	1	1	2	4	0	2	0	0	0	0	1	1	1	**12**	**14**	**3**	**29 (moderate)**
36	10.91	0	0	0	0	3	4	4	3	2	2	3	4	2	1	4	0	0	0	0	1	2	2	**11**	**21**	**5**	**37 (moderate)**
37	5.68	0	0	0	0	4	4	4	3	2	2	3	2	2	0	3	0	1	0	0	1	2	2	**12**	**18**	**5**	**35 (moderate)**
38	13.38	0	0	0	0	4	3	4	3	2	2	3	2	2	0	3	0	2	1	0	1	2	2	**11**	**20**	**5**	**36 (moderate)**
39	14.84	0	0	0	0	4	4	4	4	2	2	3	4	2	0	3	0	2	1	0	1	2	2	**12**	**23**	**5**	**40 (moderate)**
40	10.98	0	0	0	0	4	4	4	4	2	2	3	4	2	0	1	0	4	3	0	1	2	2	**12**	**25**	**5**	**42 (high)**
41	8.85	0	0	0	0	3	4	4	1	1	1	1	1	2	0	0	0	3	3	0	1	1	1	**11**	**13**	**3**	**27 (moderate)**
42	5.99	0	0	0	0	4	4	4	1	1	1	1	1	2	0	0	0	1	2	0	1	1	1	**12**	**10**	**3**	**25 (low)**
43	10.11	0	0	0	0	4	4	4	1	1	1	1	1	2	0	0	0	0	0	0	1	1	1	**12**	**7**	**3**	**22 (low)**
44	7.69	0	0	0	0	4	4	4	1	1	1	1	1	2	0	0	0	0	0	0	1	1	1	**12**	**7**	**3**	**22 (low)**
45	6.62	0	0	0	0	4	4	4	1	1	1	1	1	2	0	0	0	0	0	0	1	1	1	**12**	**7**	**3**	**22 (low)**
46	5.75	0	0	0	0	4	4	4	1	1	1	1	1	2	0	0	0	0	0	0	1	1	1	**12**	**7**	**3**	**22 (low)**
47	10.55	0	0	0	0	4	3	4	1	1	1	1	1	2	0	0	0	0	0	0	1	1	1	**11**	**7**	**3**	**21 (low)**
48	5.66	0	0	0	0	4	3	4	1	1	1	1	1	2	0	0	0	0	0	0	1	1	1	**11**	**7**	**3**	**21 (low)**



Robe River Mining Co. Pty Ltd

Mesa H – Desktop Mesa Façade Assessment, October 2017

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Figure B.1: Locations of all significant features, conservation significant species and introduced flora species recorded within the survey area

Author: J. Johnston	Date: 13-11-2017	Coordinate System: GDA 1994 MGA Zone 50
Drawn: T. Pedersen	Figure Ref: 14289-17-BIDR-1RevB_171113_FigB1	0 200 400 600 800 1,000 Metres; N

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RioTinto

Mesa H
Visual Impact Assessment

	Name	Signature	Date
Prepared By:	Thomas Linklater Analyst - GIS		May 2018
Checked By:	Mark Penter Superintendent - GIS		May 2018
Approved By:	Melinda Brand Principal Advisor - Part IV		May 2018

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Summary

The Rio Tinto Iron Ore GIS Team conducted the Visual Impact Assessment (VIA) for the proposed Mesa H Iron Ore Mine, located approximately 18km west of Pannawonica. Field work was undertaken in July and August of 2016 and the assessment was undertaken as part of the environmental impact assessment for the Proposed Mesa H Iron Ore Project.

The VIA was conducted in three phases:

- Desktop Assessment (Analysis)
- Field Assessment (Photo Locations)
- Visual Impact (Photo Montage)

Results show present, operational and closure photo montages to illustrate the indicative visual impact of the proposed operations at Mesa H.

Introduction

This report outlines the Mesa H VIA scope, methodology and results. The GIS Team was engaged to prepare a VIA report, which was developed in conjunction with several other environmental studies and reports to provide an overview of the likely impacts.

1.1 Objective & Scope

The overall objective was to assess the visual impact of the proposed mining operations at Mesa H and illustrate these impacts through photo montages. The key objectives were to:

- Analyse landscape within the development area
- Identify points of interest where potential impact may occur
- Conduct field trip to identified points to photograph
- Illustrate potential visual amenity impacts of mining stages through photo montages

1.3 Study Area

Mesa H is located approximately 18km west of Pannawonica and is adjacent to the existing Mesa J Mine (refer Figure 1).

The Pannawonica Access Road runs to the north Mesa H project area and provides access tracks to the area. This road is sealed and is the main access road to the town of Pannawonnica.

The Robe River lies immediately north and west of the project area, and Jimmawurrada Creek to the east of the project area (refer Figure 2).

1.4 Regulatory Context

The following regulatory documents and relevant sections within them were consulted as part of this work to provide context and guidance on completing a Visual Impact Assessment.

Environmental Projection Authority (EPA) and the Environmental Protection Act 1986
Amenity: “To ensure that impacts to amenity are reduced as low as reasonably practicable”.

The Western Australian Planning Commission’s (WAPC) State Planning Policy No. 2:
Environment and Natural Resource Policy for Western Australia (WAPC 2003)
“consider the need for a landscape or visual impact assessment for development proposals that may impact upon sensitive landscapes”.

The WAPC’s Pilbara Planning and Infrastructure Framework (WAPC 2012)
“protect and manage the region’s cultural heritage, arts including indigenous significant places, and landscapes of significance”.

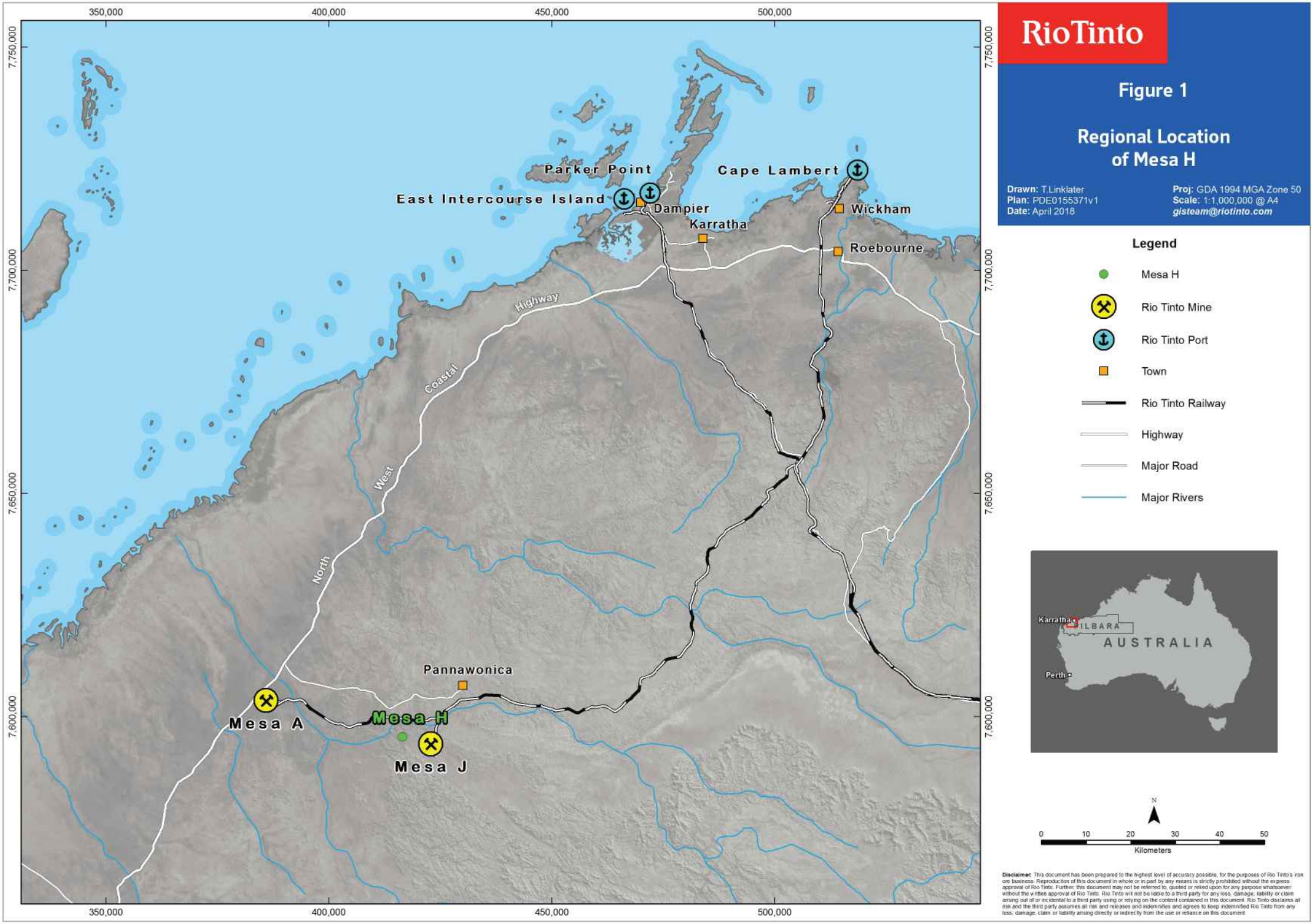

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Figure 1

Regional Location of Mesa H

Drawn: T.Linklater
Plan: PDE0155371v1
Date: April 2018

Proj: GDA 1994 MGA Zone 50
Scale: 1:1,000,000 @ A4
gisteam@riotinto.com

Legend

- Mesa H
- Rio Tinto Mine
- Rio Tinto Port
- Town
- Rio Tinto Railway
- Highway
- Major Road
- Major Rivers

N

0 10 20 30 40 50
Kilometers

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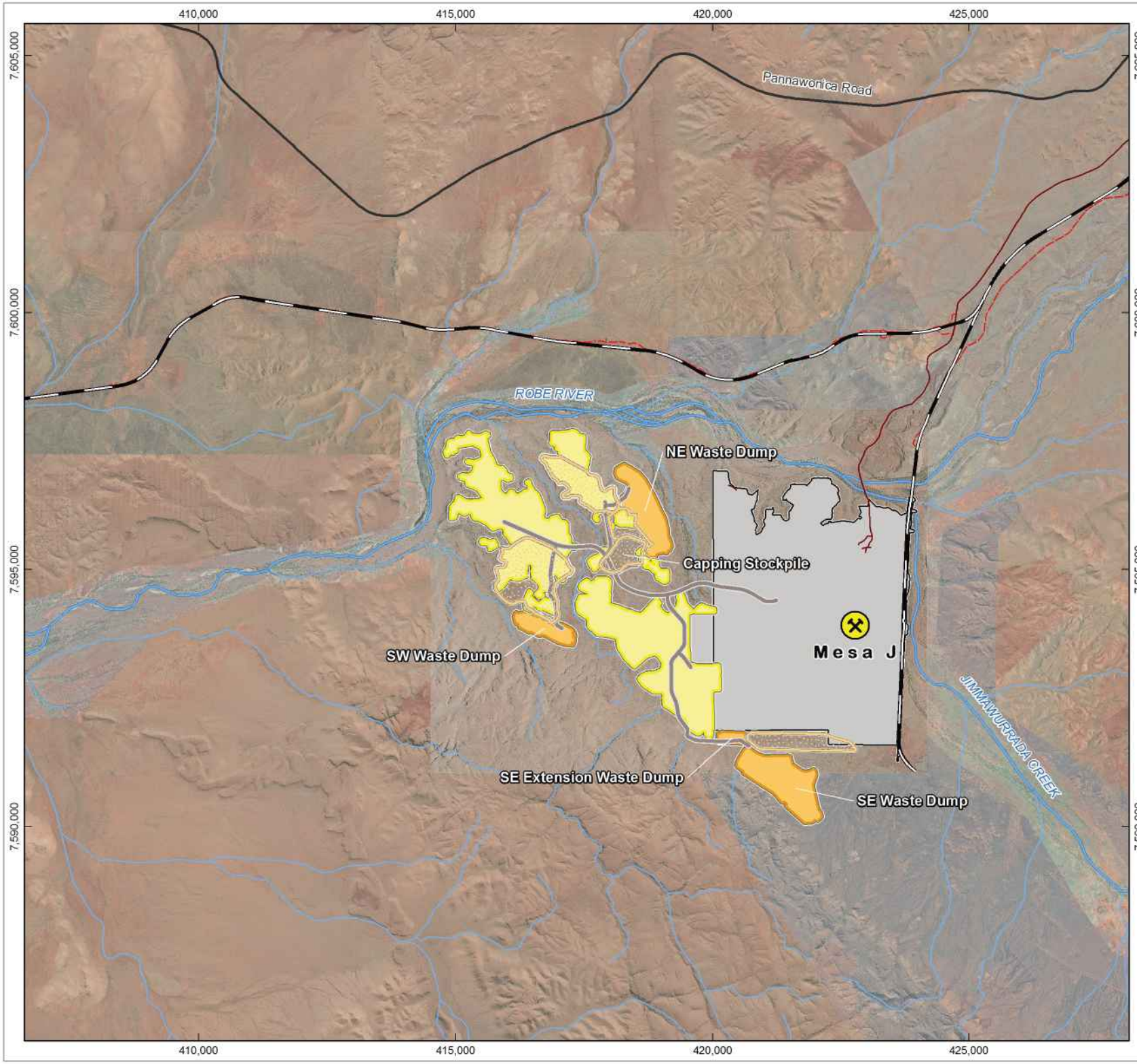

RioTinto

Figure 2

Project Layout of Mesa H

Drawn: T.Linklater
Plan: PDE0155371v1
Date: July 2018

Proj: GDA 1994 MGA Zone 50
Scale: 1:100,000 @ A4
gisteam@riotinto.com

Legend

- Rio Tinto Mine
- Current Mesa J Mine
- Rio Tinto Railway
- Major Road
- Site Road
- Rail Access Road
- Robe River
- Creek

Proposed Mine Layout

- Pit
- Waste Dump
- Topsoil/Subsoil Stockpile
- Haul Road

N

0 1 2 3 4 5
Kilometers

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Methodology

The methodology used to assess the impact to the landscape and visual amenity was conducted in three phases. This process included the following:

2.1 Desktop Assessment

The aim the desktop assessment was to produce a terrain model of the study area with the proposed infrastructure overlaid. This model was then used to conduct a viewshed analysis using the proposed infrastructure to identify potential visual impacts across the model domain. The viewshed analysis output was then combined with existing spatial data such as heritage, environment and cadastral layers to guide the selection of locations for capture of images.

Viewshed Analysis

To perform the viewshed analysis, the ArcGIS Viewshed tool within ArcMap was used. This tool can be found under Spatial Analyst > Surface > Viewshed within the Arc Toolbox.

A viewshed analysis identifies cells within a raster image (ASCII terrain model) that can be seen from any number of observer points or lines (infrastructure polylines). The identified cells are given a value of 1 for visible or 0 for not visible. This project had more than one observer point so more than 20 values have been entered. The viewshed analysis provides the starting point for all further visual impact assessment work.

The study area terrain model was created from LiDAR data and the proposed infrastructure data in Global Mapper and loaded into ArcGIS in ASCII format.

Figure 03: Viewshed Analysis Control Factors

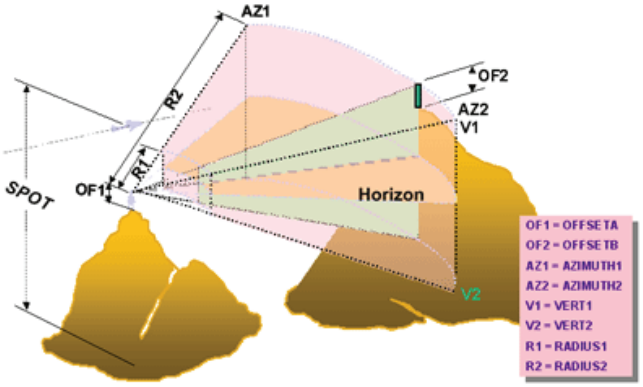
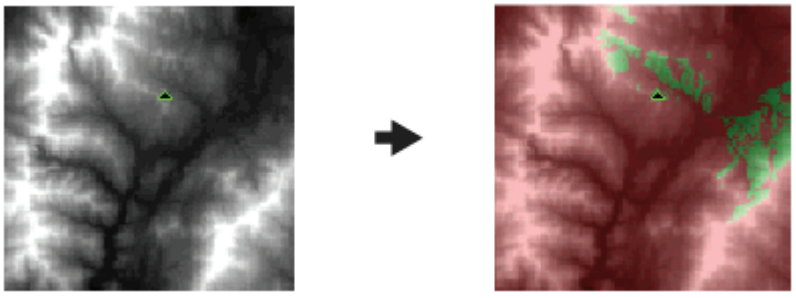


Figure 04: Viewshed Analysis Input vs Output



Input Surface with Observer Point

Output Viewshed

Output

The viewshed analysis output was then used to create a cartographic map for the study team to easily identify potential visual impacts and help determine the locations for capture of photographs.

Photo Location Selection

The study team consisted of Studies, Environment, Closure, Heritage and GIS. All teams worked together with GIS to identify and select locations for capture of images. Locations for the capture of images were selected based upon:

- proximity to significant heritage or environmental values
- line of sight to significant heritage or environmental values
- proximity to areas with public access

Traditional owner consultation was also undertaken to identify significant sites around the study area. Once all locations were selected, a field trip assessment was planned and undertaken over three days within the study area.

2.2 Field Assessment

A field assessment was conducted to capture data and photographs from selected locations around the study area, with the photographic views focusing on the proposed infrastructure such as dumps and stockpiles. Comprehensive data collection was undertaken at each location to allow for photo montages to be produced in the next phase.

Tools used in field work

Canon Digital Camera EOS 200 D
Accessories: Tripod, Stabiliser, Compass, Measuring Tape
ArcGIS Collector App (IOS Iphone)
Magellan GPS Unit
Paperwork (manual field notes)

Field Trip

Field work was undertaken in conjunction with another Rio Tinto project for the purpose of Visual Impact Assessment, this occurred in November 2017.

At each photograph location, assessment was made on the ground for accessibility and view aspect, which resulted in minor changes to photograph locations to ones agreed upon in desktop assessment. Once location and direction of photo was agreed, 3 photos of the same view were taken to reduce the risk of poor photo clarity and recorded both manually and digitally.

Data Collection

The data shown in Table 1 were collected from each photograph location to assist in the next phase of the assessment.

Table 1 - Data collected at each photograph location

Site No. and Name	Identified in desktop assessment
Date/Time	Date and time of day
Photo Number	Unique photo number as multiple taken from each point
GPS Co-ordinates	Actual photo location for GPS unit
Bearing	Direction of the photo with the aid of compass
Camera Height	Height of the camera from ground level
Atmospheric Conditions	Weather and lighting
Description of View	Vegetation cover and infrastructure within the area
Comments	Additional detail

Field Photos Review

Once field work was complete, the study team reviewed the adjusted photograph locations and selected photos that would best illustrate the potential visual impact.

2.3 Visual Impact Assessment process

Photo montages were generated from the photographs selected to best illustrate the potential visual impact of the proposed development. Generation of the photo montages involved a multistep process of data creation, view setup, image rendering, output and final mock up. Software required for this process were; Global Mapper, Microstation V8i, ArcGIS Desktop, Adobe Photoshop and Adobe InDesign.

The following sections outline the process to create the final photo montage showing the current view, operational view and closure view along with any relevant supporting data.

Data

The terrain model created desktop assessment was used in the final phase to create surface features, for the purpose of lining up these features in the montage view.

The first feature captured was the bearing of the photo point (field data collection); then a 3D profile of the surface along the bearing alignment was created in 3D DXF line format (see Figure 05 & 06). Additionally, landmark topography in each photo was captured from the terrain model in 3D Mesh DXF format to assist in the final alignment. All photos required the bearing and at least two 3D Mesh DXF models to successfully line up the photo.

Figure 05: Global Mapper Model Bearing

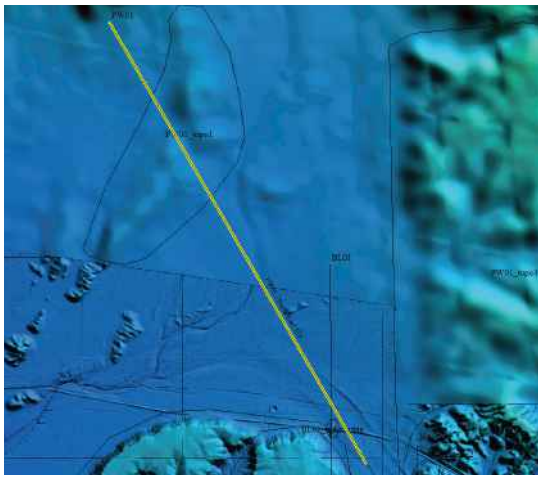
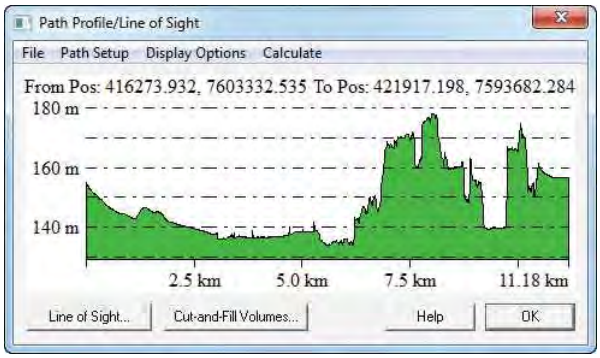


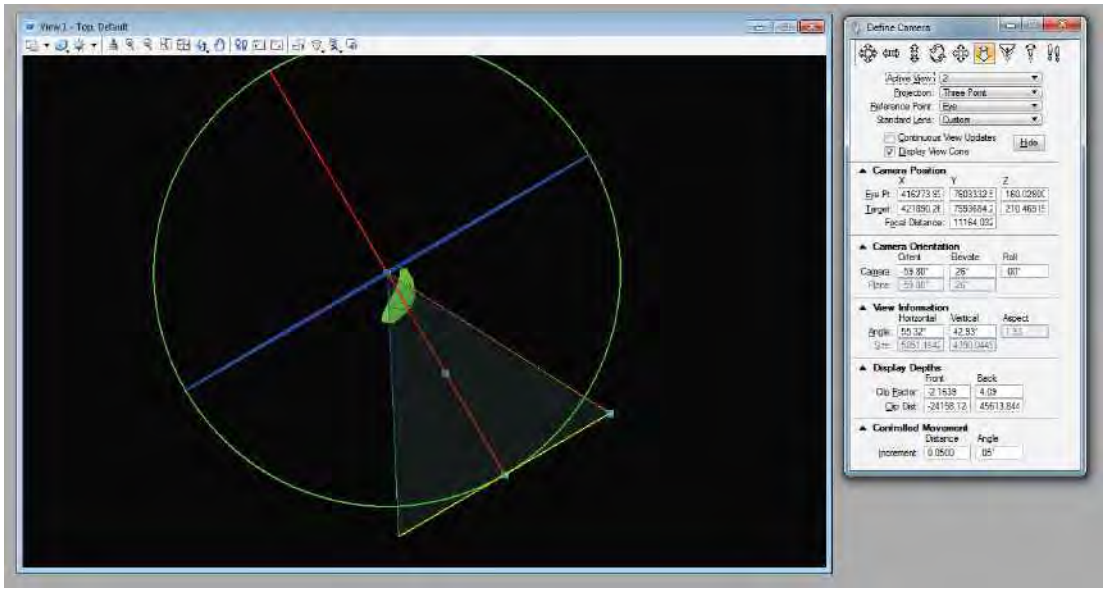
Figure 06: Global Mapper Model 3D Profile



Montage Setup

Once data were captured in Global Mapper, a montage was created in Microstation. The photo size was kept proportional to actual size, then a view was created in the image by using the Define Camera alignment tools in the construction view (see Figure 07).

Figure 07: Microstation Construction View and Camera Define Tools



The Define Camera alignment tools allowed the montage view to be altered by units distance and degrees in all directions which gave more control to exactly line up features in the image.

Figure 08: Montage View - after alignment completed

Montage Rendering

The next step was to add the proposed infrastructure to the montage view in Microstation, these data were provided from the Mine Planning Engineers and converted to 3D Mesh DXF. The rendering tool was then applied to convert the proposed infrastructure line strings to surface areas (see Figure 09). The image was then exported from Microstation to a JPG format.

Figure 09: Rendered View

Montage Output

To create the final image, the original photo was loaded into Adobe Photoshop and the rendered image from Microstation was overlaid to show the location of the proposed infrastructure. A realistic texture (of proposed infrastructure) was then placed under the original image and parts of the image were erased to expose texture in the proposed infrastructure location (See Figure 10). The final image was then exported from Adobe Photoshop to JPG format. A closure version was also created to show rehabilitated infrastructure.

Figure 10: Texture Exposed on Original Image in Adobe Photoshop

Final Mock Up

The Current View, Operations View, Closure View were then combined into the final mock up in Adobe InDesign with location map and photo location details as the final output for the Visual Impact Assessment.

Results

The results section outlines a description of the maps and figures produced during the Visual Impact Assessment. The final output produced 15 figures showing the potential visual impact of the Mesa H mine development.

3.1 Desktop Assessment

The desktop assessment resulted in the output maps of the Planned Photo Locations and Viewshed Analysis. These assisted the team into the second phase of the Visual Impact Assessment.

Figure 11 - Planned Photo Locations

Figure 12 - Viewshed Analysis - Map shows the blue shaded area shows all locations where any component of the Mesa H mine development may be visible based on the topography of the area and the dimensions of the proposed infrastructure.

3.2 Field Assessment

Sites with the greatest potential for visual impact and sites of interest were selected from the view shed analysis for field assessment. The field assessment resulted in a map of actual photo locations taken on the ground. These altered slightly from planned location in some cases due to access or view aspect. This data was used in the final phase of the Visual Impact Assessment.

Figure 13 - Actual Photo Locations

3.3 Visual Impact

The final output from this assessment was to show the visual impact of the Mesa H mine development, the following figures outline how each view will be impacted visually.

Figure 14 - BL01

Figure 15 - Jimmawurrada Creek

Figure 16 - Mesa H

Figure 17 - Mesa H

Figure 18 - Northern Access

Figure 19 - Pannawonnica Road

Figure 20 - Robe River

Figure 21 - Robe River

Figure 22 - Robe River

Figure 23 - Robe River

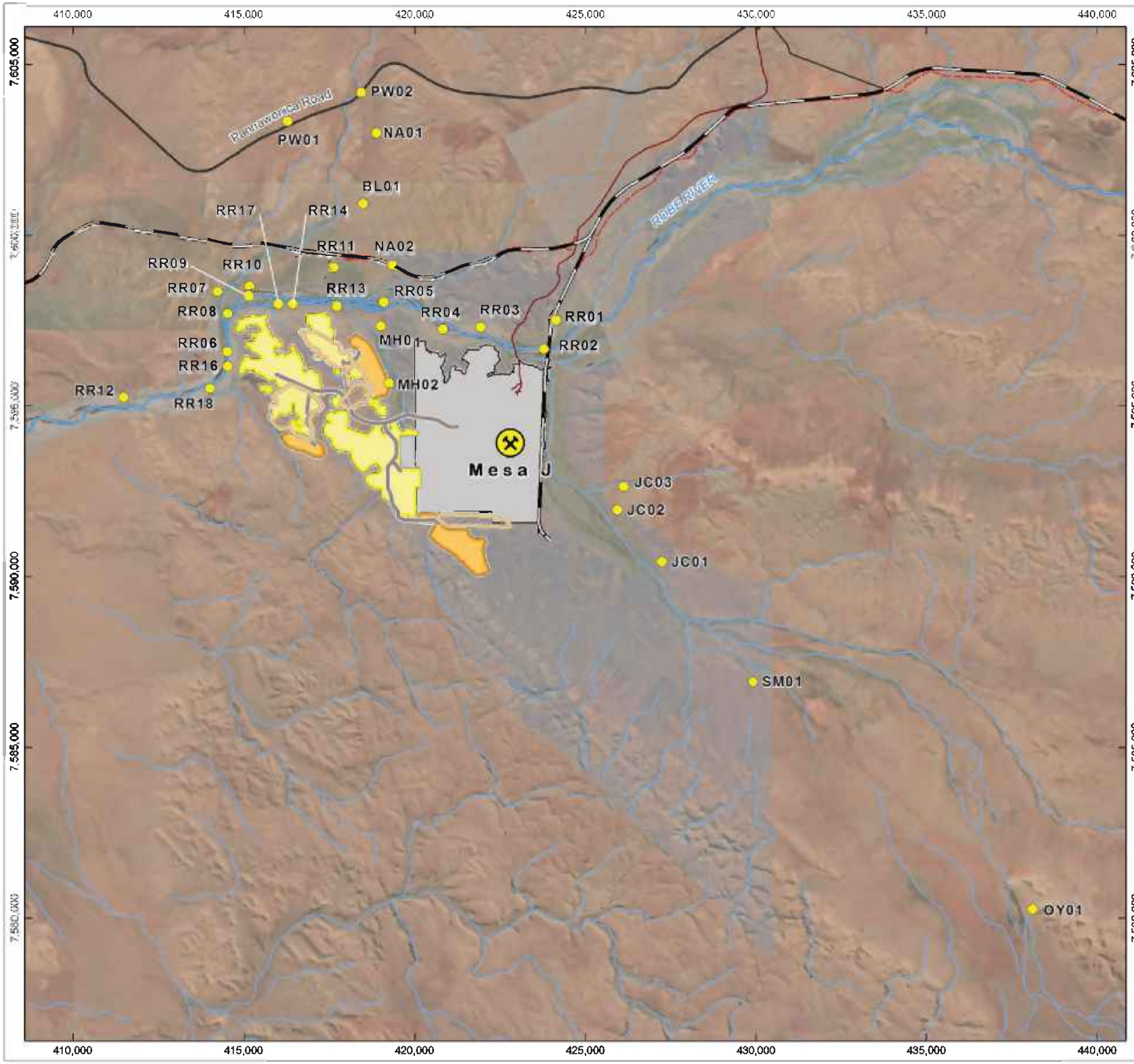
Figure 24 - Robe River

Figure 25 - Robe River

Figure 26 - Robe River

Figure 27 - Robe River

Figure 28 - Six Mile Well



RioTinto

Figure 11

Proposed Photo Locations

Drawn: T Linklater
Plan: PDE0155371v1
Date: April 2018

Proj: GDA 1994 MGA Zone 50
Scale: 1:150,000 @ A4
gisteam@riotinto.com

Legend

- Proposed Photo Locations
- Rio Tinto Mine
- Current Mesa J Mine
- Rio Tinto Railway
- Major Road
- Minor Road
- Site Road
- Rail Access Road
- Robe River
- Creek

Proposed Mine Layout

- Pit
- Waste Dump
- Topsoil/Subsoil Stockpile
- Haul Road

N

0 2 4 6 8
Kilometers

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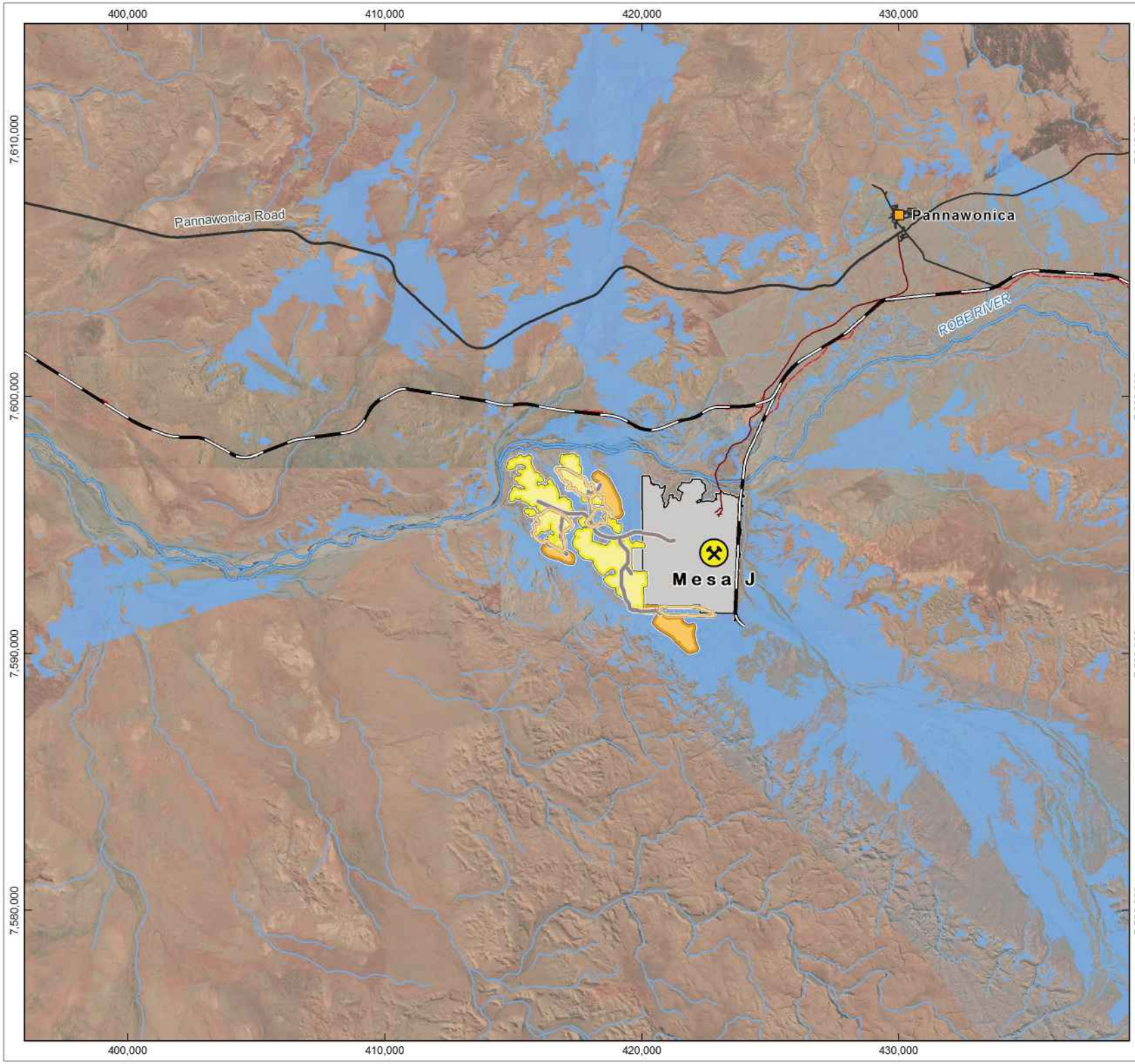

RioTinto

Figure 12

Viewshed Analysis

Drawn: T.Linklater
Plan: PDE0155371v1
Date: April 2018

Proj: GDA 1994 MGA Zone 50
Scale: 1:200,000 @ A4
gisteam@riotinto.com

Legend

- Rio Tinto Mine
- Town
- Viewshed Analysis
- Current Mesa J Mine
- Rio Tinto Railway
- Major Road
- Minor Road
- Site Road
- Rail Access Road
- Robe River
- Creek

Proposed Mine Layout

- Pit
- Waste Dump
- Topsoil/Subsoil Stockpile
- Haul Road

N

0 2 4 6 8 10
Kilometers

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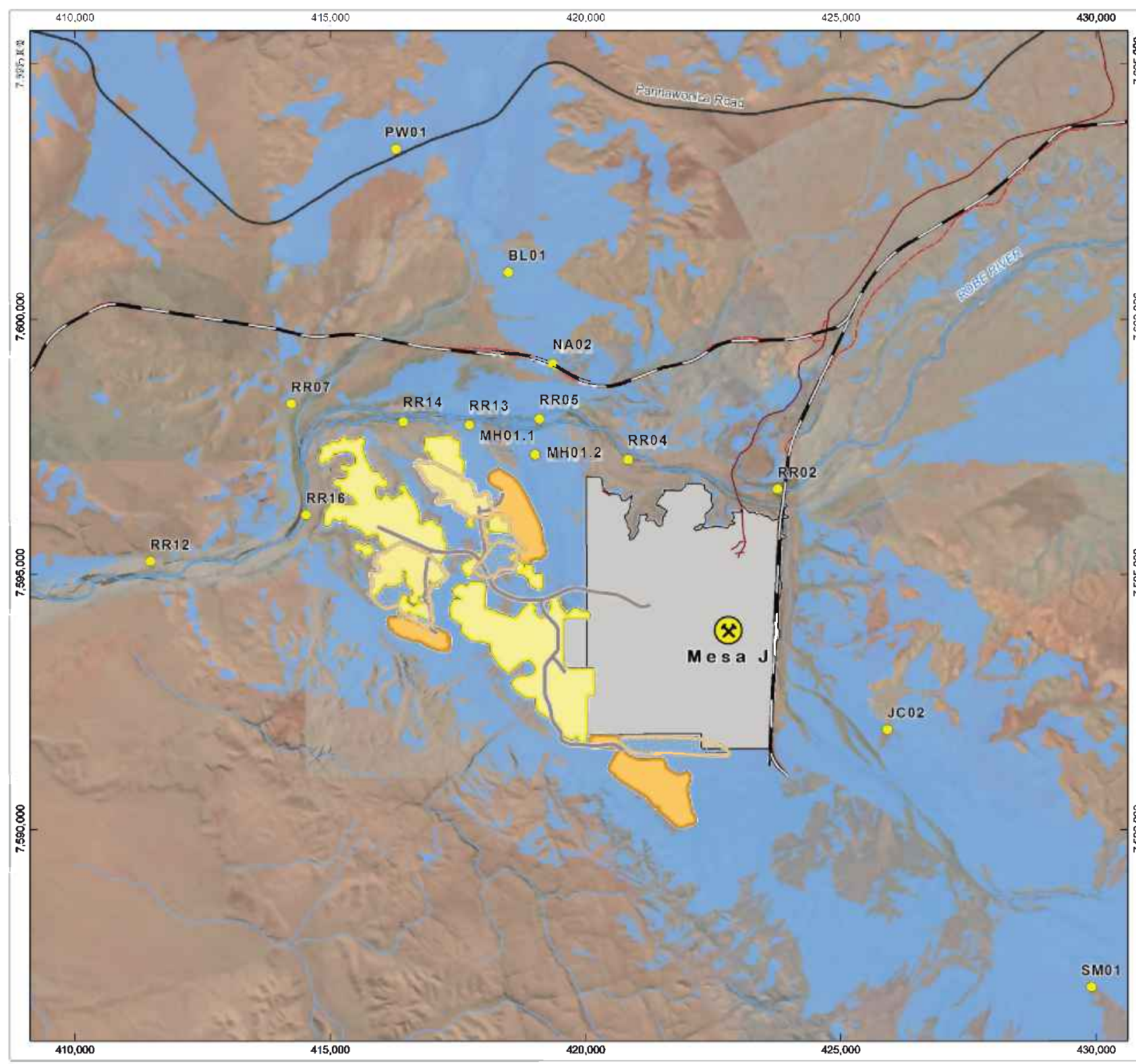

RioTinto

Figure 13

Actual Photo Locations

Drawn: T.Linklater
Plan: PDE0155371v1
Date: May 2018

Proj: GDA 1994 MGA Zone 50
Scale: 1:100,000 @ A4
gisteam@riotinto.com

Legend

- Actual Photo Locations
- Rio Tinto Mine
- Viewshed Analysis
- Current Mesa J Mine
- Rio Tinto Railway
- Major Road
- Site Road
- Rail Access Road
- Robe River
- Creek

Proposed Mine Layout

- Pit
- Waste Dump
- Topsoil/Subsoil Stockpile
- Haul Road

N

0 1 2 3 4 5
Kilometers

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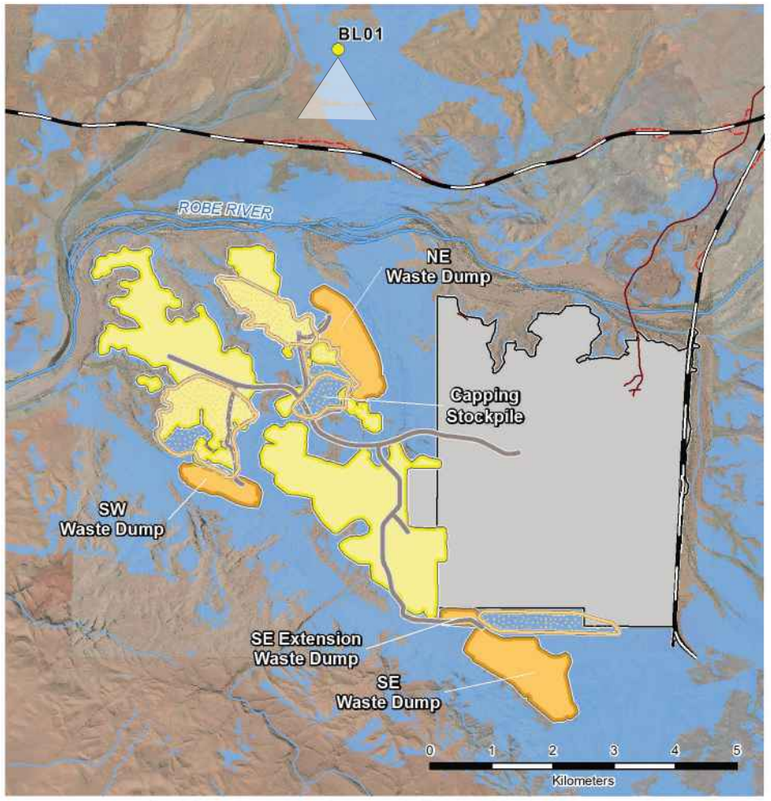
Location Map



View Aspect

Viewpoint Characteristics

Name	01 - BL01
Direction	South (Bearing 180°)
Description	Elevated hill looking towards Mesa H escarpment with low vegetation cover. Clear view along flat ground across railway line.
Site Significance	The site has cultural significance for the Kuruma Marthudunera People.
Comments	The photo was taken from highest point.

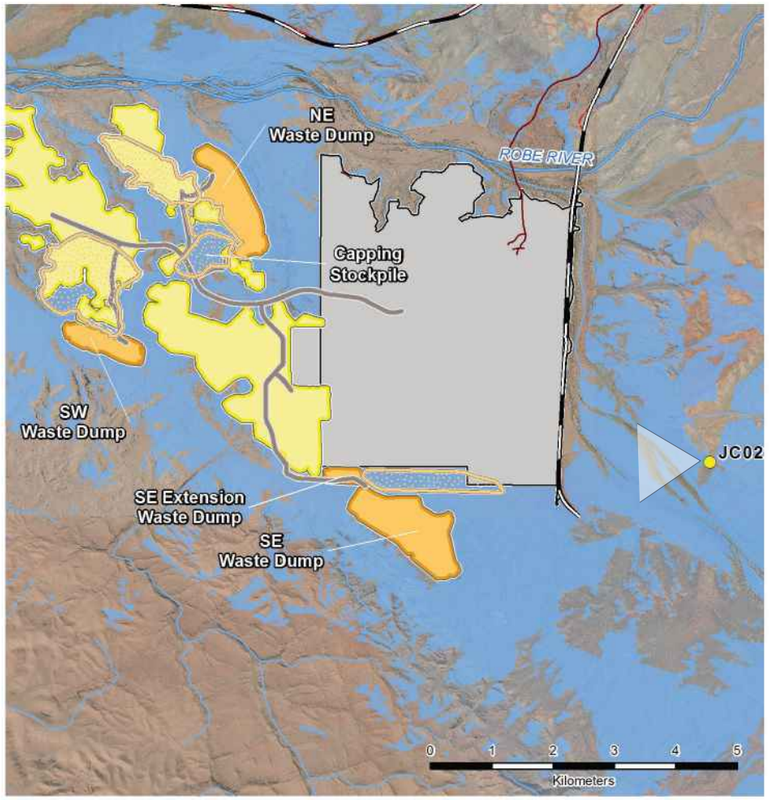
Figure 14 - BL01

Current View

Operations View

Closure View

Location Map



View Aspect

Viewpoint Characteristics

Name	03 - JC02 - Jimmawurrada Creek
Co-ordinates	425,917.43 mE / 7,591,963.07 mN
Direction	West (Bearing 288°)
Description	Western view across creek (above treeline) with clear view of Mesa J operations to the north west. Powerline alignment above photo location.
Site Significance	Creek in the Robe Valley.
Comments	The photo was taken on slightly elevated on crest in road.

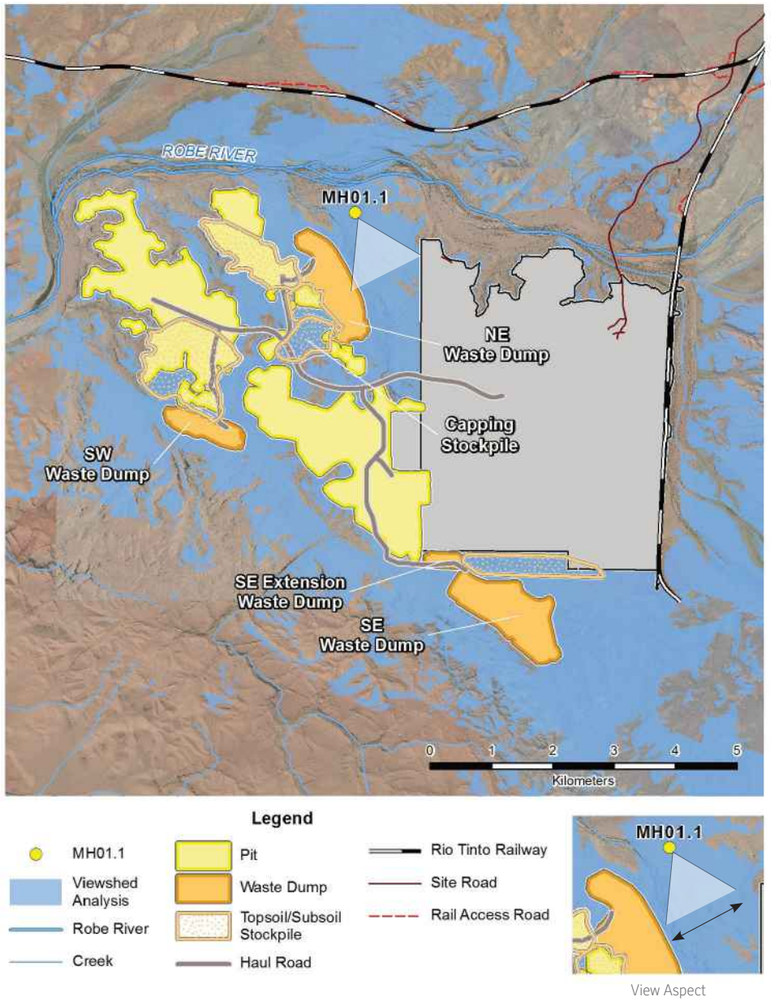
Figure 15 - Jimmawurrada Creek

Current View

Operations View

Closure View

Location Map

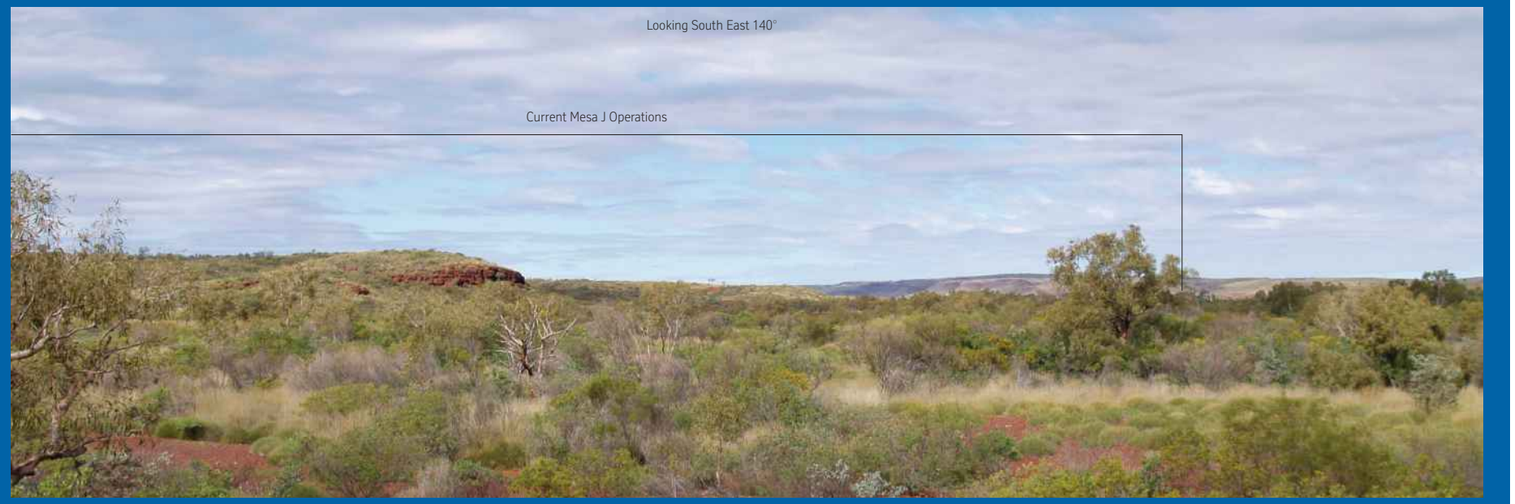


Viewpoint Characteristics

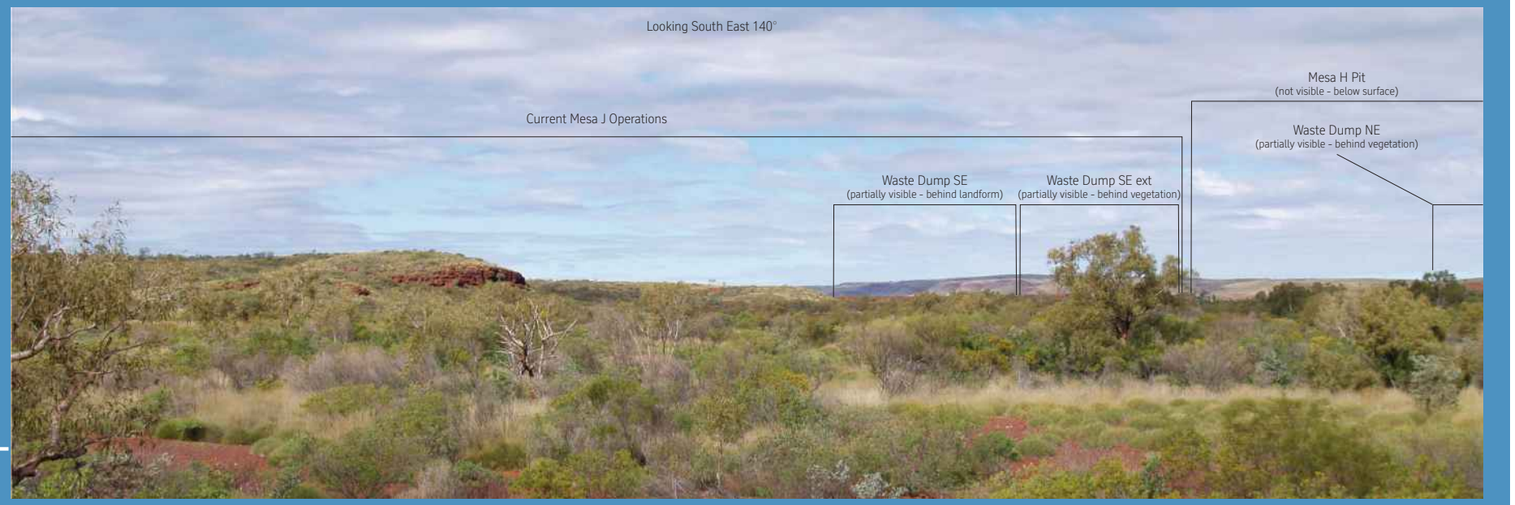
Name	05 - MH01.1 - Mesa H
Direction	South East (Bearing 140°)
Description	Small eleveated hill looking towards Mesa H escarpment, high level of vegetation coverage.
Site Significance	Significant cultural heritage site for the Kuruma Marthudunera People.
Comments	Photo was taken inside the Kuruma Marthudunera People site boundary, looking towards proposed waste dump.

Figure 16 - Mesa H

Current View

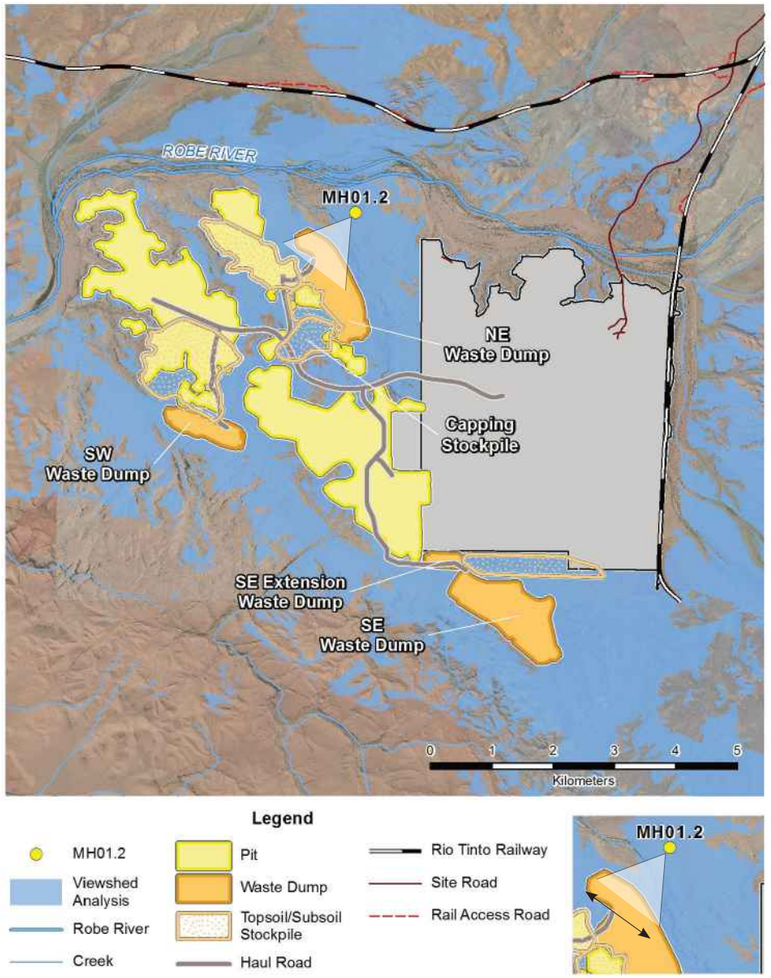


Operations View



Closure View

Location Map



View Aspect

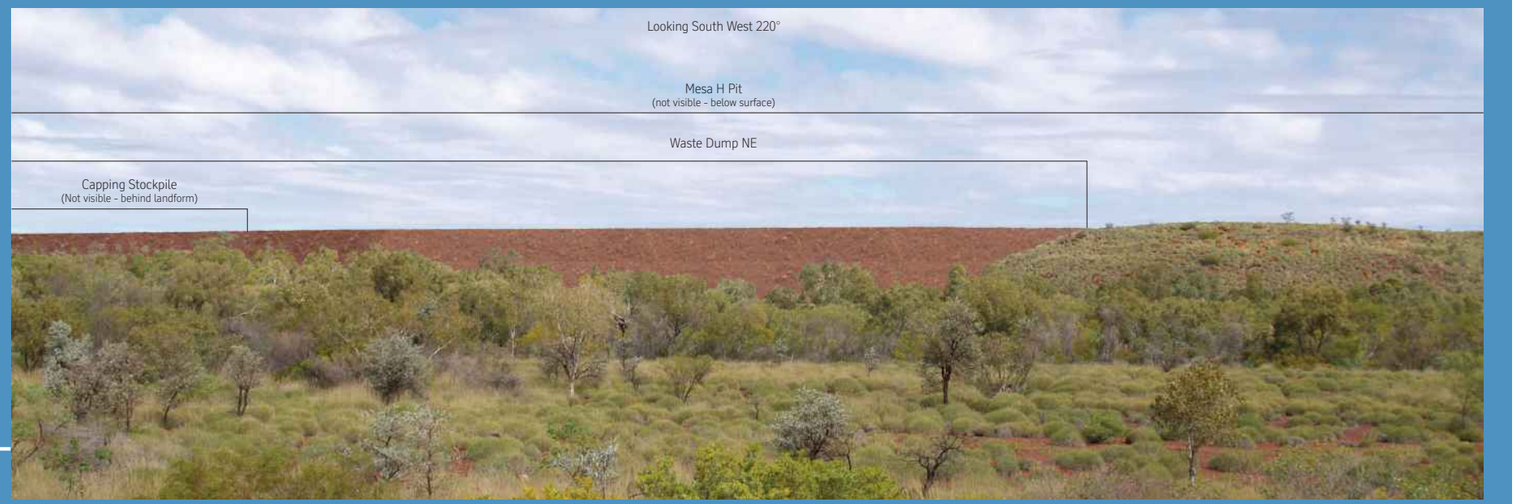
Viewpoint Characteristics

Name	06 - MH01.2 - Mesa H
Direction	South West (Bearing 220°)
Description	Small eleveated hill looking towards Mesa H escarpment, high level of vegetation coverage.
Site Significance	Significant cultural heritage site for the Kuruma Marthudunera People.
Comments	Photo was taken inside the Kuruma Marthudunera People site boundary, looking towards proposed waste dump.

Figure 17 - Mesa H

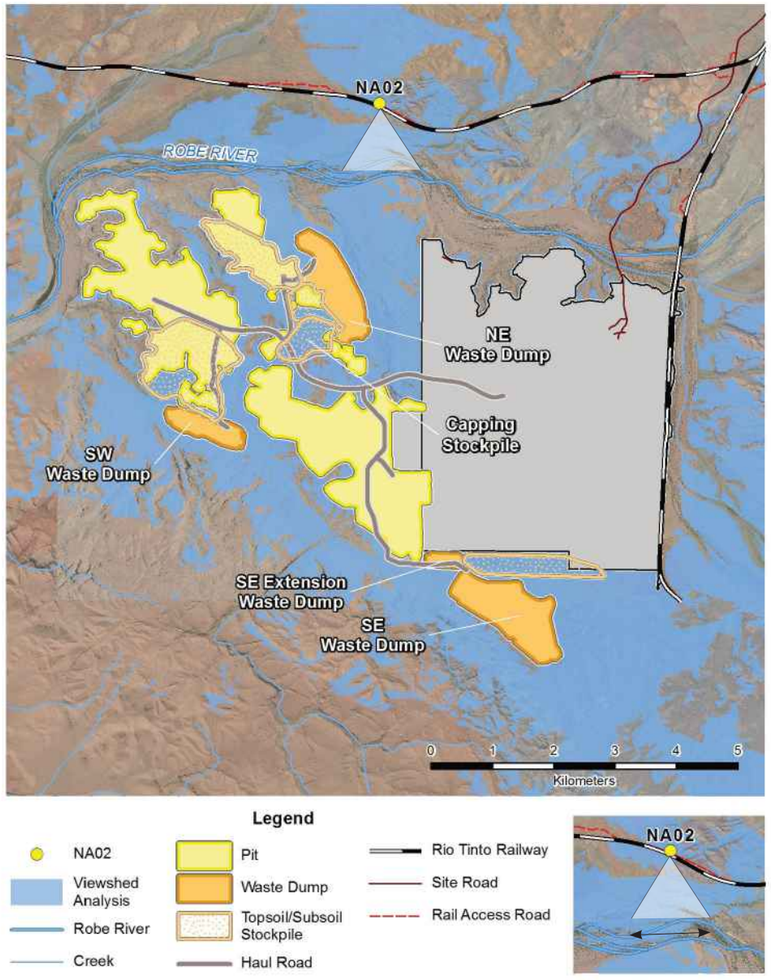
Current View

Operations View



Closure View

Location Map



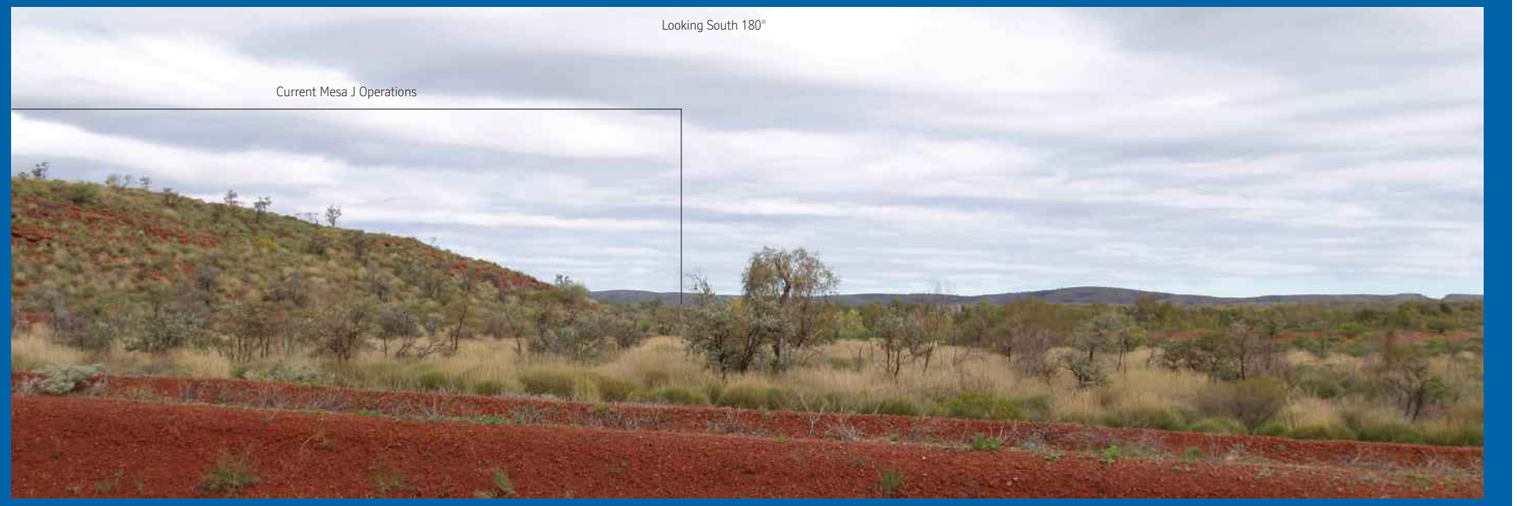
View Aspect

Viewpoint Characteristics

Name	12 - NA02 - Northern Access
Co-ordinates	419,347.47 mE / 7,599,126.40 mN
Direction	South (Bearing 180°)
Description	Flat ground with low vegetation coverage looking towards Mesa H escarpment.
Site Significance	Access track to Robe River and alongside the Rio Tinto Railway.
Comments	The photo was taken on the northern side of the Rio Tinto Railway on windrow.

Figure 18 - Northern Access

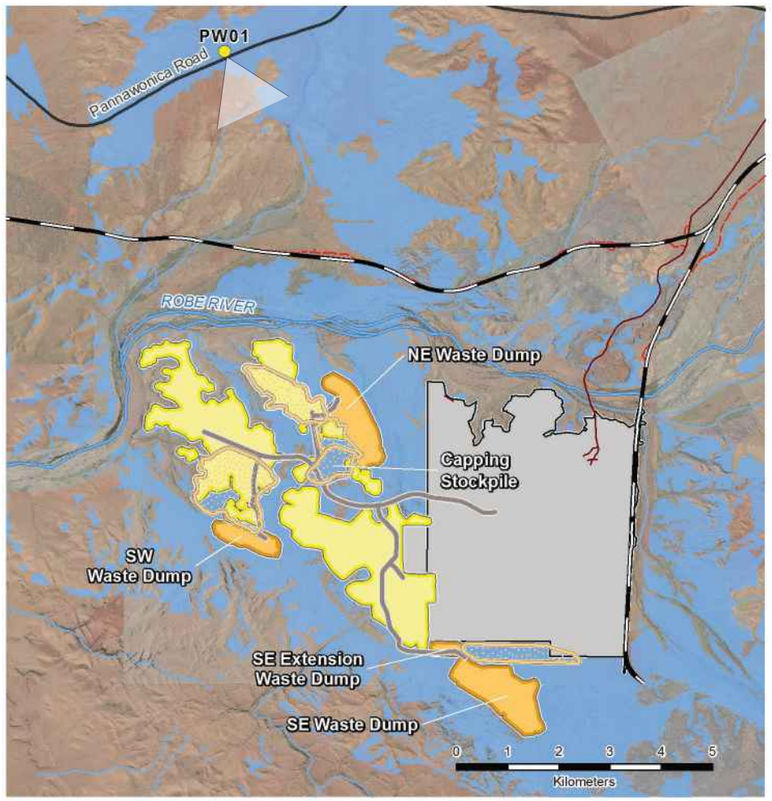
Current View



Operations View

Closure View

Location Map



View Aspect

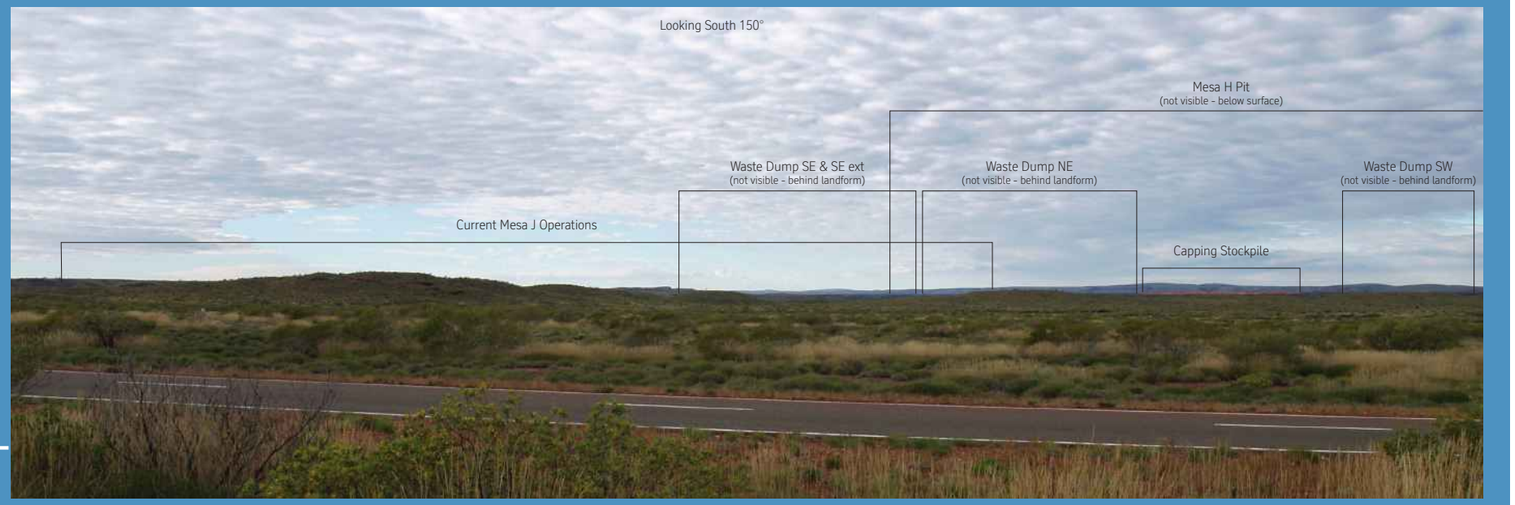
Viewpoint Characteristics

Name	14 - PW01 - Pannawonica Road
Co-ordinates	416,273.93 mE / 7,603,332.53 mN
Direction	South (Bearing 150°)
Description	Flat ground with low vegetation coverage looking towards Mesa H escarpment.
Site Significance	Access road to the town of Pannawonica from the North West Coastal Highway.
Comments	The photo was taken on northern side of Pannawonica Road.

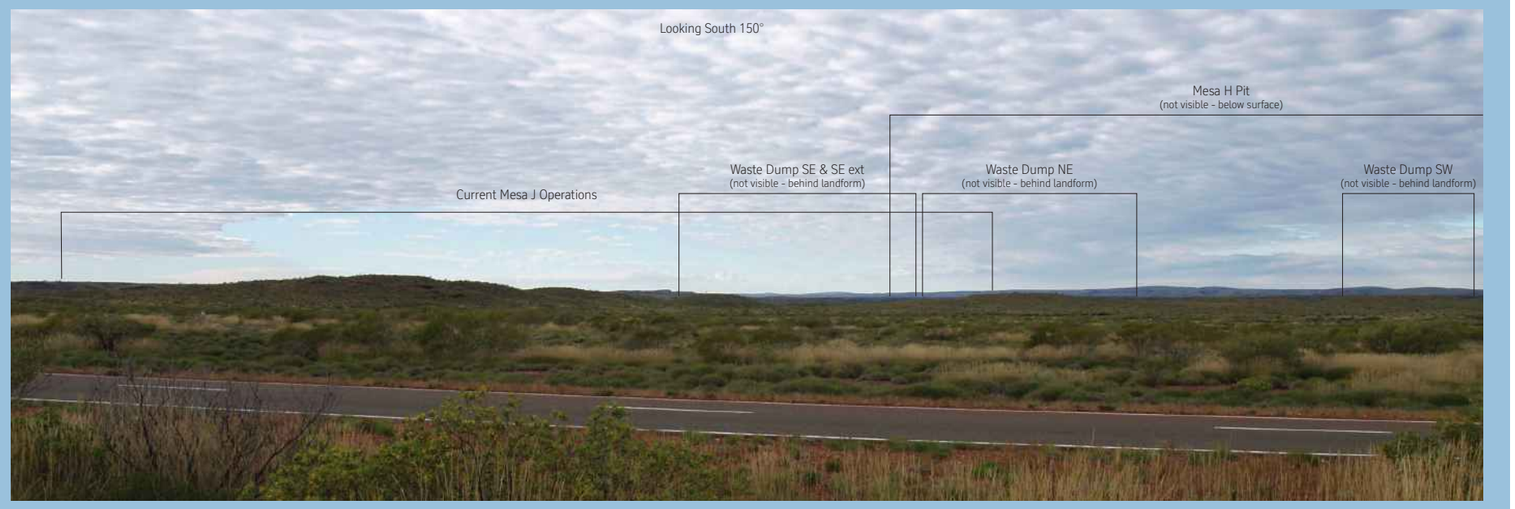
Figure 19 - Pannawonica Road

Current View

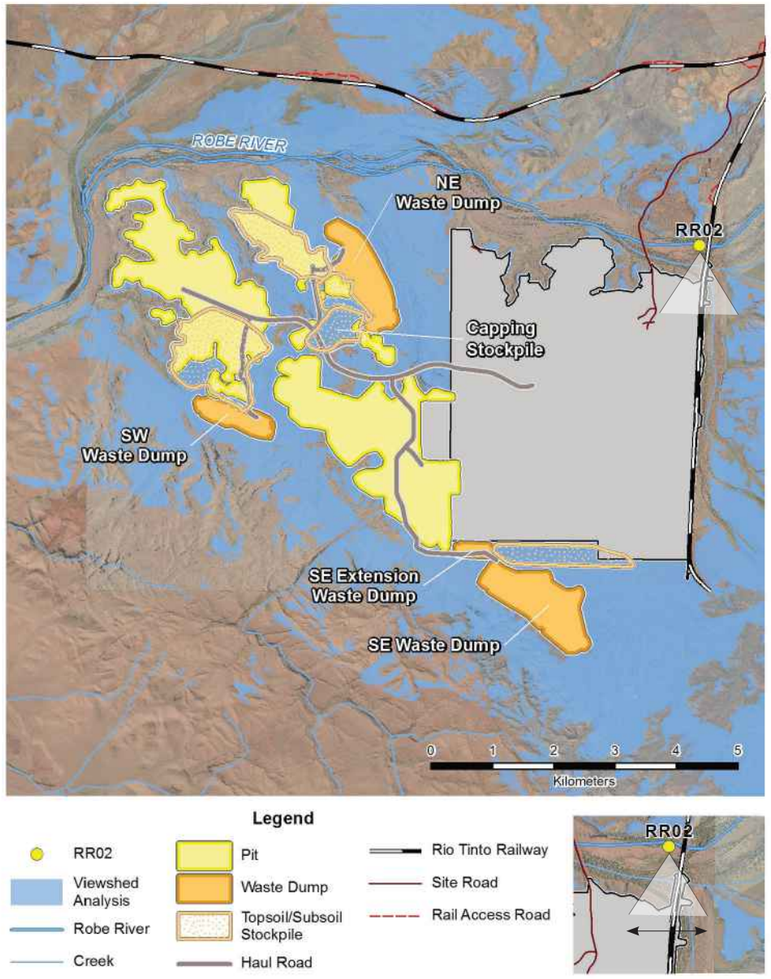
Operations View



Closure View



Location Map



Viewpoint Characteristics

Name	18 - RR02 - Robe River
Co-ordinates	423,766.21 mE / 7,596,675.71 mN
Direction	South (Bearing 180°)
Description	Flat ground with moderate vegetation coverage looking towards Mesa J escarpment.
Site Significance	Main river in the Robe Valley. It is a significant site for Kuruma Marthudunera People.
Comments	The photo was taken down in the dry river bed, next to rail bridge.

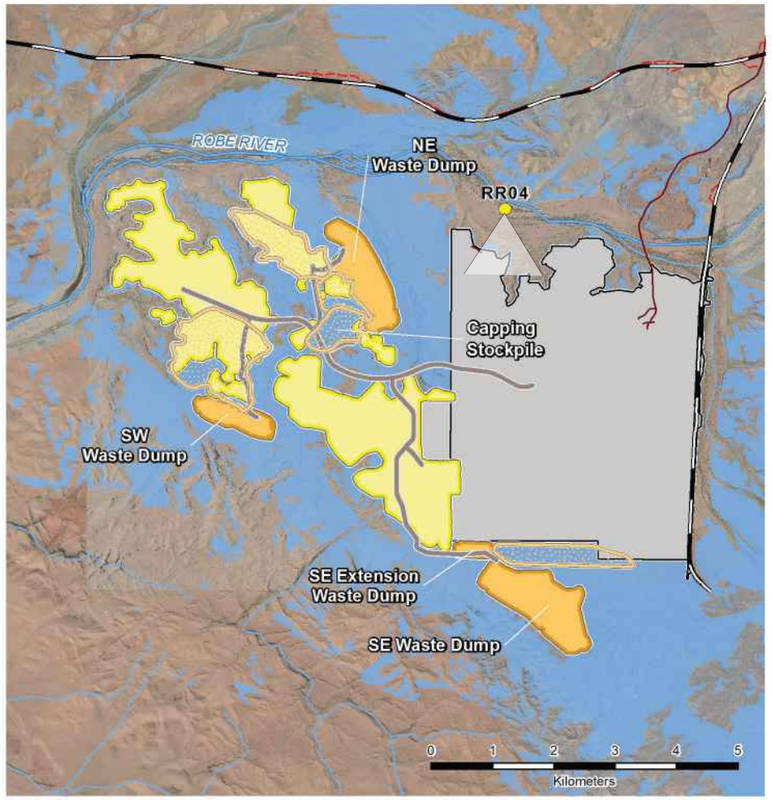
Figure 20 - Robe River

Current View

Operations View

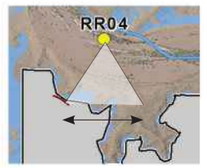
Closure View

Location Map



Legend

- RR04
- Viewshed Analysis
- Robe River
- Creek
- Pit
- Waste Dump
- Topsoil/Subsoil Stockpile
- Haul Road
- Rio Tinto Railway
- Site Road
- Rail Access Road



View Aspect

Viewpoint Characteristics

Name	21 - RR04 - Robe River
Co-ordinates	420,817.63 mE / 7,597,252.13 mN
Direction	South (Bearing 180°)
Description	Flat ground with moderate vegetation coverage looking towards Mesa J escarpment.
Site Significance	Main river in the Robe Valley. It is a significant site for Kuruma Marthudunera People.
Comments	The photo was taken down in the dry river bed.

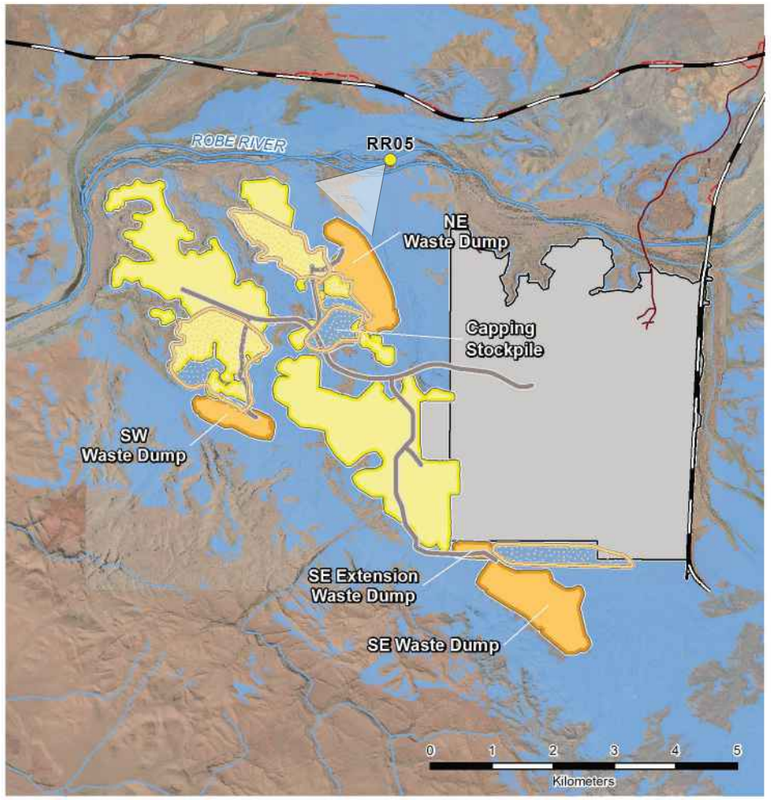
Figure 21 - Robe River

Current View

Operations View

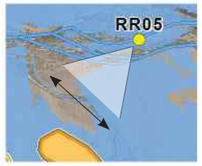
Closure View

Location Map



Legend

- RR05
- Viewshed Analysis
- Robe River
- Creek
- Pit
- Waste Dump
- Topsoil/Subsoil Stockpile
- Haul Road
- Rio Tinto Railway
- Site Road
- Rail Access Road



View Aspect

Viewpoint Characteristics

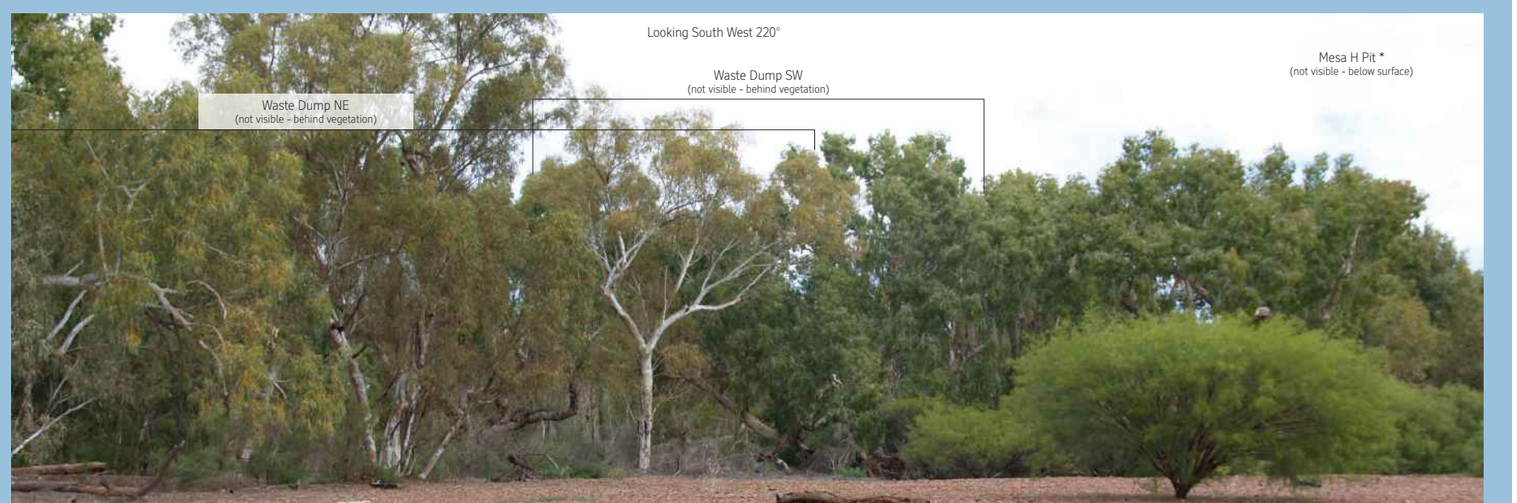
Name	23 - RR05 - Robe River
Co-ordinates	419,083.87 mE / 7,598,045.85 mN
Direction	South West (Bearing 220°)
Description	Flat ground with high vegetation coverage impeding view.
Site Significance	Main river in the Robe Valley. It is a significant site for Kuruma Marthudunera People.
Comments	The photo was taken down in the dry river bed.

Figure 22 - Robe River

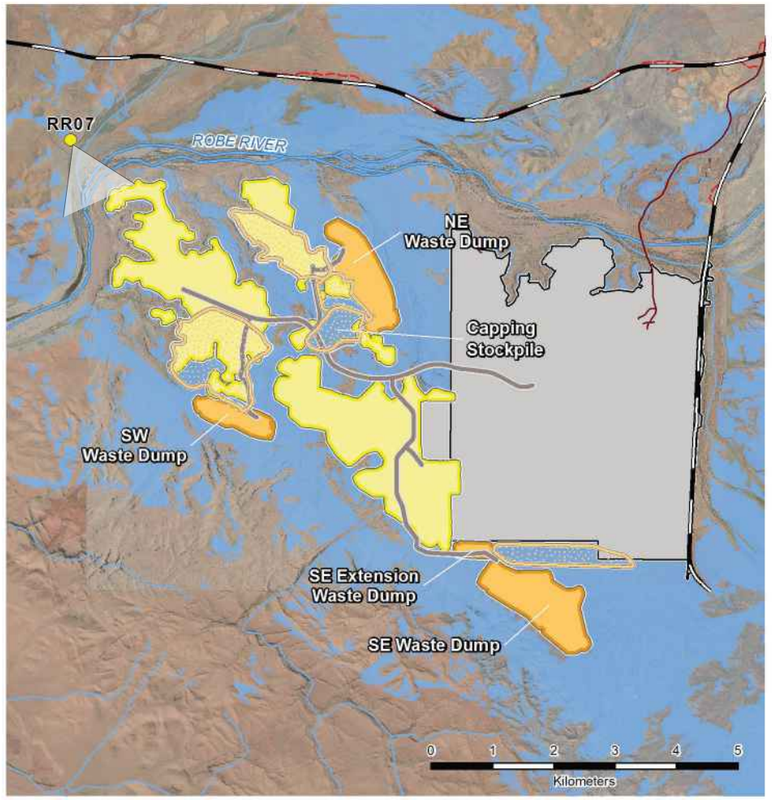
Current View

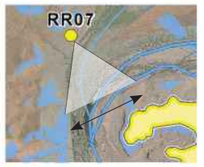
Operations View

Closure View



Location Map





View Aspect

Viewpoint Characteristics

Name	25 - RR07 - Robe River
Co-ordinates	414,228.27 mE / 7,598,343.52 mN
Direction	South East (Bearing 150°)
Description	Elevated above the treeline with Mesa H escarpment and Yura Bluff in view. High level of vegetaton coverage in river bed.
Site Significance	Main river in the Robe Valley. It is a significant site for Kuruma Marthudunera People.
Comments	The photo was taken on the north side of the Robe River.

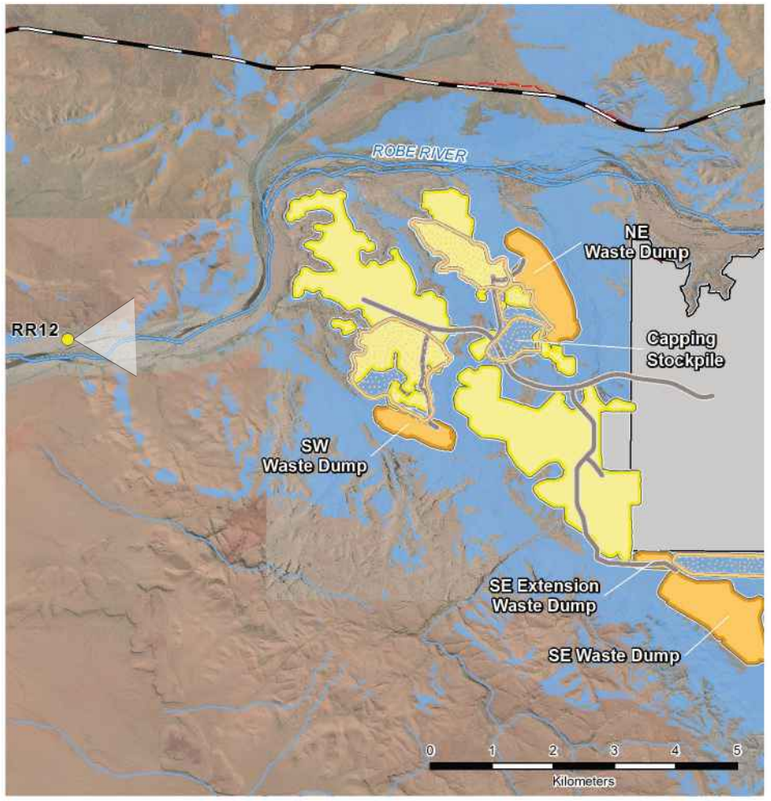
Figure 23 - Robe River

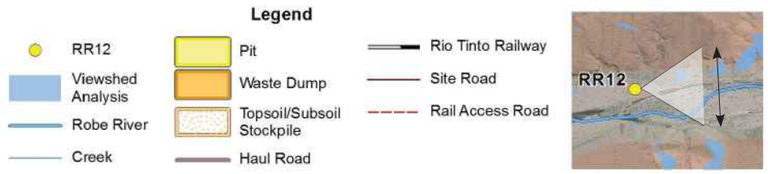
Current View

Operations View

Closure View

Location Map





View Aspect

Viewpoint Characteristics

Name	30 - RR12 - Robe River
Co-ordinates	411,470.04 mE / 7,595,250.80 mN
Direction	East (Bearing 90°)
Description	Flat ground with moderate vegetation coverage looking towards Mesa H escarpment.
Site Significance	Main river in the Robe Valley. It is a significant site for Kuruma Marthudunera People.
Comments	The photo was taken down in the dry river bed, adjacent to Mesa G escarpment on the left side of the photo.

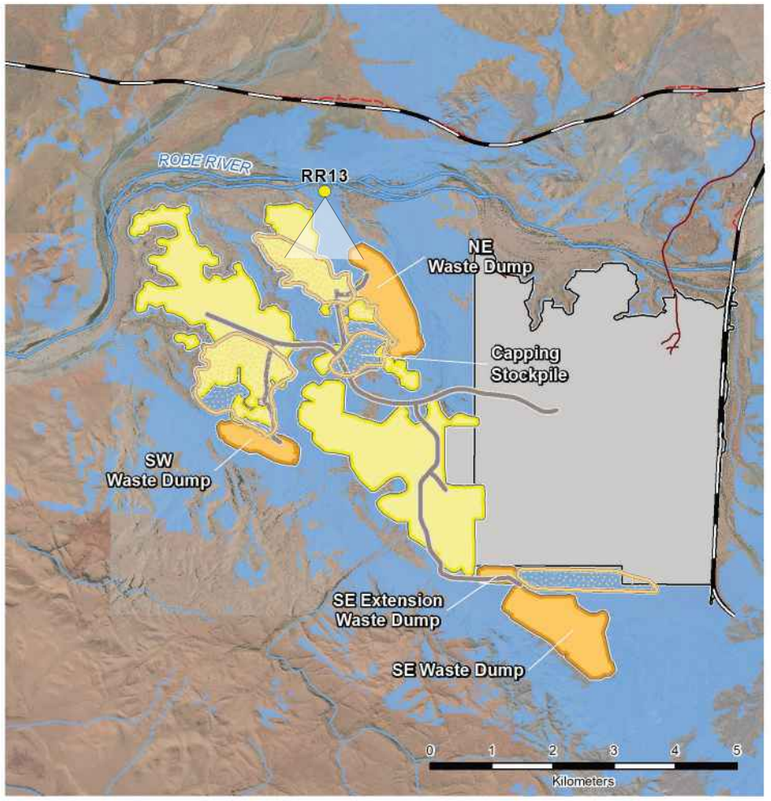
Figure 24 - Robe River

Current View

Operations View

Closure View

Location Map



View Aspect

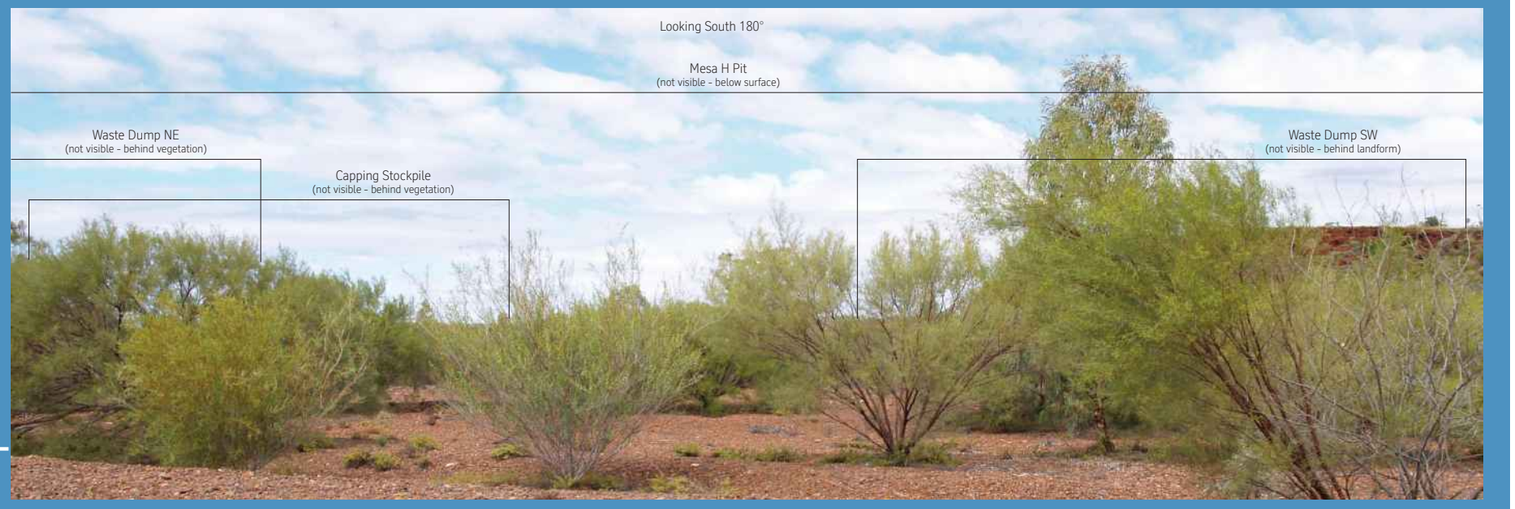
Viewpoint Characteristics

Name	33 - RR13 - Robe River
Co-ordinates	417,711.46 mE / 7,597,927.20 mN
Direction	South (Bearing 180°)
Description	Flat ground with moderate vegetation coverage looking towards Mesa H escarpment.
Site Significance	Main river in the Robe Valley. It is a significant site for Kuruma Marthudunera People.
Comments	The photo was taken down in the dry river bed.

Figure 25 - Robe River

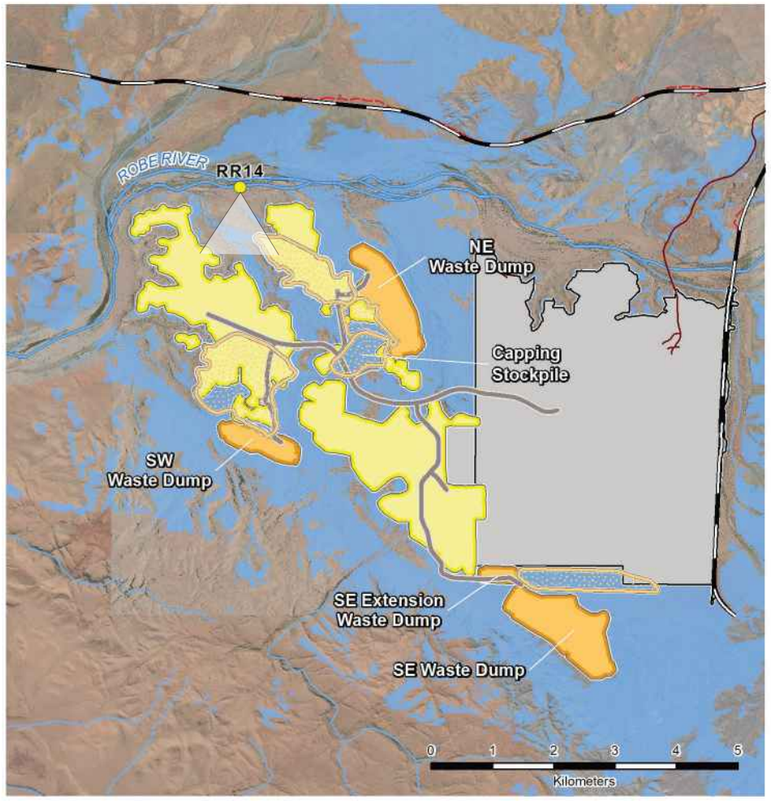
Current View

Operations View



Closure View

Location Map



View Aspect

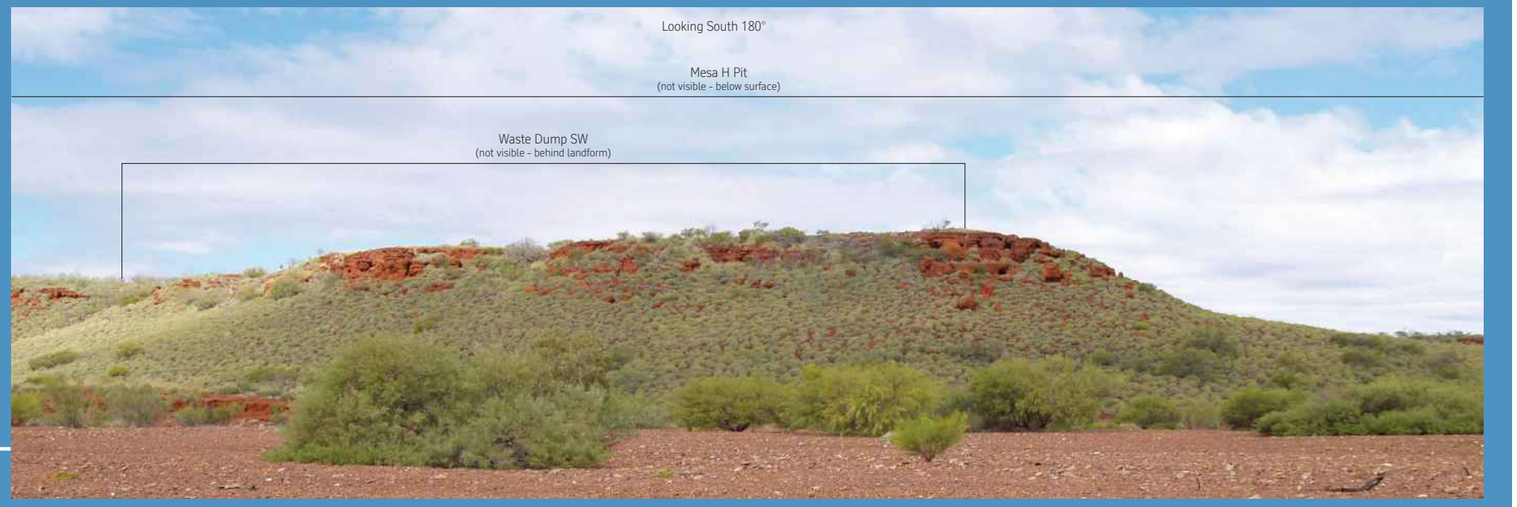
Viewpoint Characteristics

Name	34 - RR14 - Robe River
Co-ordinates	416,420.47 mE / 7,597,991.95 mN
Direction	South (Bearing 180°)
Description	Flat ground with low vegetation coverage looking towards Mesa H escarpment.
Site Significance	Main river in the Robe Valley. It is a significant site for Kuruma Marthudunera People.
Comments	The photo was taken down in the dry river bed.

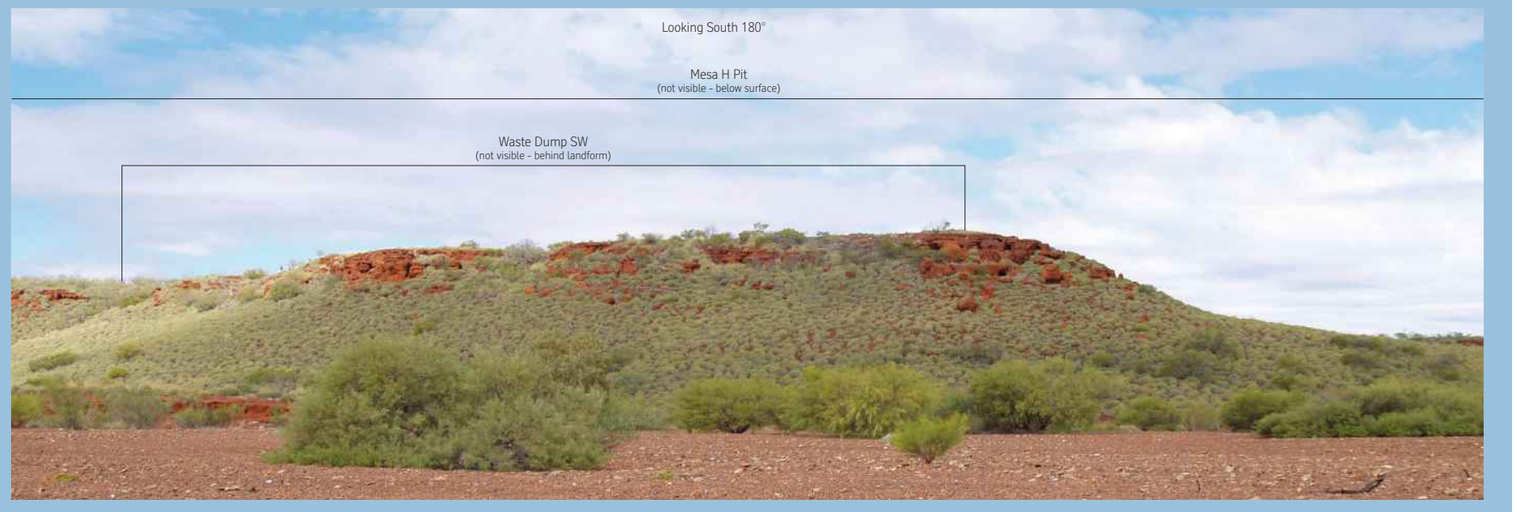
Figure 26 - Robe River

Current View

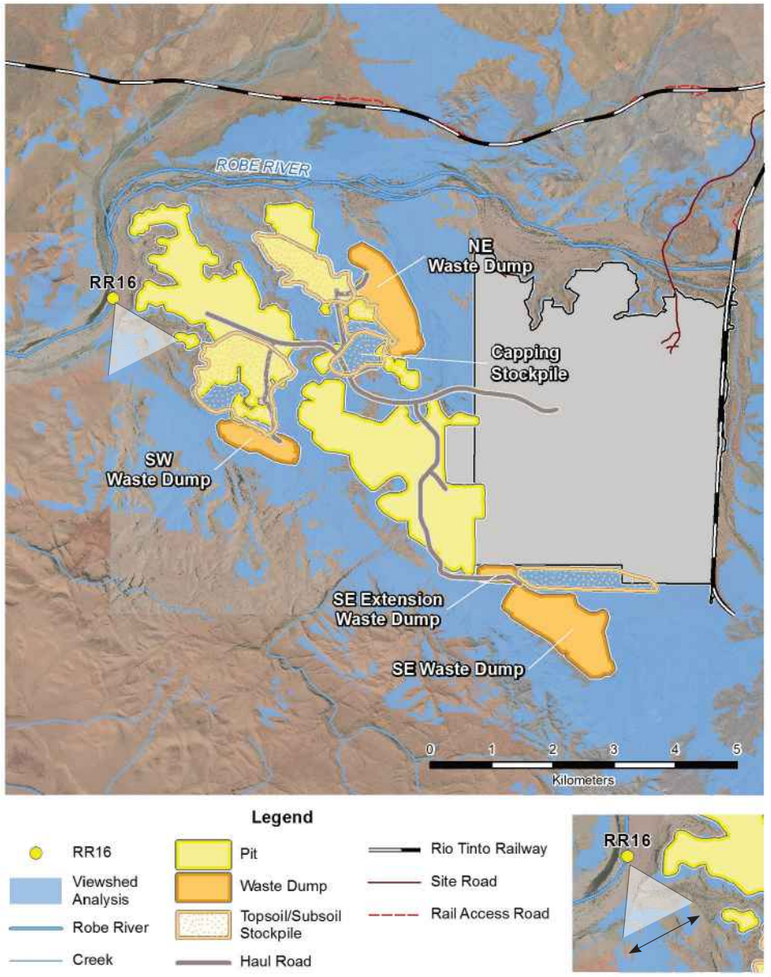
Operations View



Closure View



Location Map



View Aspect

Viewpoint Characteristics

Name	39 - RR16 - Robe River
Co-ordinates	414,516.16 mE / 7,596,165.67 mN
Direction	South East (Bearing 170°)
Description	Flat ground with moderate vegetation coverage looking towards Mesa H escarpment.
Site Significance	Main river in the Robe Valley. It is a significant site for Kuruma Marthudunera People.
Comments	The photo was taken down in the dry river bed. Taken as a view point from the entrance to Gnieraoora Pool.

Figure 27 - Robe River

Current View

Looking South East 170°

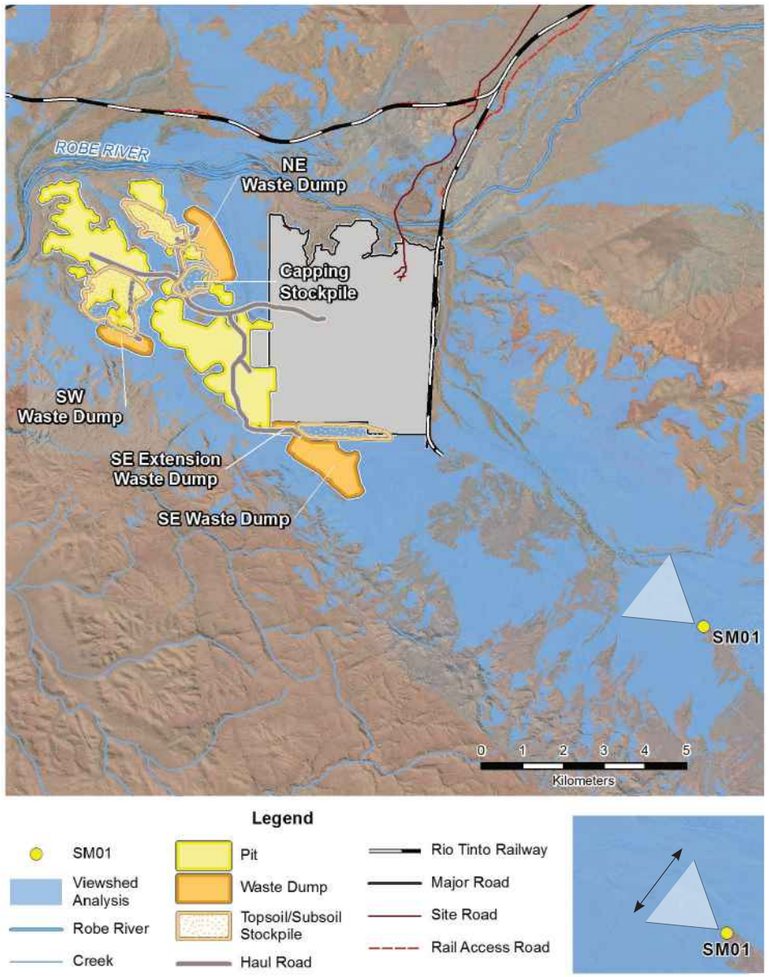
Operations View

Looking South East 170°

Closure View

Looking South East 170°

Location Map



View Aspect

Viewpoint Characteristics

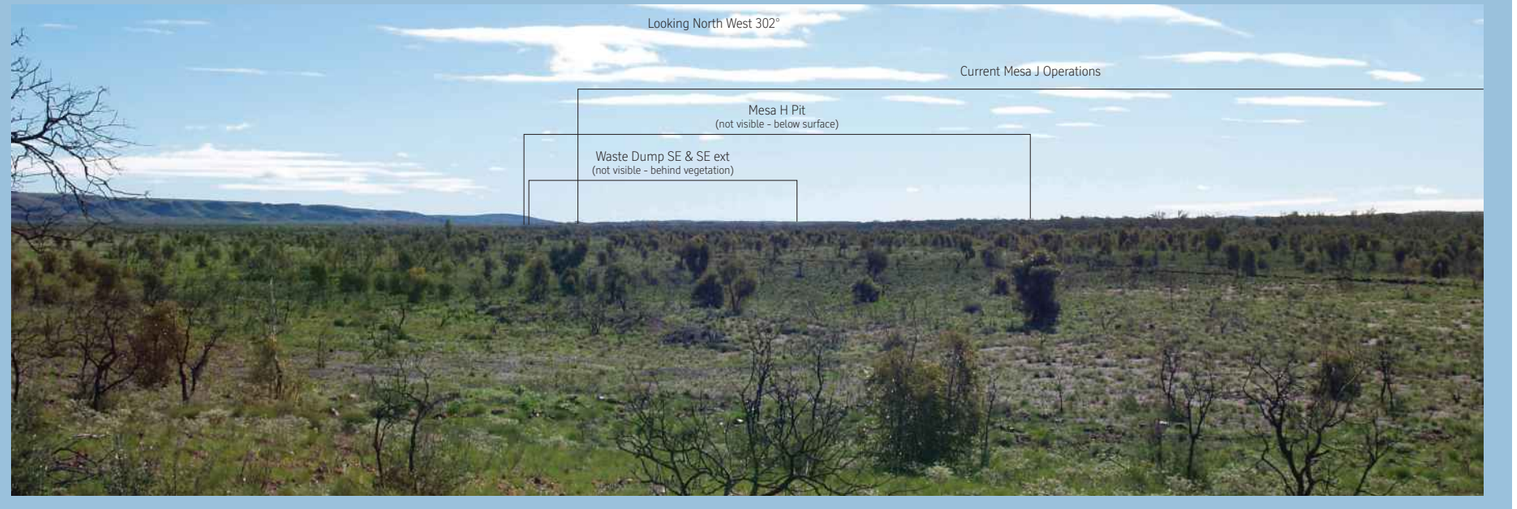
Name	35 - SM01 - Six Mile Well
Direction	North West (Bearing 302°)
Description	Slight elevation looking accross flat Bungaroo Valley towards Mesa H.
Site Significance	This is a cultural heritage site for Kuruma Marthudunera People.
Comments	The photo was taken elevated on a hill near the coastal water project pumping station.

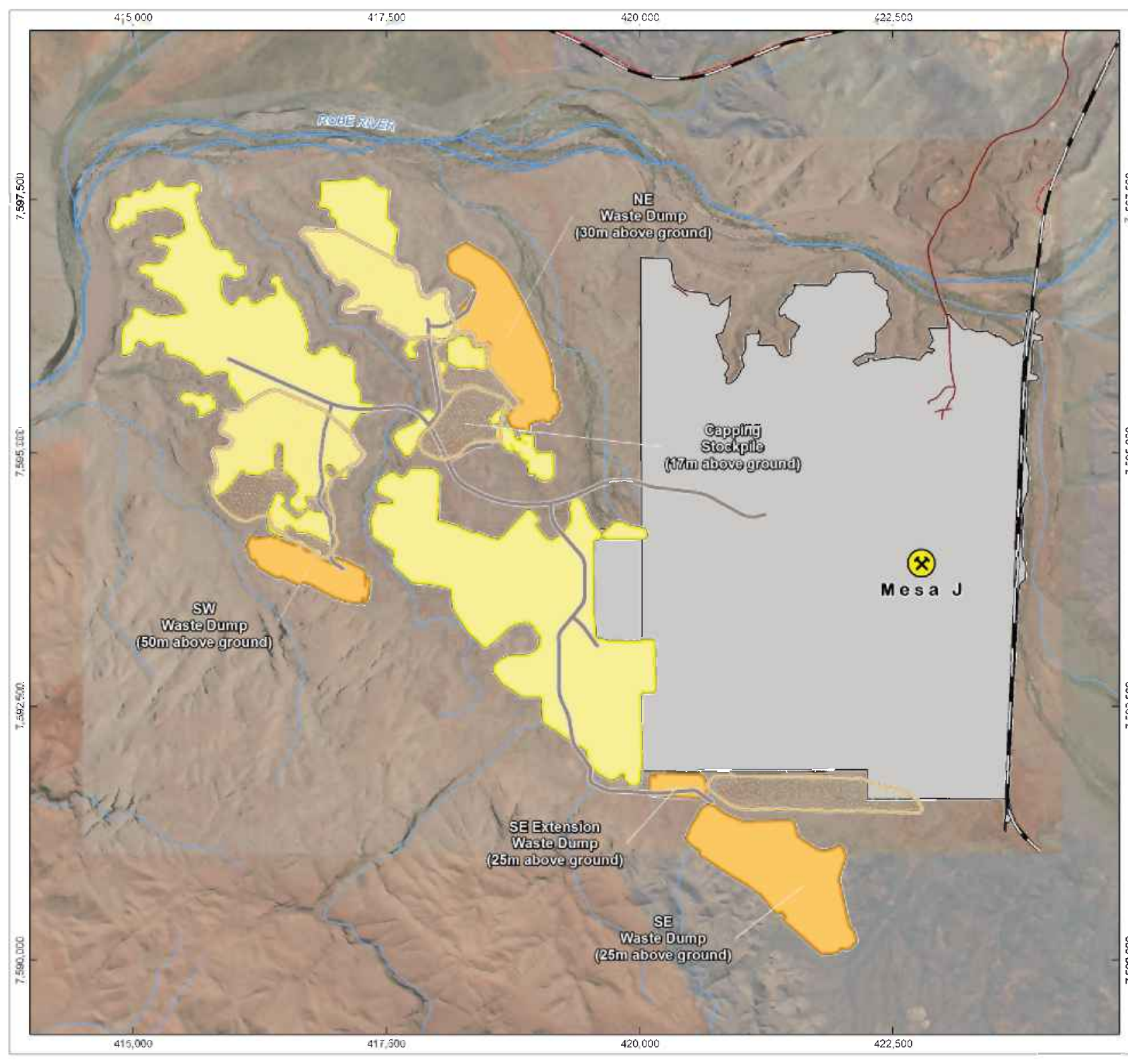
Figure 28 - Six Mile Well

Current View

Operations View

Closure View





RioTinto

Figure 29

Infrastructure Height & Data Source

Drawn: T Linklater
Plan: PDE0155371v1
Date: May 2018

Proj: GDA 1994 MGA Zone 50
Scale: 1:50,000 @ A4
gisteam@riotinto.com

Legend

- Rio Tinto Mine
- Current Mesa J Mine
- Rio Tinto Railway
- Site Road
- Rail Access Road
- Robe River
- Creek

Proposed Mine Layout

- Pit
- Waste Dump
- Topsoil/Subsoil Stockpile
- Haul Road

Data source for proposed infrastructure:
CappingStockpile.dxf
WasteDump_NE.dxf
WasteDump_SE.dxf
WasteDump_SE_ext.dxf
WasteDump_SW.dxf

N

0 0.5 1 1.5 2 2.5
Kilometers

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From	Xuzheng Gao
Department	Mine Engineering Geotechnical (MEG)
To	Melinda Brand; Fiona Bell
CC	Agus Rachman; Solomon Oppong
Reviewed By	Agus Rachman; Solomon Oppong
Reference	
Date	13 November 2017
Number of pages	37

Robe Valley Deposits Façade Stand-Off Distance Memo

Executive Summary

The Robe Valley is located in the Pilbara region of Western Australia and contains numerous Pisolite Mesa formations (also known as Channel Iron Deposits (CID)), which are characterised by steep 20-30 m high cliffs (façades) and flat tops. A number of these deposits have been mined, are active operations or are proposed for mining.

In order to protect environmental, heritage and visual amenity values associated with Mesa's particularly the façade fronting the Robe River during mining operations, a safe stand-off distance (the distance between the crest of the pit and that of the mesa's natural slope) is required to be determined to ensure the long term stability of the facade.

Since 2007 several Geotechnical studies have been carried out on the facade stability including internal Rio Tinto studies and external Consultant studies. The previous façade stability studies have recommended stand-off distances ranging between 10m to 50m. However, the current review identified that these results were based on different levels of orebody and geotechnical knowledge. An attempt was made to simplify and determine the appropriate stand-off distance to the Mesa façade. The current review utilized the following approach:

1. A review relevant Geotechnical reports relating to the Mesa façade stability (Sections 1 through 5),
2. A review of the pit slope performance of as-built slopes (Section 6), and
3. A review of the façade stability during closure (Section 7)

The outcome of this report can be used as a guideline for current and future mining operations in Robe Valley region.

1 Introduction

The current and proposed pits at Robe Valley Mesa deposits are generally shallow and are above the water table. As such, geotechnical hazards pose a relatively low risk to mine operations. The key focus of the assessment is to ensure preservation of the majority of the Mesa façades to protect associated environmental, heritage and visual amenity values particularly the façade fronting the Robe River.

A stand-off distance (the distance between the crest of the pit and that of the mesa's natural slope) based on a geotechnical assessment is required to ensure that the façades can be preserved and also allow for resource recovery.

This memorandum aims to recommend the minimum stand-off distance by reviewing historical geotechnical studies and based on the current pit wall performance.

2 Geology

Robe Valley is located in the Western Pilbara region of Western Australia. Mining commenced in 1972 from Middle Robe Valley and were relocated to the west as mining progressed. The locations of all the deposits are shown in Figure 1.

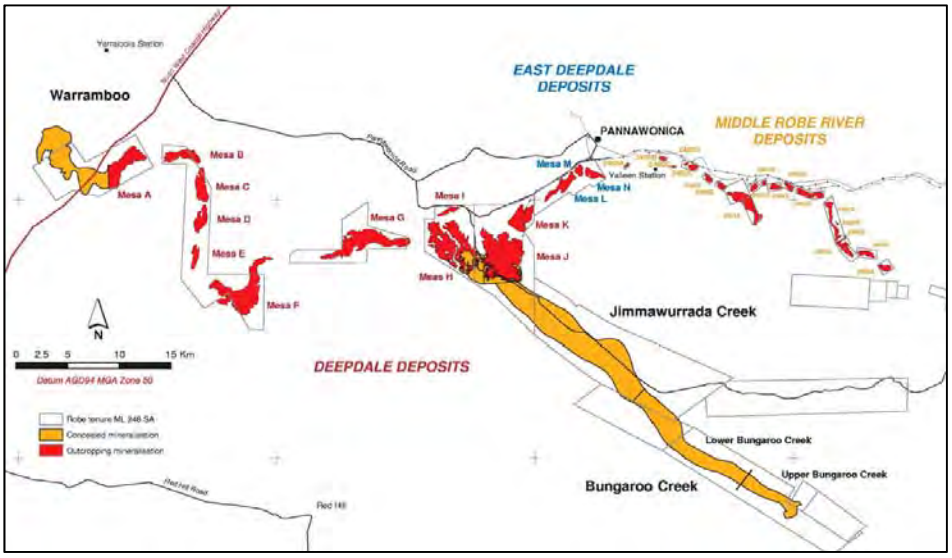


Figure 1. Location of Robe Valley Iron Ore Operations.

Mesa deposits are broad flat-topped hills with a number of deeply incised gullies. The deposit is bounded by 20-30 m high cliffs (façade). The channel at Mesa is incised through the Yarraloola Conglomerate into sediments interpreted to be part of the older Proterozoic Ashburton Formation, which forms the majority of the basement.

Mineralization within the Mesa deposits is generally hosted in the Tertiary Pisolite (TP) units. The TP has a pisolitic texture and is cemented together by a goethitic matrix. Internal zones of poorer quality material exist in the form of clay or as hydrated/denatured pisolite, but these are infrequent. Overlying the TP zone is the Semi-hardcap Tertiary Pisolite (HTP), which is a weathered/laterized form of the TP zone and contains secondary soils and silica. The transition between the HTP and TP is gradational and visually difficult to identify. Underlying the TP is the Mixed/Massive Sub-Grade Pisolite (TPM). This zone is also gradational from the TP. It is characterised by a limonitic, denatured/massive appearance and clay is common throughout. This contact is also visually difficult to identify due to its gradational nature. It is suggested that this zone has been subjected to a palaeo-water table, which has resulted in a significant hydration effects in comparison to the overlying TP.

The typical sequence of Mesa geological units are:

- Quaternary alluvium (variable thickness);
- HTP (Hardcap Tertiary Pisolite) (variable thickness);
- TPC (Tertiary Pisolites Clay) (variable thickness);
- TPM (Tertiary Pisolites Mixed) (variable thickness);
- TPH (Tertiary Pisolites Hard) (variable thickness); and
- TPB (Tertiary Pisolites Base) (variable thickness);

An in-situ geology sections and models are shown in Figure 2-5.

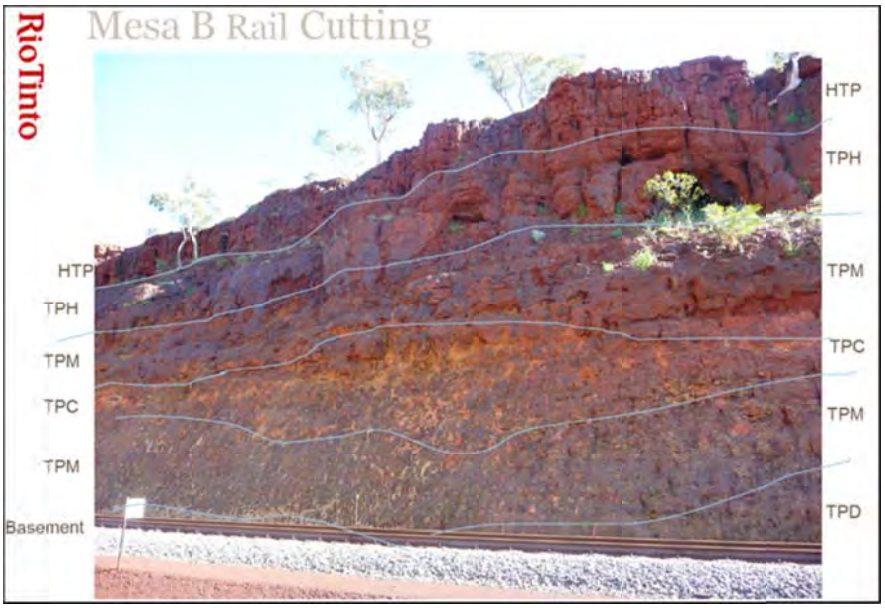


Figure 2. In-situ Geology Units Cross Section in Mesa B.

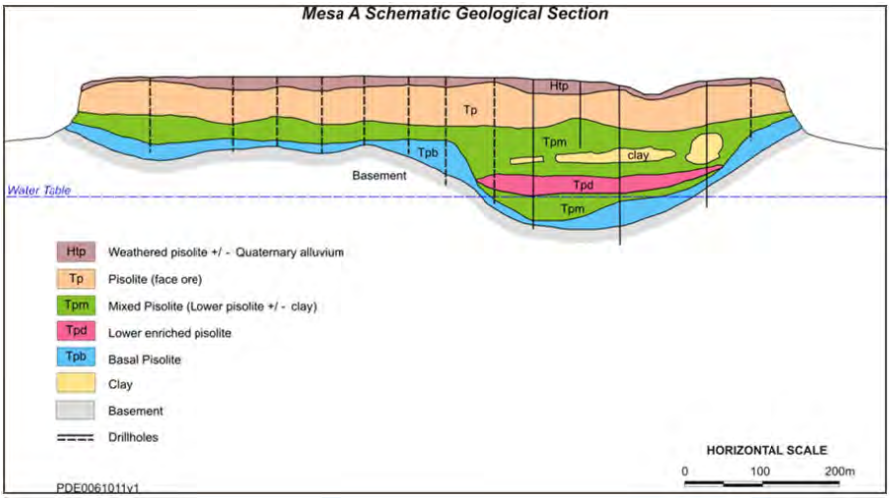


Figure 3. Geology Section of Mesa A.

Apart from other Robe Valley deposits, recent geology drilling indicated (refer Figure 4 and Figure 5) that unconsolidated alluvial cover (ALL) extends up to 15m in the upper most portion of the Mesa H and Mesa J deposit.

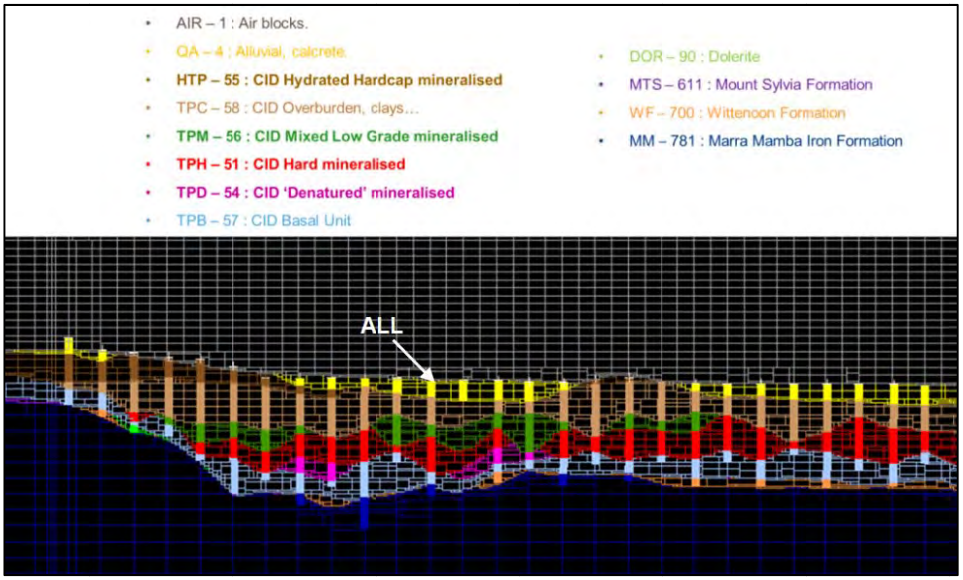


Figure 4. Mesa H Geology Cross Section.

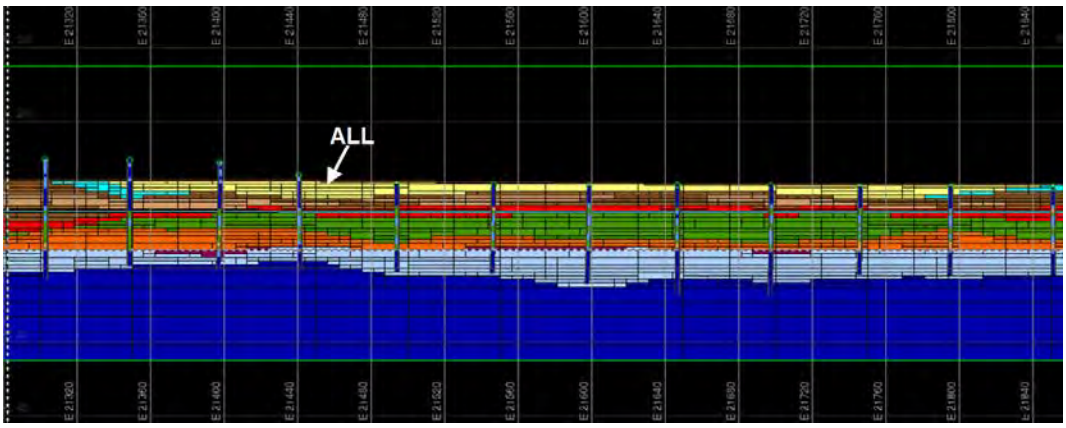


Figure 5. Mesa J Geology Cross Section.

3 Hydrology and Hydrogeology

Surface water and groundwater can impact the stability of façade. Most of the Robe deposits are above the groundwater table and the facade surrounding the Mesas further protect the mining operations from flooding of the Robe River.

3.1 Hydrology

The Robe Valley area is hot and persistently dry. Rainfall is also highly seasonal, with approximately 69% of the annual total occurring between December and April.

The Robe Valley deposits reviewed in this report are located on high ground, outside the 1% annual exceedance probability (AEP) floodplain of the Robe River. Riverine flooding of the deposits is not considered as a geotechnical issue. An example of the Mesa A, Mesa B, Mesa C, Mesa K and Mesa J 1% Annual Exceedance Probability (AEP) flood extent is shown in Figure 6, Figure 7 and Figure 8.

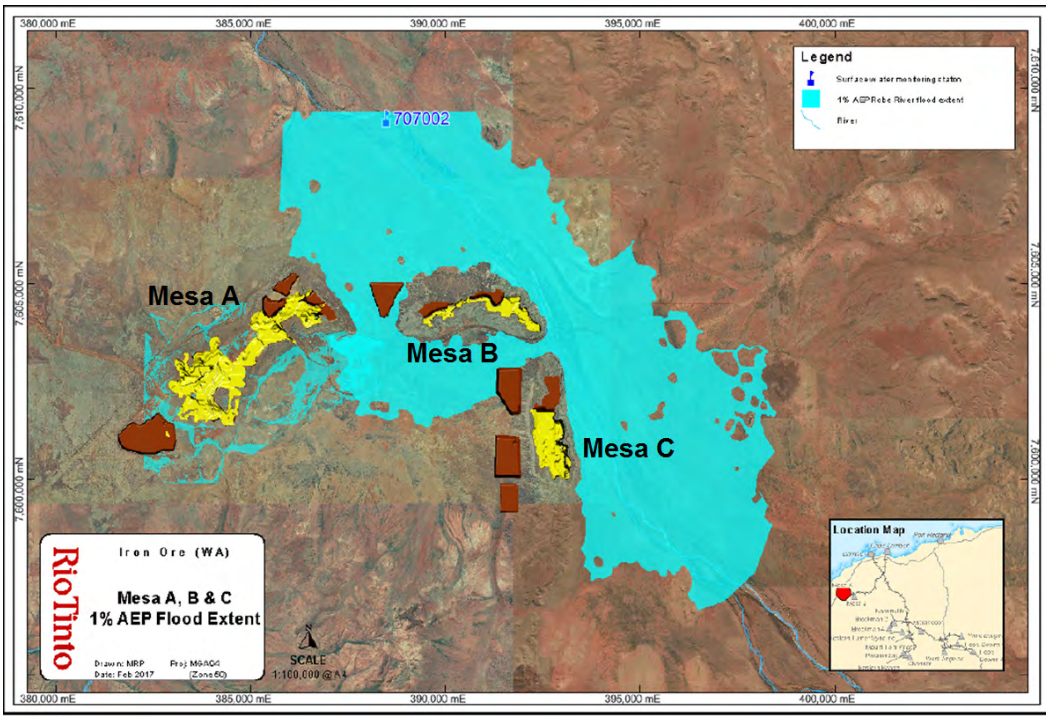


Figure 6. Mesa A, B and C Deposits in relation to the 1% AEP flood extent of the Robe River.

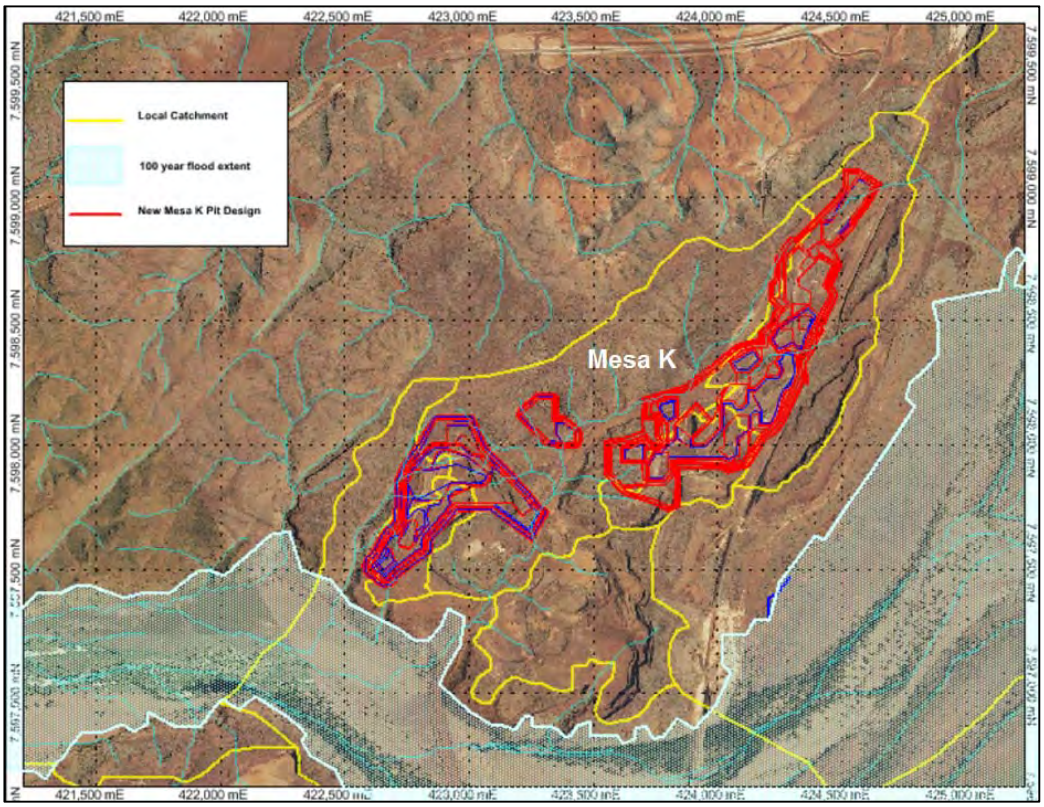


Figure 7. Mesa K Deposits in relation to the 1% AEP flood extent of the Robe River.

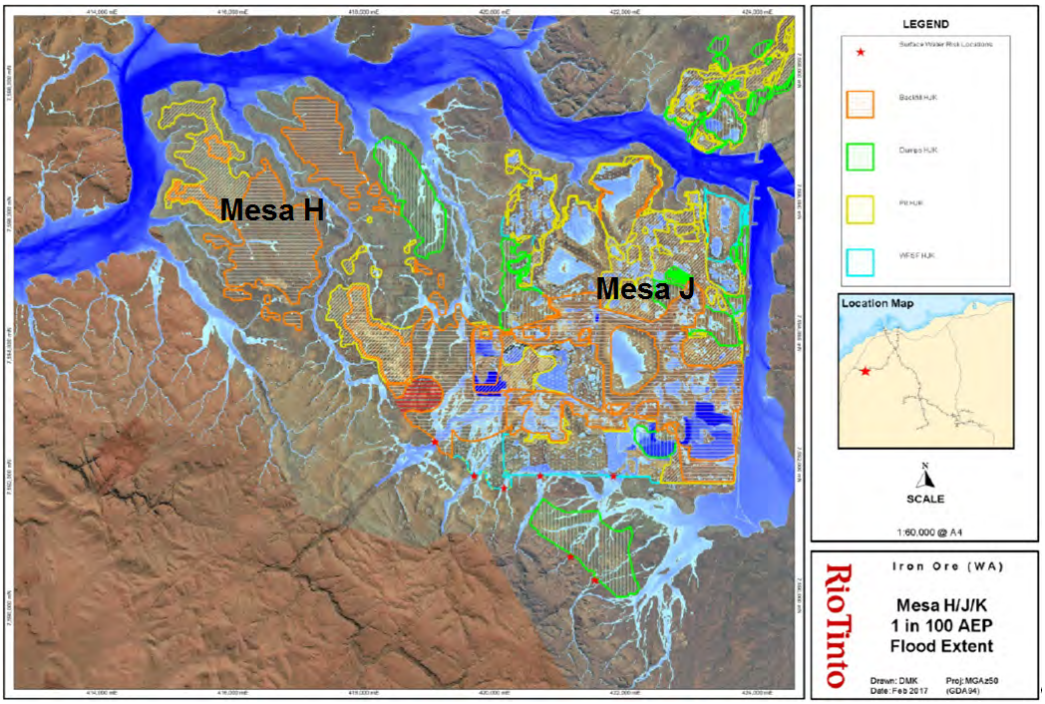


Figure 8.Mesa J and Mesa H Deposits in relation to the 1% AEP flood extent of the Robe River.

3.2 Hydrogeology

The key hydrogeological concepts at the Robe Valley are summarized based on groundwater investigations and groundwater modelling work summarised in Table 1: Dewatering is needed to mine the areas below pre-mining water table as shown from Figure 9 to Figure 13.

Table 1. Intersection Area between Robe Valley Pits and the Pre-Mining water Table.

Deposit	Pit Floor (mRL)	Benches	Pre-Mining Water Table (mRL)	Bench below Water Table
Mesa A	44	3	48.5	1
Mesa B	80	4	65	0
Mesa C	52	7	69	4
Mesa H	110	9	121	2
Mesa J	130	5	135	1
Mesa K	156	5	145	0
Warramboo	20	6	39	4

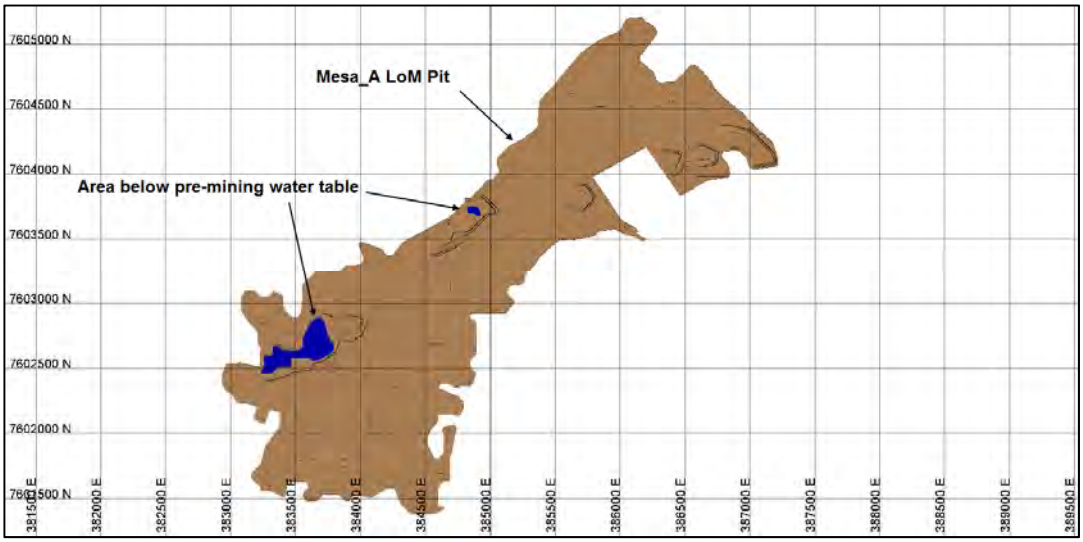


Figure 9. Areas in Mesa A Life of Mine (LoM) Pit Below Pre-mining Water Table.

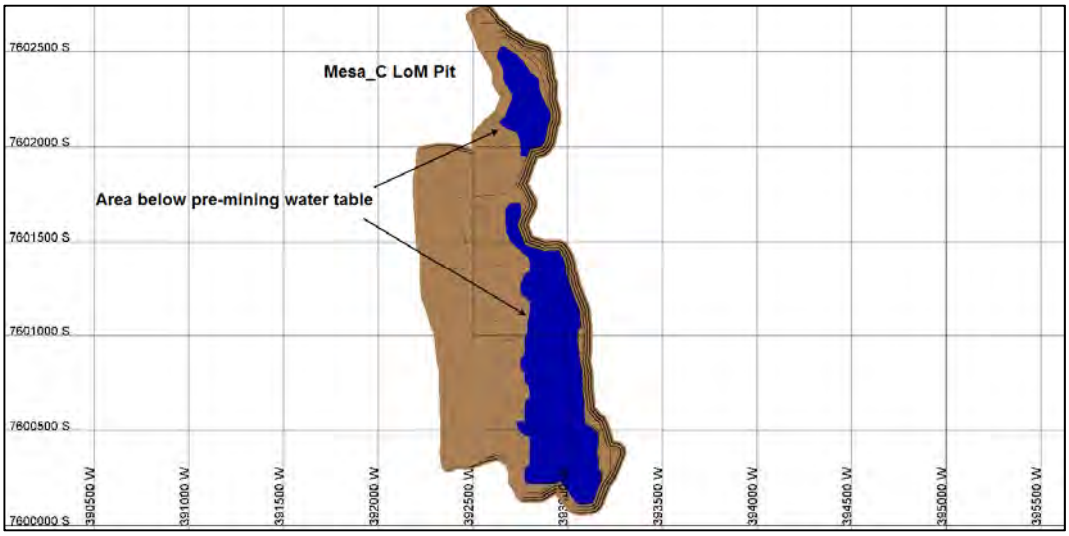


Figure 10. Areas in Mesa C Life of Mine (LoM) Pit Below Pre-mining Water Table.

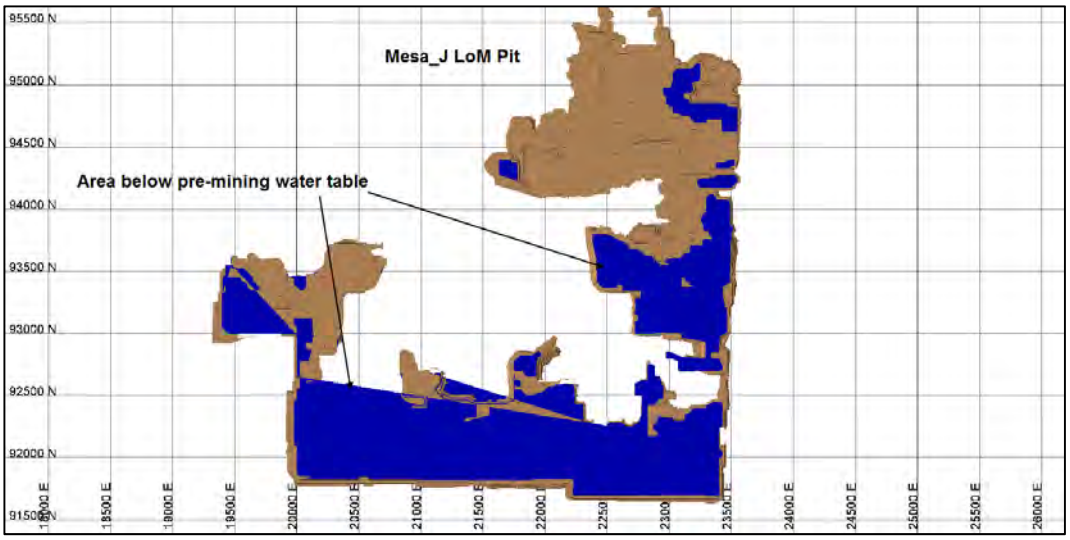


Figure 11. Areas in Mesa J Life of Mine (LoM) Pit Below Pre-mining Water Table.

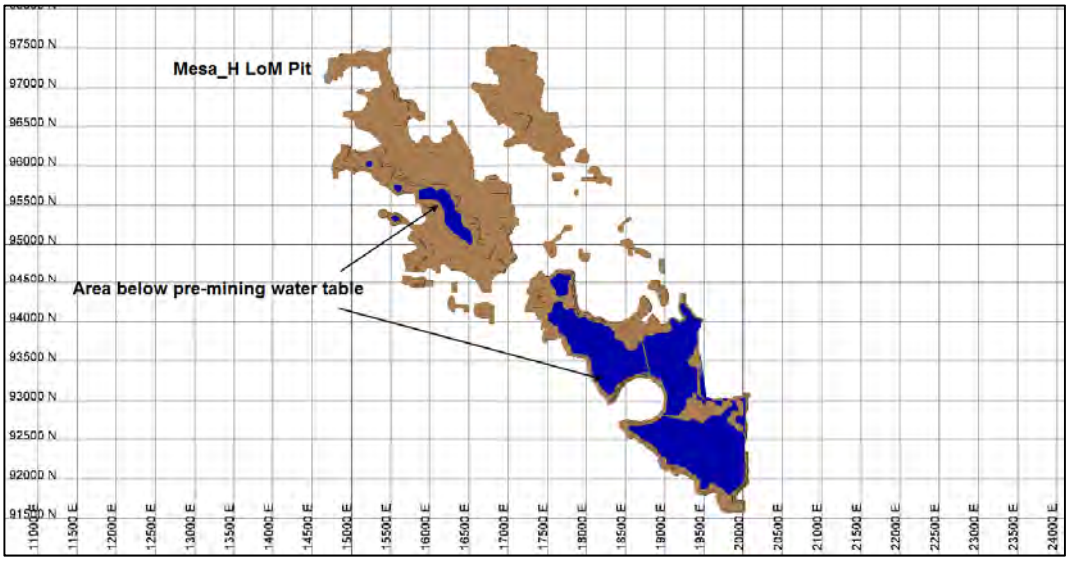


Figure 12. Areas in Mesa H Life of Mine (LoM) Pit Below Pre-mining Water Table

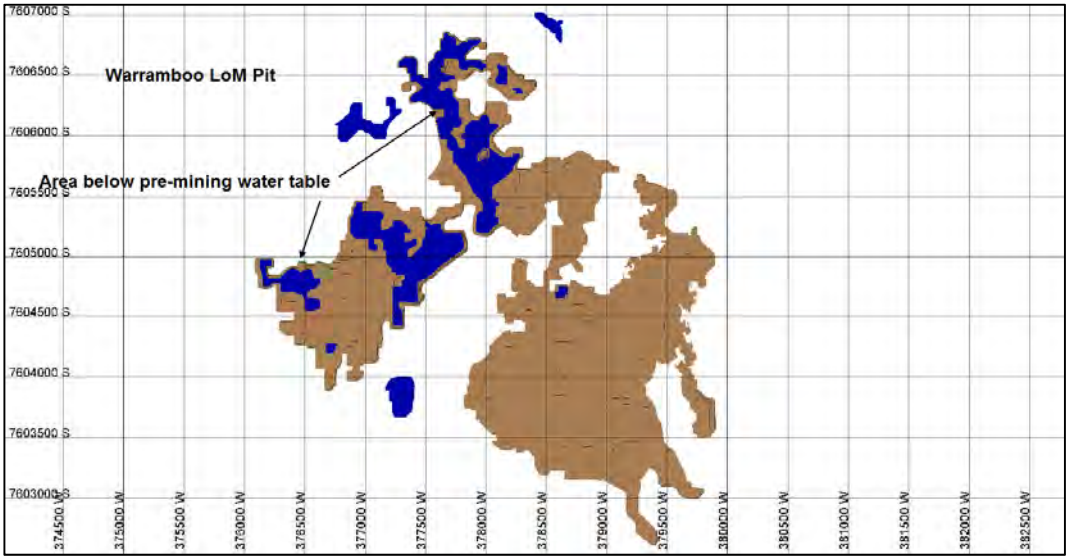


Figure 13. Areas in Warramboo Life of Mine (LoM) Pit Below Pre-mining Water Table

4 Geotechnical Field Investigation

The geotechnical site investigations have been undertaken at Robe Valley since 1999, Table 2 summarises all the completed geotechnical drilling to date and the drill hole locations are plotted in Figure 14, Figure 16, Figure 24, Figure 25 and Figure 26.

Table 2. Robe Valley Geotechnical Drilling Summary.

Year	Deposit	Drill Type	Actual Meters (m)	Number of Holes
1999	J	Diamond	129.8	3
2005	A	Diamond	182	6
2006	A	Diamond	195.5	5
2013	H	Diamond	486	10
2016	B	Diamond	230.1	4
2016	C	Diamond	749.7	10
2016	H	Diamond	900.1	12
Total			2873.2	51

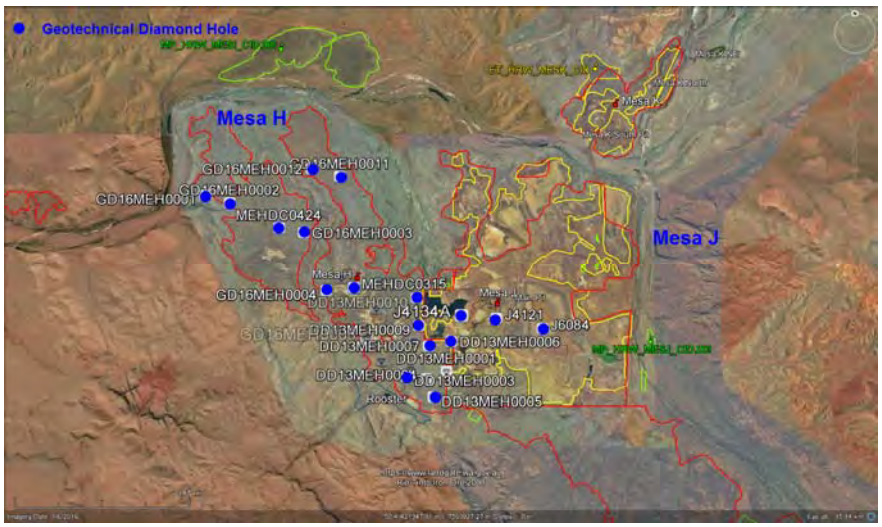


Figure 14. Historical Geotechnical Drill Holes in Mesa J and Mesa H.

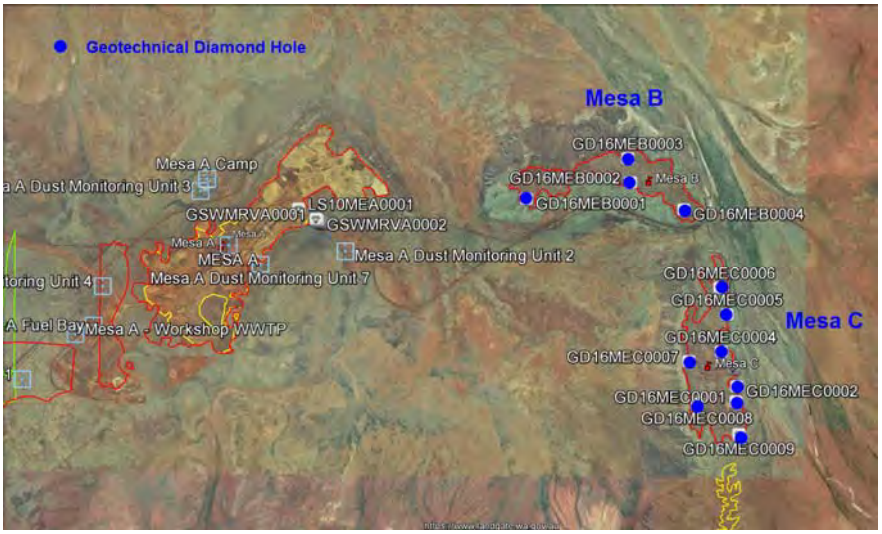


Figure 15. Historical Geotechnical Drill Holes in Mesa B.

5 Geotechnical Studies for Facades

Since 2007, several geotechnical studies were completed by Rio Tinto and external consultants, which included façade reviews. The results are summarised below.

5.1 Mesa A and Warramboo Geotechnical PFS (Snowden Mining Consulting, 2007)

Snowden undertook a review of the status of geotechnical knowledge and the proposed pit design criteria as part of the Warramboo and Mesa A pre-feasibility study (PFS) in 2007. This work was later substantiated by two programs of geotechnical investigations by PSM involving a total of 11 HQ3 diamond drill holes initially completed along the steeper and deeper sections of the proposed pit walls, and subsequently within the 50 m façade planned to be retained.

5.1.1 Site Investigation and Analysis Approach

Phase 2 of this project focused on investigating the stability of the 50 m wide façade. This program involved five vertical HQ3 diamond drill holes for a total of 195.52 m and was completed in December 2006 as shown in Figure 16.

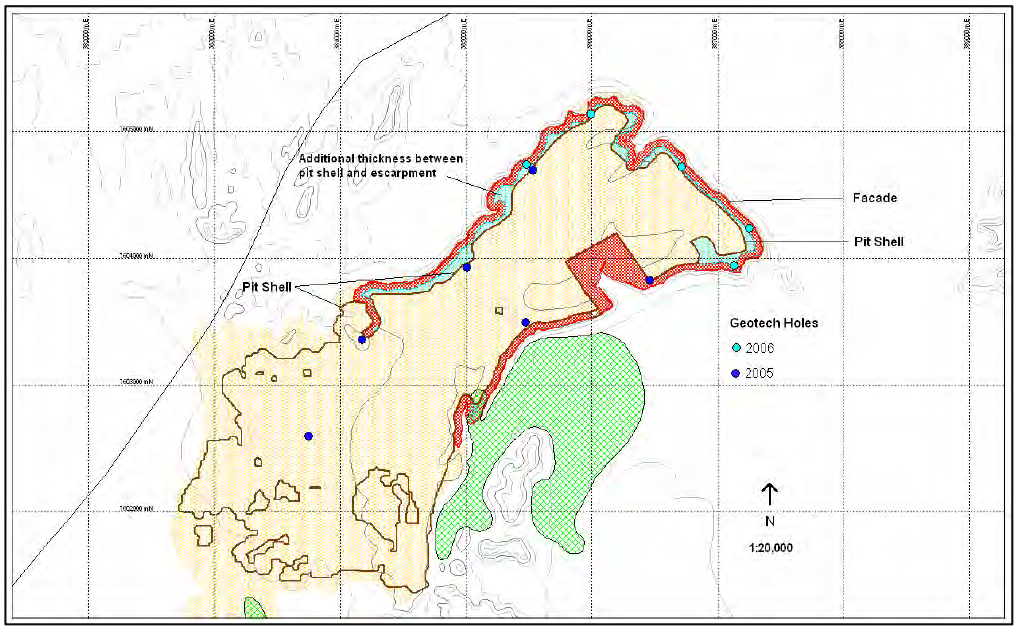


Figure 16. 2006 Snowden Façade Study Mesa A Geotechnical Drill Holes Locations.

The actual core data collection and collation was undertaken by Pells Sullivan Meynink Pty Ltd. Laboratory tests were carried out and the diamond cores were logged for geotechnical use. Snowden was engaged to undertake site visits to Mesa A, J, K and M to assess the conditions of natural and mined mesas in March 2007.

It was observed that visible blast damage typically extends 1 -2 m beyond the pit crest at Mesa J, K and M. Furthermore sections of 25-year-old remnant mesa only showed blast damage where the width of remnant façade was reduced to 15 m.

5.1.2 Results

- Mining operations adjacent to natural mesa facades have not caused large (face) scale instability of the natural slopes or escarpment at these sites;
- Visible damage from blast practices typically extends < 2m behind the slope crest; and
- Mesa A façade to have a probability of failure of 0.1%. It should be noted that none of the critical failure paths assessed involved the full 50m width of the façade.

5.2 Robe Valley Sustaining (Middle Robe, East Deepdale, Mesa B and Mesa C) Geotechnical Design Report (RTIO, 2015)

This report outlines the geotechnical slope design recommendations and mesa façade stand-off requirements associated with geotechnical risks.

5.2.1 Site Investigation and Analysis Approach

There was no specific geotechnical information, either measured or logged, for the Mesa B, Mesa C, East Deepdale or Middle Robe deposits and therefore for this study, geotechnical parameters were inferred from CID units found at Mesa A by Snowden in 2007.

To account for geological uncertainty and provide robust slope configurations, the entire slope was modelled using TPB/TPM strength parameters as a base case. A series of typical sections as shown from Figure 17 to Figure 20 were selected from Middle Robe, Deepdale, Mesa B and Mesa C for the 2D slope stability analysis.

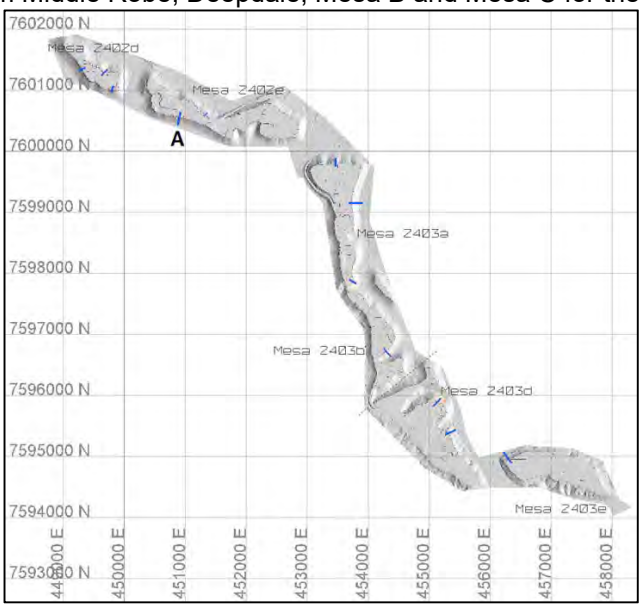


Figure 17. 2015 RTIO Robe Valley Pre-Feasibility Study (PFS) Middle Robe Section lines.

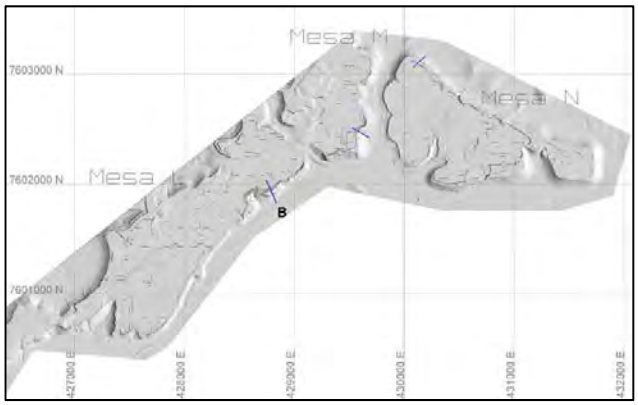


Figure 18. 2015 RTIO Robe Valley Pre-Feasibility (PFS) East Deepdale Section lines.

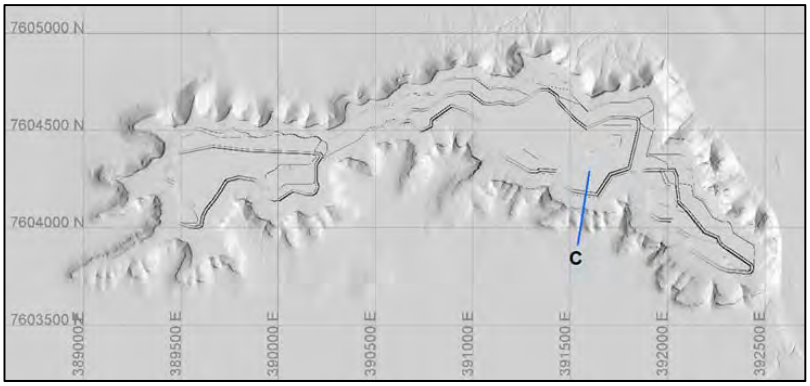


Figure 19. 2015 RTIO Robe Valley Pre-Feasibility Study (PFS) Mesa B Section lines.

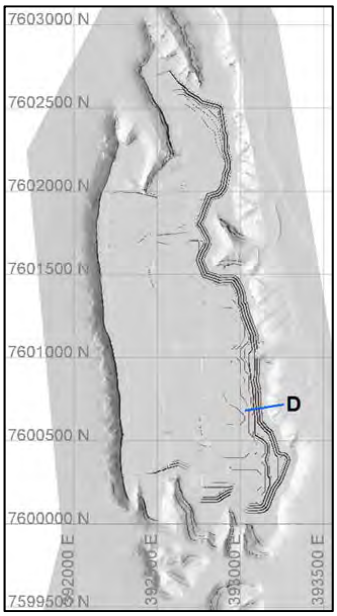


Figure 20. 2015 RTIO Robe Valley Pre-Feasibility Study (PFS) Mesa C Section lines.

5.2.2 Results

The façade stand-off distance recommendations were calculated based on the risk associated with different slope heights as outlined in Table 3.

Table 3. 2015 RTIO Robe Valley Slope Design Recommendations and Corresponding Minimum Mesa Facade Stand-Off Distance.

Deposit	Maximum Slope Height	Strand	Maximum IRA (°)	Maximum BFA (°)	Minimum Berm Width (m)	Max Bench Height (m)	Minimum Mesa Façade Stand-off (m)
Middle Robe / East Deepdale / Mesa B & C	20m high, AWT	HTP/ TPB/ TPM/ TPH/ TP	56	75	8	20	15
	40m high, AWT		56	75	8	20	20
East Deepdale	50m high, AWT		56	75	8	20	26
Mesa C	70m high, 13m BTW		52	75	10	20	35

5.3 Mesa H Pit crest/Façade Stand-off Distance Geotechnical Recommendations Update (RTIO, 2016)

A geotechnical assessment was undertaken in 2016 by Rio Tinto to review façade stand-off requirements.

5.3.1 Site Investigation and Analysis Approach

Review of the existing geotechnical data together with updated geological modelling and drilling data across the Robe Valley was undertaken and was analysed taking into consideration the distance to the 1.5 FOS failure surface in order to refine the stand-off distance from the pit crest to the mesa façade crests.

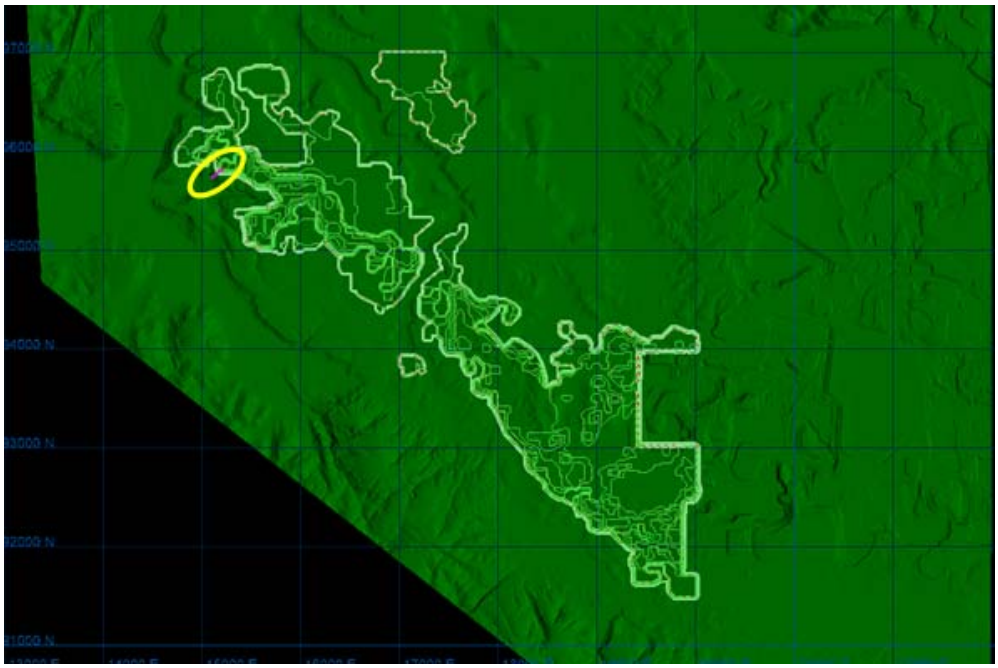


Figure 21. 2016 RTIO Mesa H Analysis Section.

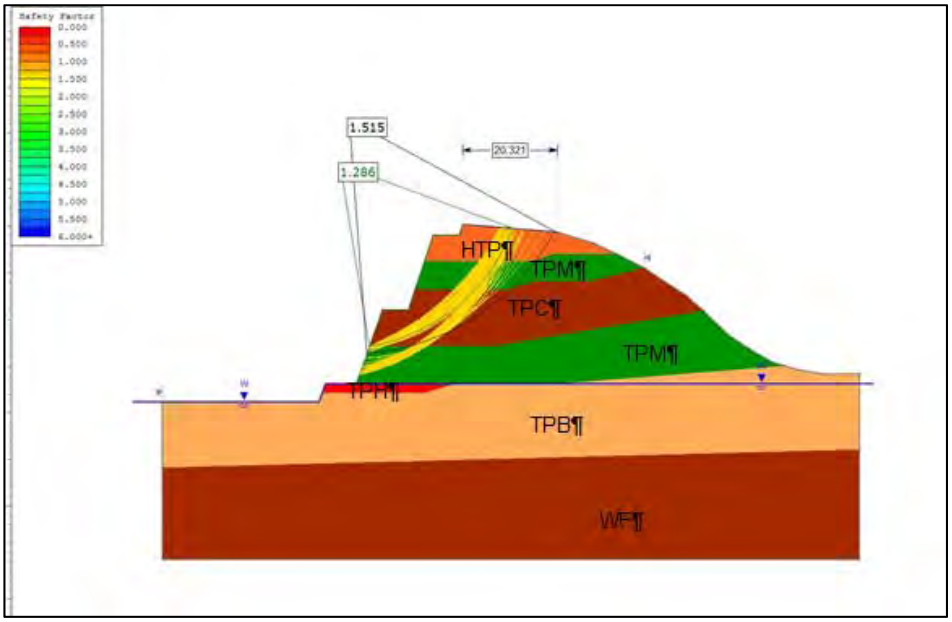


Figure 22. 2016 Mesa H Section Stability with 20m Stand-Off Distance on Pit Side (FoS=1.5).

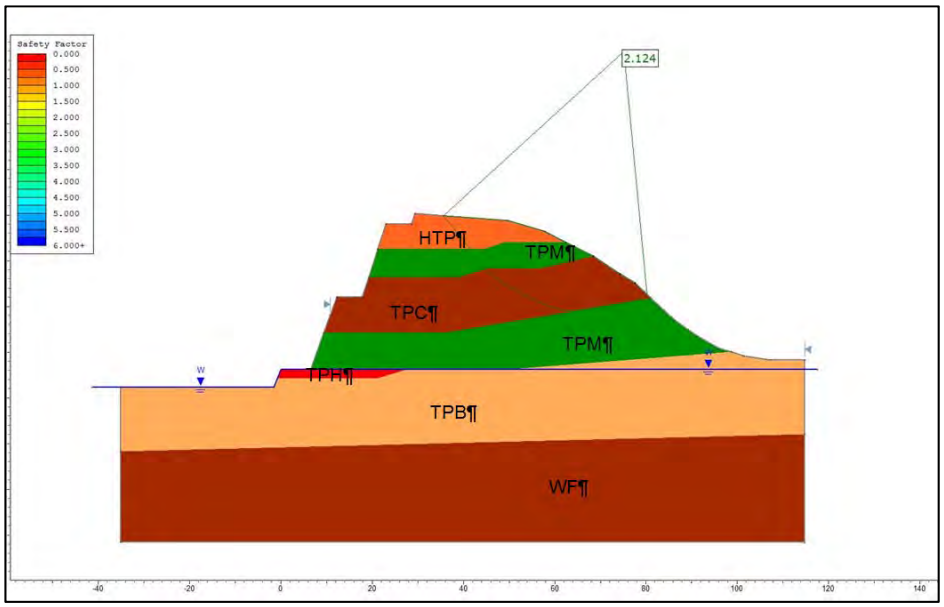


Figure 23. 2016 Mesa H Section Stability with 20m Stand-Off Distance on Façade Side (FoS>1.5).

5.3.2 Results

It was found that the FoS for the façade is below 1.5 using a 20m stand-off distance and above 1.5 with 30m stand-off distance. It was recommended that a minimum 30m stand-off is required between the Mesa H pit crest and façade crest.

5.4 Robe Valley mesa B, C and H Pits Geotechnical Feasibility Study, (3rd Rock Consulting, 2017)

3rd Rock Consulting (3RC) was commissioned to carry out a Life of Mine (LoM) geotechnical feasibility level design for Mesas B, C and H deposits.

5.4.1 Site Investigation and Analysis Approach

A total of 2690m of core were drilled and logged over seven drilling campaigns since 1999 with 1880m drilled in 2016 as shown in Figure 24, Figure 25 and Figure 26. A total of 435 geotechnical laboratory tests have been undertaken on core samples in the same period.

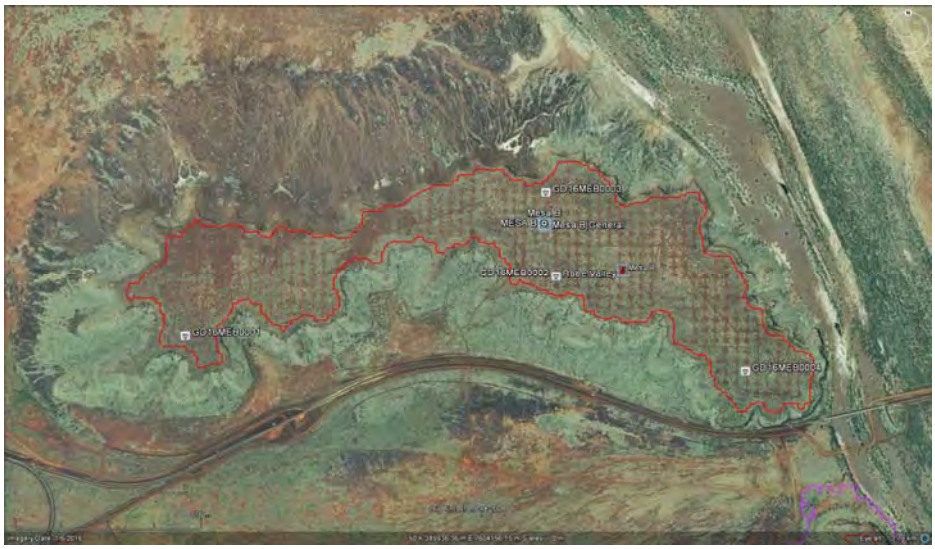


Figure 24. 2016 Mesa B Geotechnical Drill Hole Locations.

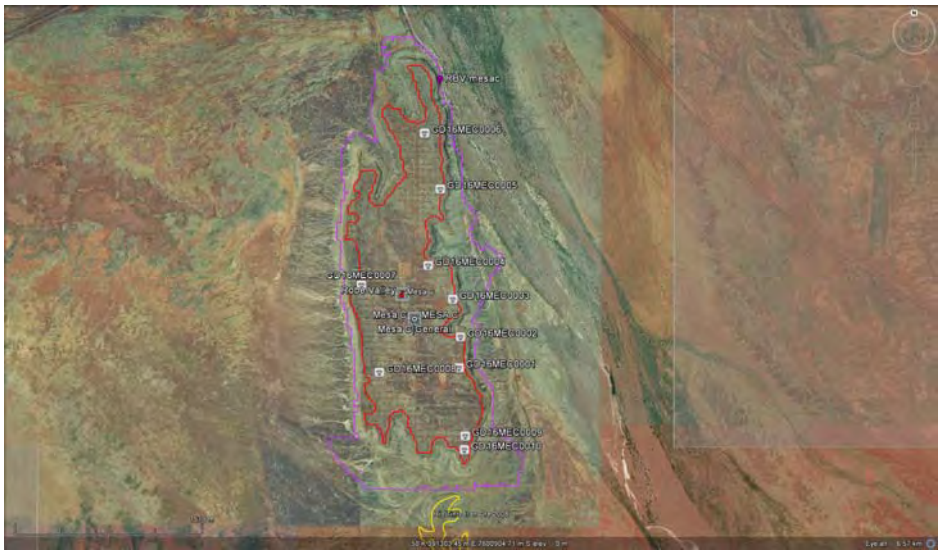


Figure 25. 2016 Mesa C Geotechnical Drill Hole Locations.

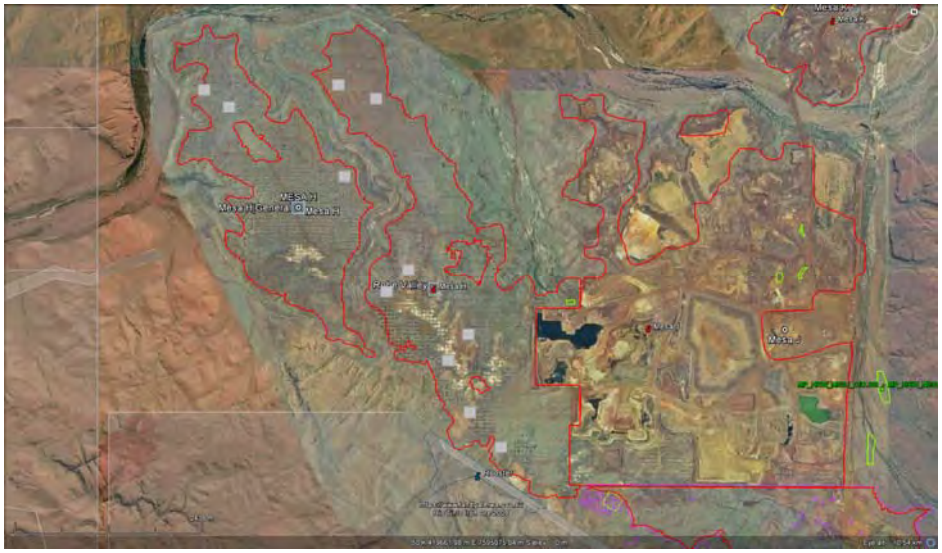


Figure 26. 2016 Mesa H Geotechnical Drill Hole Locations.

5.4.2 Results

3rd Rock developed material shear strengths which derived for both best-estimate and reduced (Lower Quartile) shear strengths for limit equilibrium stability analysis to meet Rio Tinto geotechnical Design Acceptance Criteria (DAC).

The SLIDE modelling results shown that the Factor of Safety meets the geotechnical DAC for both the estimated and lower quartile rock mass strength. The result also shows that the Factor of Safety of the façade is greater than 1.5 even with lower quartile rock mass strength and 30m stand-off distance as shown in Figure 27.

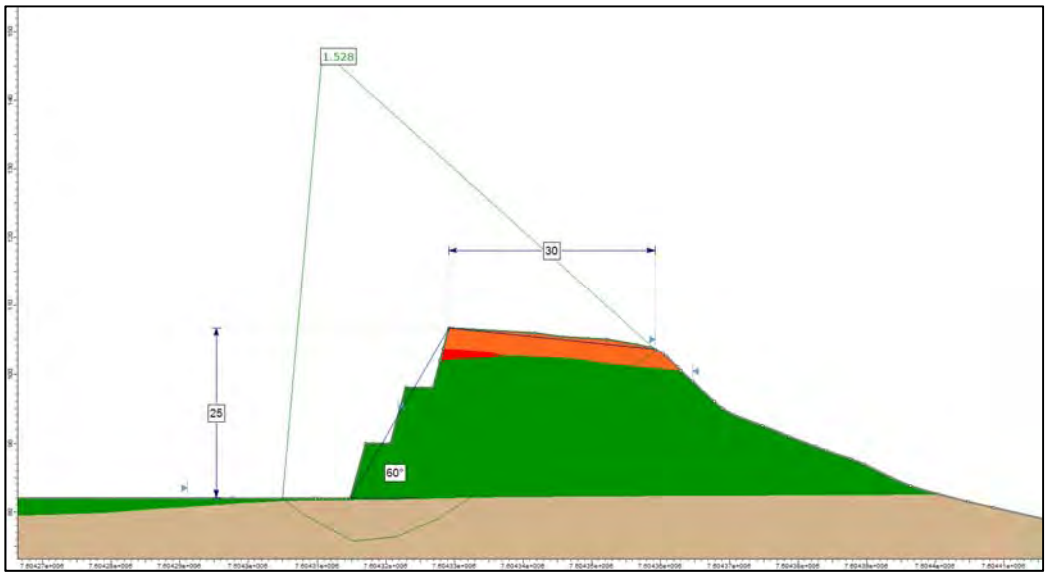


Figure 27. 2017 3rd Rock RV Study Mesa B Section A Facade Factor of Safety =1.53 with Lower Quartile Strength 30m from façade.

3rd Rock concluded:

- The slope stability results for Rio Tinto's designs for all three Mesas show that the Factor of Safety (FoS) for all sections are greater than Rio Tinto's Design Acceptance Criteria; in most cases significantly greater. This is because the final pit slopes are shallow and will perform well in competent cemented material; and
- The slopes were optimised in order to increase the overall slope angles and to reduce the façade width (that is the distance between the crest of the pit and that of the mesa's natural slope) to a minimum of 30m.

It has been implicitly assumed that best practise blasting methods will be used in order to minimise disturbance to the façade rock mass.

5.5 Robe Valley Operational Geotechnical Function Independent Review (Xstract, 2017)

Xstract Mining Consultants (Xstract) undertook an independent Operational Geotechnical review of the Mesa A and Mesa J mining areas at Robe Valley Operations in March 2017.

5.5.1 Site Investigation and Analysis Approach

This review mostly focused on the performance of the current slope, compliance to D3 standards by performing a desktop review, a site visit and discussion with key personnel.

5.5.2 Results

It was determined to be important to consider the likely depth of blast disturbance into the perimeter rock mass, behind the mined batters, which is generally taken as one to two mining bench heights but can be greater depending on the blasting methods used. Further, the impact of the blast disturbance on façade stability will be increased where the outer slope of the mesa forms a steep slope, forming a more slender perimeter "Pillar" as shown in Figure 28.

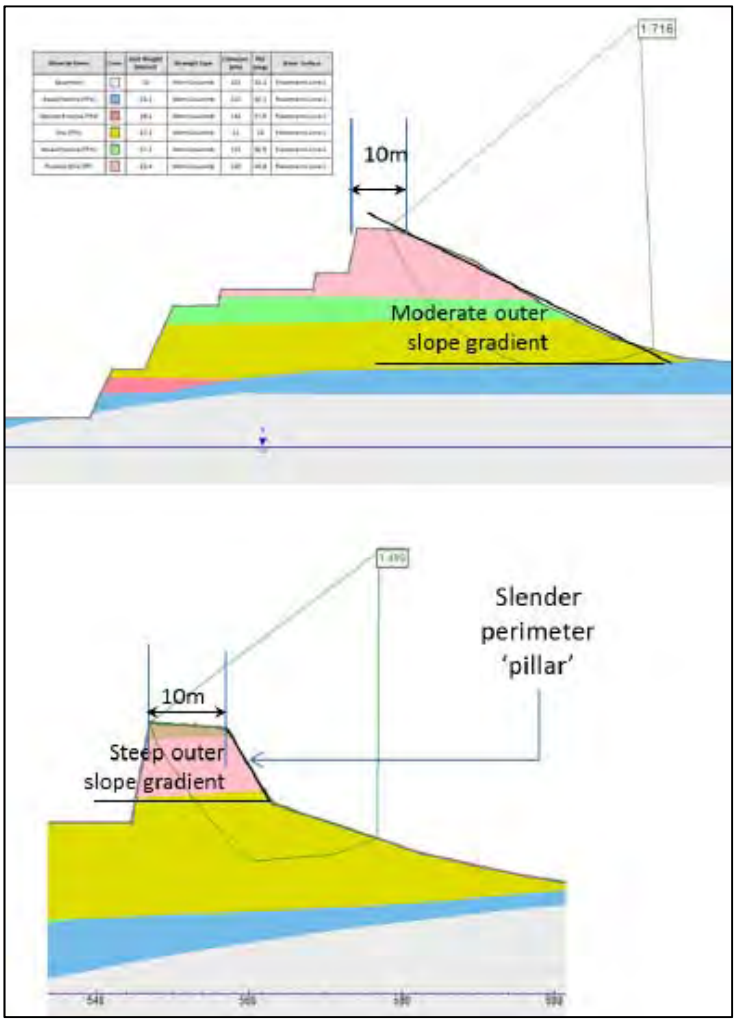


Figure 28. Example of Facade geometry in RTIO 2015 "Mesa B and C Façade Slope Stability Analysis for Closure" Report.

The long term stability of the mesa façade will be controlled, in part, by the level of blast damage and relaxation undergone by the perimeter material. Xstract recommended a minimum stand-off distance of 20m (i.e. approximately twice the standard mining bench height) be employed where the outer slope of the mesa is relatively steep (i.e. a 'slender' perimeter pillar may be formed).

6 Current Wall Performance

Current Mesa deposits wall performance was also evaluated to assist in deciding the minimum stand-off distance. The wall performance was evaluated in two ways:

- By reviewing wall condition utilizing UAV fly-over images (March, 2017) and
- By reviewing the prism monitoring data.

6.1 Wall Conditions

In Robe Valley, Mesa A, Mesa J and Warramboo are currently in an operational stage. Other deposits are currently under assessment. As there is no façade in Warramboo, only the current as-built slopes in Mesa A and Mesa J were reviewed. The existing walls have minimum stand-off distance of 50m as shown in Figure 29 and Figure 32.

In order to check geotechnical assumptions (design parameters) applied to the façade modelling, the installed prisms movements have been reviewed. The intent was to correlate the wall performance to the geotechnical parameters assuming the geotechnical parameters are not overly conservative.

The as-built wall conditions for Mesa A and Mesa J are shown in Figure 30, Figure 31, Figure 33 and Figure 34. Compared with Mesa J slope, the top benches in Mesa A demonstrated better performance. It was estimated that better wall performance in Mesa A contributed by more competent material intersected in the wall (HTP, TP TPM, and TPB). Mesa J has softer material (Alluvium and Colluvium) on the top benches. However, there were no indications that this condition has any impact on the façade.

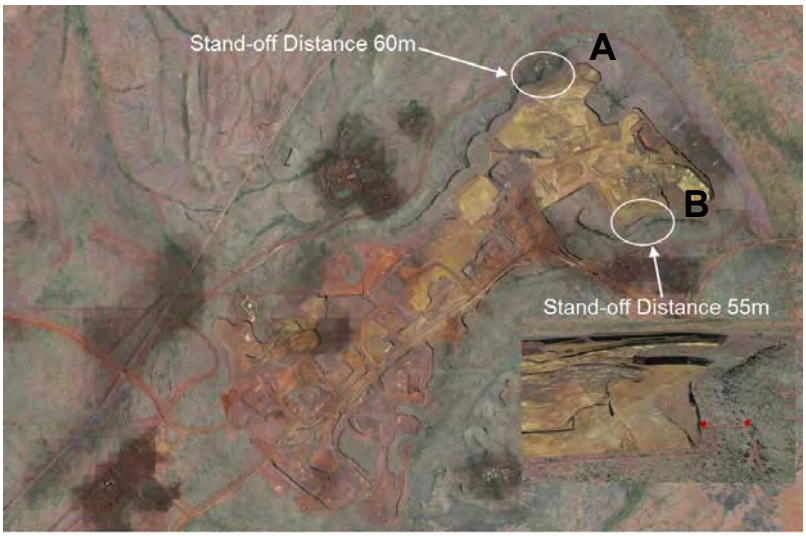


Figure 29. Mesa A As-Built Stand-Off Distance

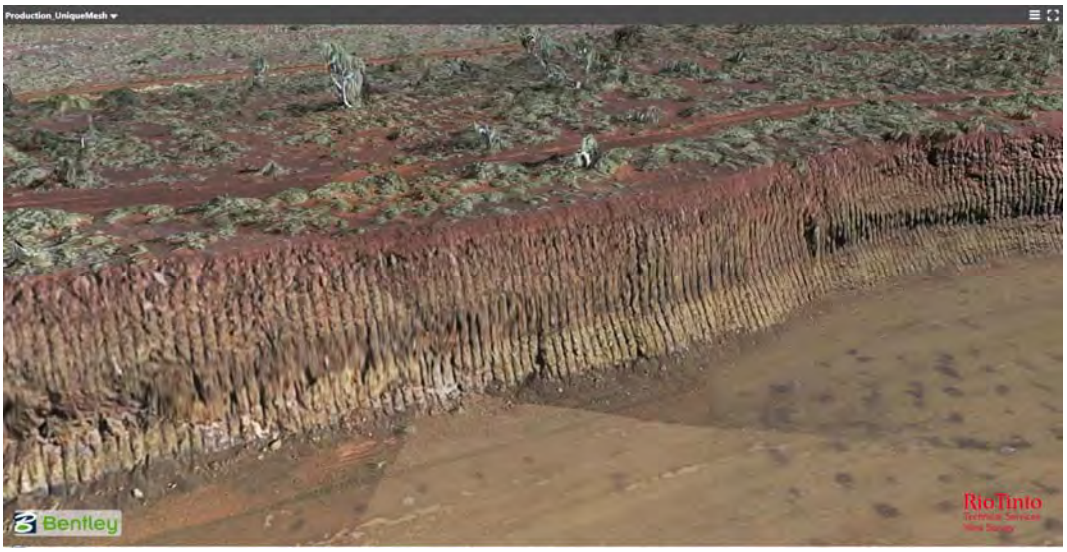


Figure 30. Mesa A Area A Wall Conditions.

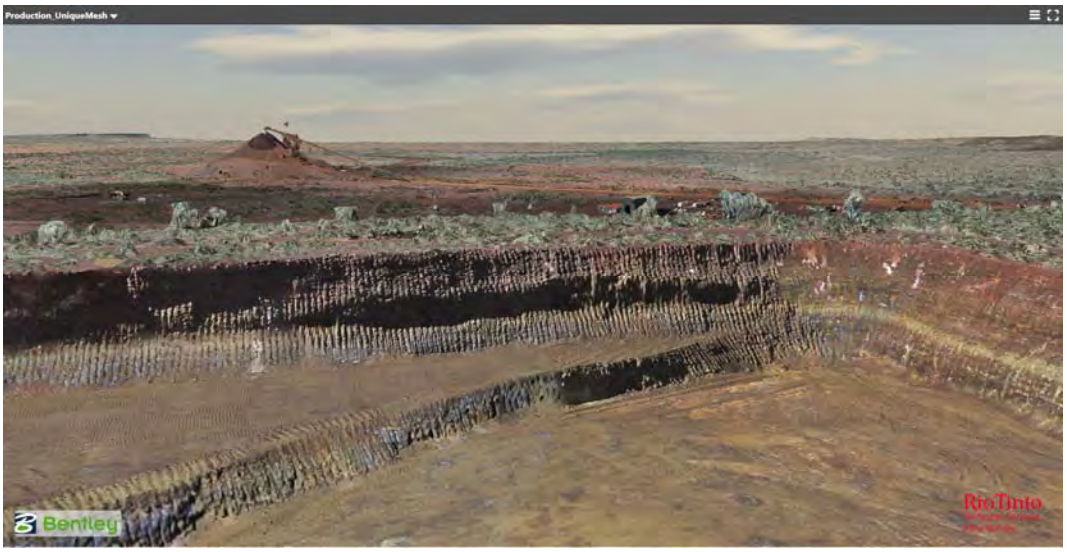


Figure 31.Mesa A Area B Wall Conditions.

Figure 32. Mesa J As Built Stand-Off Distance.

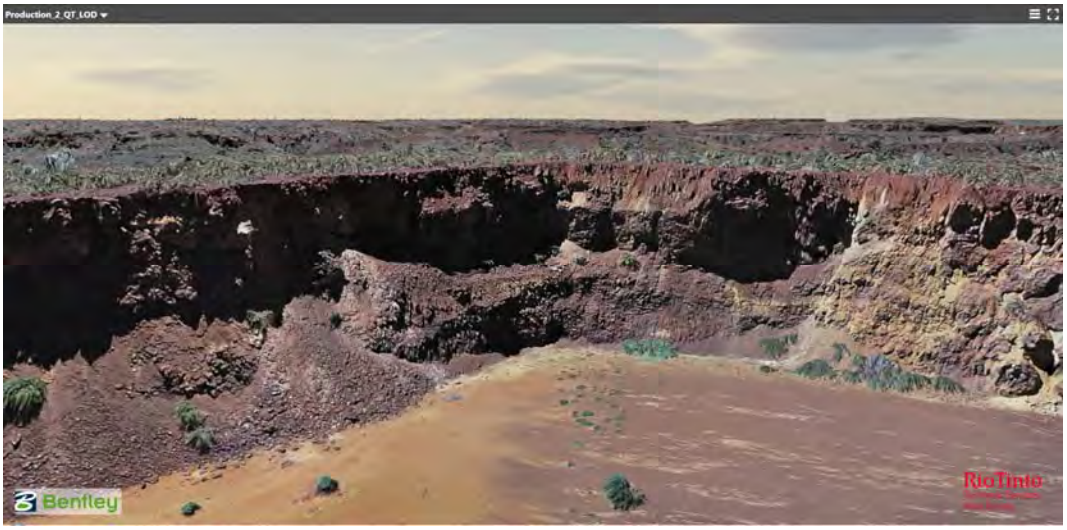


Figure 33.Mesa J Area A Wall Conditions.

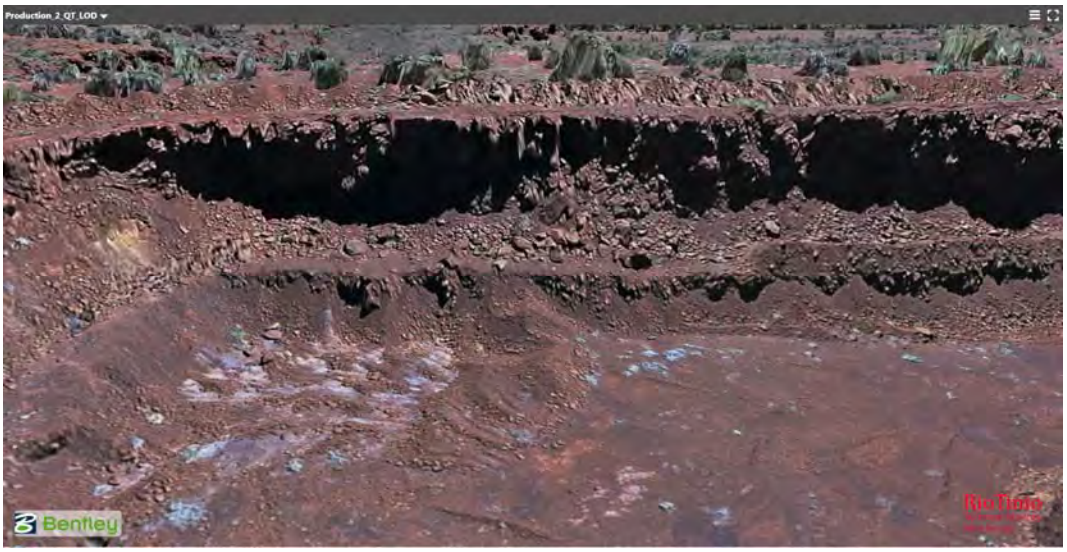


Figure 34.Mesa J Area B Wall Conditions.

6.2 Prism Monitoring Data

Based on the geotechnical risk assessment, prisms have been installed in several areas in Mesa A and Mesa J to monitor the wall performance. The prisms are monitored manually on a fortnightly basis.

The prisms 3D movements were used to analyse the current as-built wall stability.

6.2.1 Mesa A Prisms

Eight prisms were installed on the cut slopes crest close to the façade in Mesa A Breach area (5 on the North wall and 3 on the South wall) as shown in Figure 35. A cross section of the slopes with the geological setting is shown in Figure 36. The wall in this area intersected HTP, TPH, TPM and TPB with 25m slope height. The Inter Ramp Angle (IRA) is 30 degrees in the north wall and 48 degrees in the south wall. Both are still below the maximum IRA recommended by Snowden in the 2007 report.

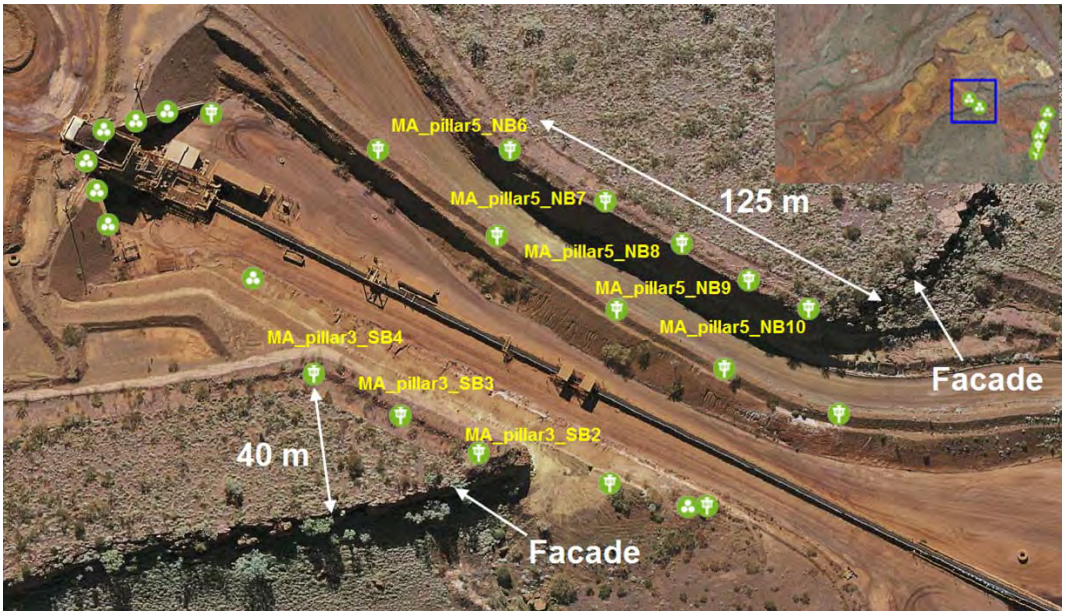


Figure 35. Prisms location in Mesa A Breach Area.

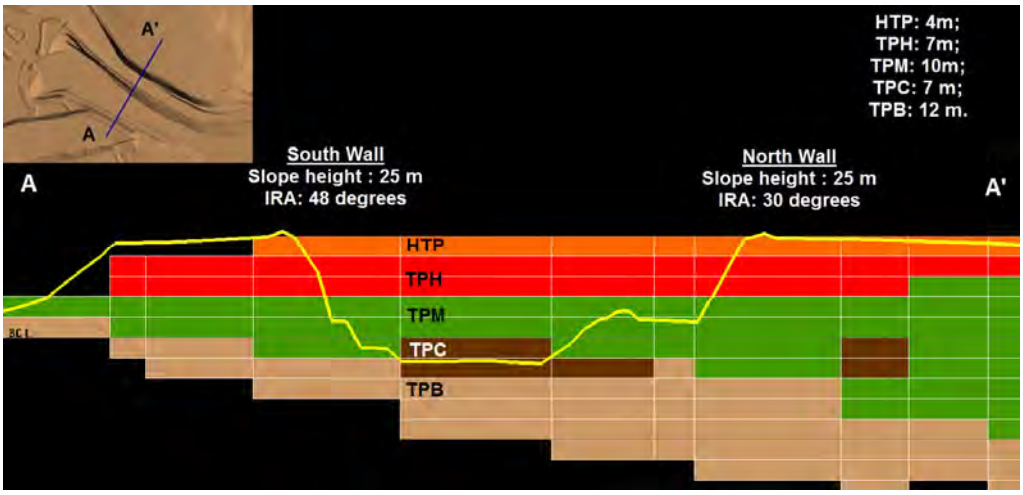


Figure 36. Mesa A Pit Cross Section where Prisms were installed.

The expected movement direction in the north wall prisms (NB6 toNB10) was south/south-west and north/north-east for the south wall prisms (SB2 to SB4). The prisms movements between May 2016 and April 2017 are summarized in Table 4.

Table 4. Mesa A Breach Area prisms movements summary

Deposit	Prism Name	3D Movement (mm/month)	Actual Movement direction	Expected movement direction	Note
Mesa A	SB2	-0.35	S-E	S / S-E / N / N-E / N-W	
Mesa A	SB3	-0.067	S-E	N-E / N / N-W	Invalid movement direction
Mesa A	SB4	0.00	N-E	N-E / N / N-W	
Mesa A	NB6	0.1	N	S / S-E / S-W	Invalid movement direction
Mesa A	NB7	0.00	N-W	S / S-E / S-W	Invalid movement direction
Mesa A	NB8	0.00	NA	S / S-E / S-W	
Mesa A	NB9	0.00	N-E	S / S-E / S-W	Invalid movement direction
Mesa A	NB10	0.00	N	S / S-E / S-W	Invalid movement direction

The recorded prism movement rates were minor. Five out of eight prisms movements also indicated invalid movement directions (moving towards the wall), possibly impacted by errors in the readings. Therefore, it was concluded that there was no apparent movement trend observed.
Mesa A prisms movement charts were included in Appendix A.

6.2.2 Mesa J Prisms

In order to check geotechnical assumptions (design parameters) applied to the façade modelling, the installed prisms movements have been reviewed. The intent is to correlate the wall performance to the geotechnical parameters assuming the geotechnical parameters are not overly conservative.

There is a Tailings Storage Facility (TSF4) behind the east wall of Pit 8 in Mesa J. The distance between the pit crest and the toe of TSF4 is around 25m. In total there are 17 prisms installed on the wall; 145mRL (prisms #17 and #18), 155mRL (prisms #10 to #16) and 161mRL (prisms 1 to 9) and monitored since February 2017 to monitor the impact of TSF4 to the pit 8 stability. The prisms locations are shown in Figure 37 and the as-built wall conditions are shown in Figure 38.

There is no façade near or might be impacted in this area. Monitoring results of this area is included to demonstrate stability of wall with worse conditions compared to most of the pit wall with façade in vicinity.

Prisms #1 to #9 are located in the tailing embankment to monitor the tailing slope stability. Therefore they were not included for analysing the slope stability. Only the prisms on the Pit 8 slope (#10 to 18) were investigated.

Figure 37. Mesa J TSF4 Prisms Locations.

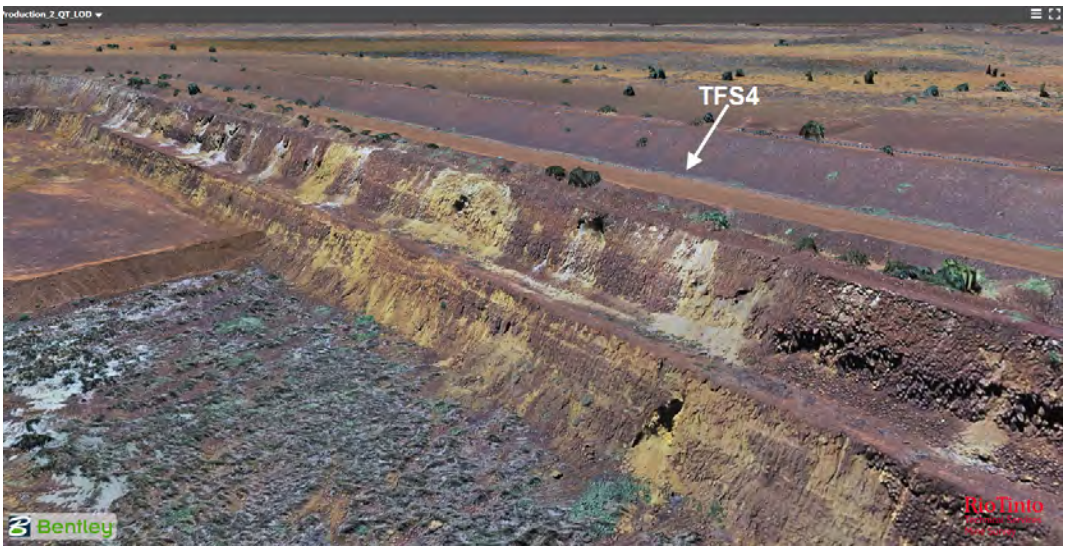


Figure 38. Mesa J Slope Under TFS4 Wall Conditions.

The slope intersected HTP (2m) and TPM (20m). The slope height is 25m with IRA 40 degrees as shown in Figure 39 which is lower than the maximum IRA recommended by 3rd Rock in their 2017 Mesa B, C and H FS report for similar material.

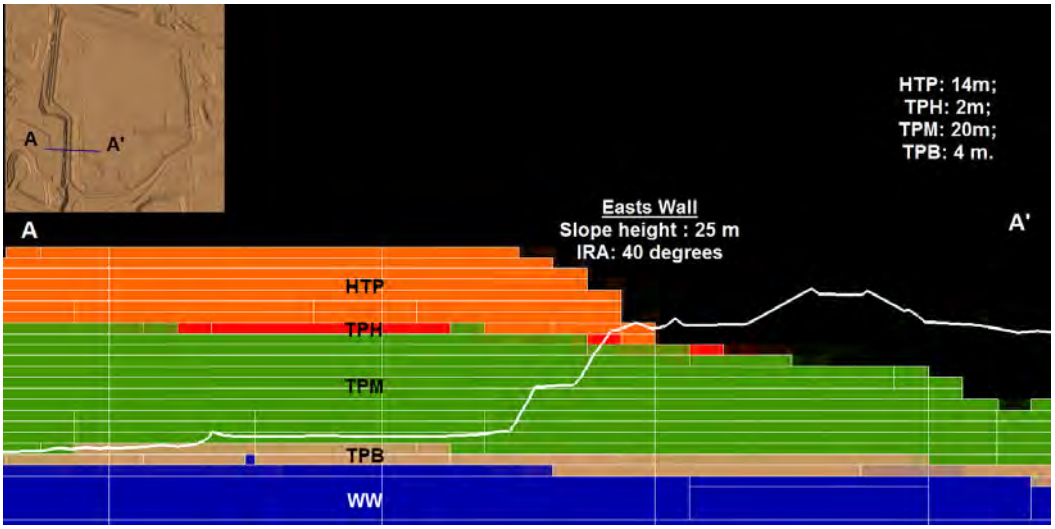


Figure 39. Mesa J South West Dump Cross Section Geology Setting.

Table 5.Mesa J TSF4 Area Prisms Movements Summary

Deposit	Prism Name	3D Movement (mm/month)	Actual movement direction	Expected movement direction	Note
Mesa J	10	1.40	S-E	W / N-W / N-E	Invalid movement direction
Mesa J	11	1.10	S-E	W / N-W / N-E	Invalid movement direction
Mesa J	12	0.00	N-E	W / N-W / N-E	No movement
Mesa J	13	1.10	S-E	W / N-W / N-E	Invalid movement direction
Mesa J	14	0.90	S-E	W / N-W / N-E	Invalid movement direction
Mesa J	15	1.20	S-E	W / N-W / N-E	Invalid movement direction
Mesa J	16	2.4	S-E	W / N-W / N-E	Invalid movement direction
Mesa J	17	1.80	S-E	W / N-W / N-E	Invalid movement direction

The recorded prism movement rates were minor with most of them showing invalid movement direction (moving towards the wall) Therefore, it can be concluded that there was no apparent trend of movement observed.
The Mesa J Pit 8 TFS4 prisms movement charts were included in Appendix A.

7 Façade Stability in Closure Stage

Stability of the mesa facades post closure had not been considered in historical Robe Valley Closure studies. There is a risk that the facade stability may be impacted if the water table returns to pre-mining levels. This risk must have been considered as part of the closure study.

7.1 Robe Valley Closure Plan

Closure studies have been completed for the Mesa A Hub (including Warramboo, Mesa A, B & C) and the Mesa J Hub (including Mesa J, K & H) by RTIO in 2017. The surface water, ground water and back fill plan are the factors which can affect the façade stability; therefore these parameters were reviewed in this report.

7.1.1 Surface Water

Flood modelling has been undertaken for the Robe Valley deposits as mentioned in Section 3.1. Mesa A and Mesa J hub deposits are not subject to riverine flooding from the Robe River. Waste Dumps currently proposed for a breakout flood area between Mesa A and Mesa B located in an area subject to infrequent and shallow flow. Flow velocities are less than 2 m/s and not expected to result in erosion of landforms (RTIO, 2017).

7.1.2 Ground Water

During mining, there will be a total of four deposits which will have the deepest part of their pit floors under the pre-mining ground water table level including: Mesa C, Mesa H, Mesa J and Warramboo. Predicted groundwater recovery levels and the modelled time to recovery are listed in Table 6.

Table 6. Predicted Ground water Level and Approximate time for Recovery (RTIO, 2017)

Deposit	Pre-mining Water Level (mRL)	Estimated water table level at mining stage(mRL)	Estimated maximum drawdown level (mRL)	Estimated recovery level (mRL)	Time (years)
Warramboo	25-50	18	18	25-50	100
Mesa A	48-50	No change-AWT mining	NA	NA	NA
Mesa B	55-58	No change-AWT mining	NA	NA	NA
Mesa C	67-70	47	20	TBC	TBC
Mesa H	120-144	110	34	120-144	30
Mesa J	142-155	110	45	142-155	30
Mesa K	144-146	No change-AWT mining	NA	NA	NA

7.1.3 Backfill Plan

The distribution of closure domains are illustrated in Figure 40, Figure 41 and summarized in Table 7.

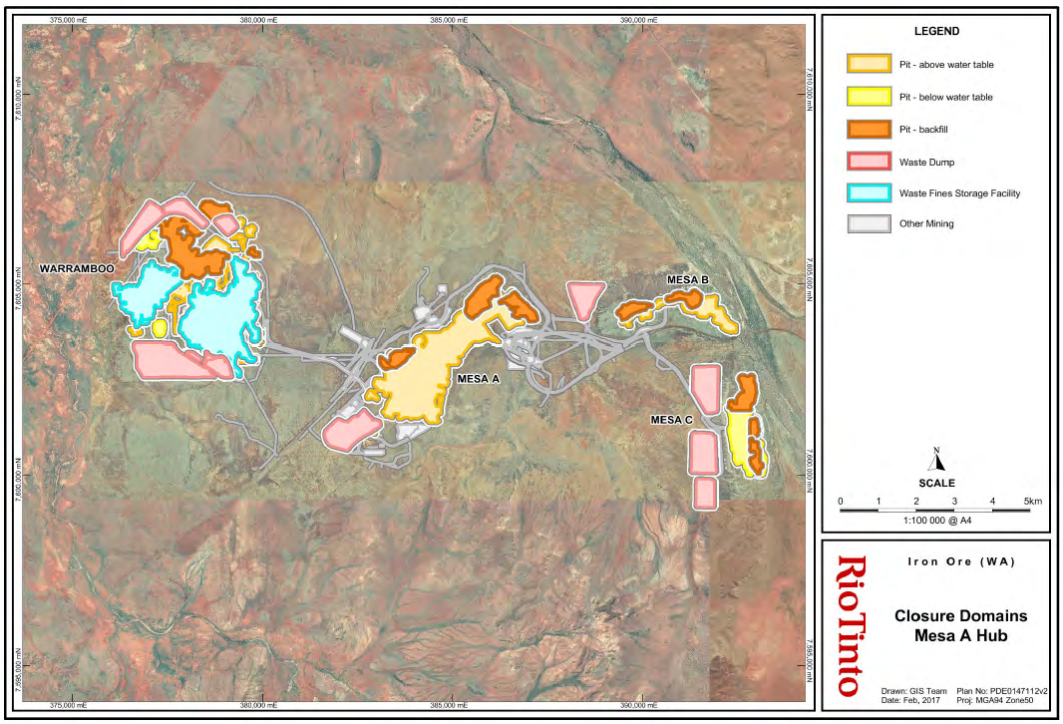


Figure 40. Robe Valley Mesa A, Mesa B, Mesa C and Warramboo Closure Domains.

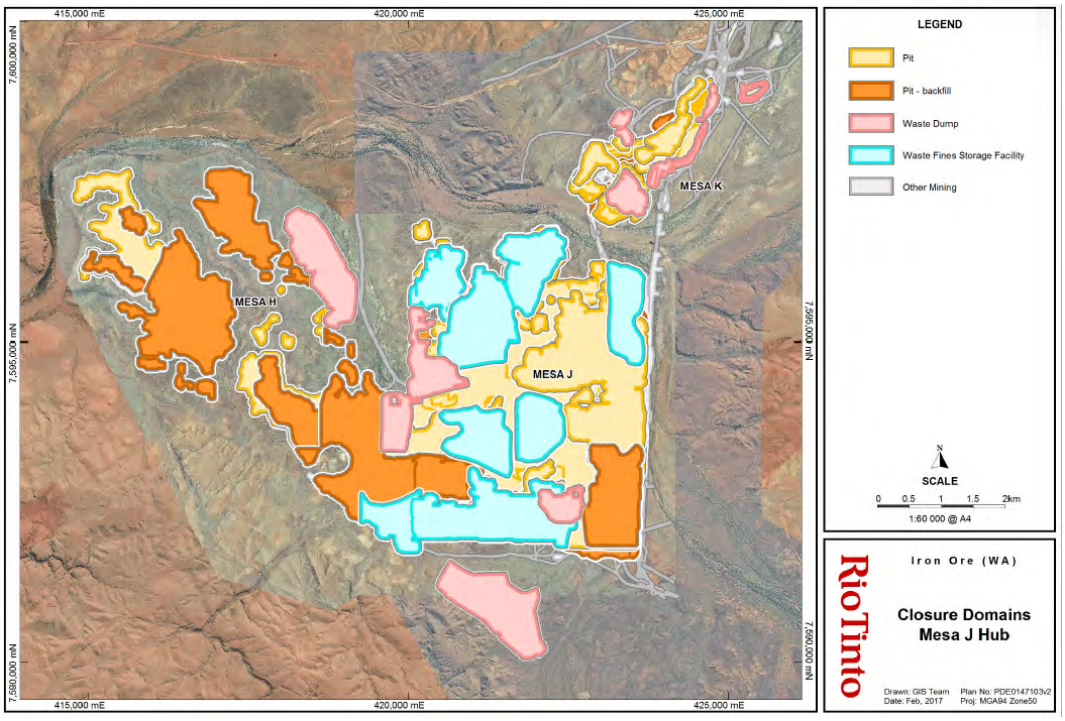


Figure 41.Robe Valley Mesa J, Mesa H and Mesa K Closure Domains

Table 7. Robe Valley Deposits Backfill Plan.

Deposits	Below/Above Water Table	Pits	Backfill Plan
Mesa J Mesa H Mesa K	AWT	Other pit except BWT pits	Pits may be partially backfilled
	BWT	Mesa H Pit 1 Mesa H Pit 3 Mesa H Pit 4 Mesa H Pit 5 Mesa H Pit 6 Mesa H Pit 7 Mesa J Pit 6 Mesa J Pit 11 Mesa J Pit 12 Mesa J Pit 15	Undertake opportunistic backfill during operations
		Mesa J Pit 15	Mesa J pit 15 will have an area partially left as a pit lake.
Mesa A Mesa B Warramboo	AWT	Other pits except BWT pits	Pits may be partially backfilled where possible to minimise the volume of waste in out of pit waste landforms
	BWT	Mesa C_pit01 Mesa C_pit02 Mesa C_pit03 Wboo_pit3	Undertake opportunistic backfill during operations

In order to assess the slope stability close the façade after ground water recovery, two sections were selected from Mesa C and Mesa H in the area where pit floors will be under the pre-mining water table as shown in Figure 42 and Figure 43. The pit floors will be 15m below pre-mining water table in section A Mesa C, and 10m below pre-mining water table in section J of Mesa H.

The closure plan has consequently prioritised these areas for backfill in the future. Additional stability analyses in these sections were intended to check the stability of the slopes prior to backfill.

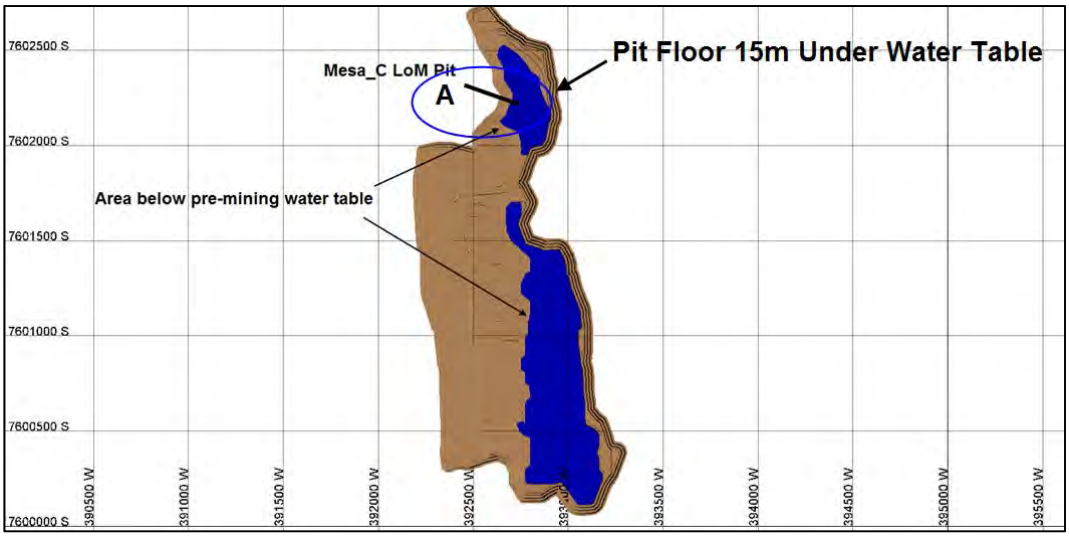


Figure 42. Closure Slope Stability Geotechnical Section in Mesa C.

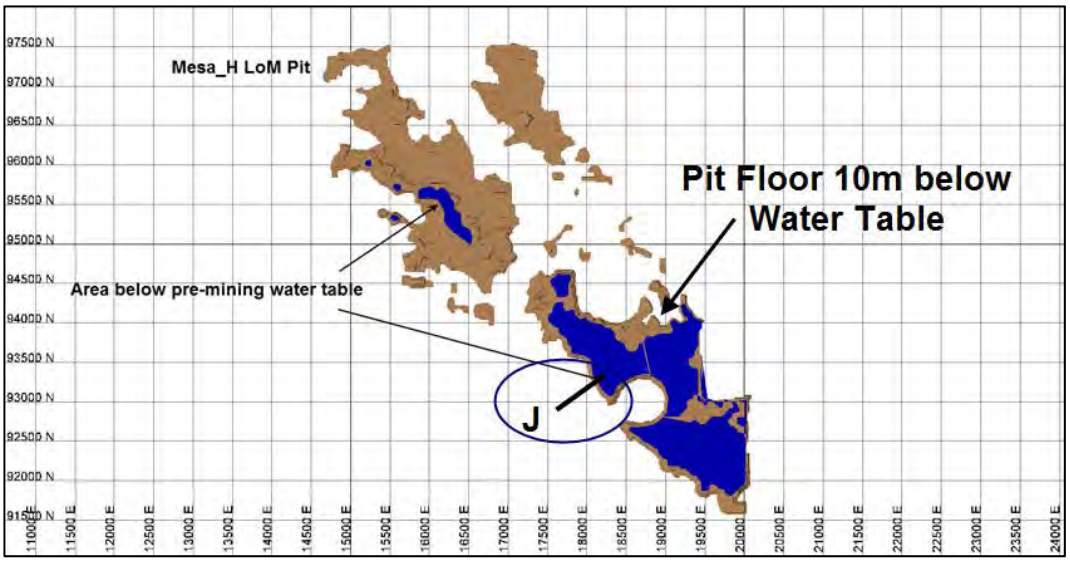


Figure 43.Closure Slope Stability Geotechnical Section in Mesa H.

The SLIDE models for the two sections used the rock mass parameters from 2017 3rd Rock study, and the pre-mining water table levels (69mRL in Mesa A and 135mRL in Mesa H). The results were plotted in Figure 44 and Figure 45.

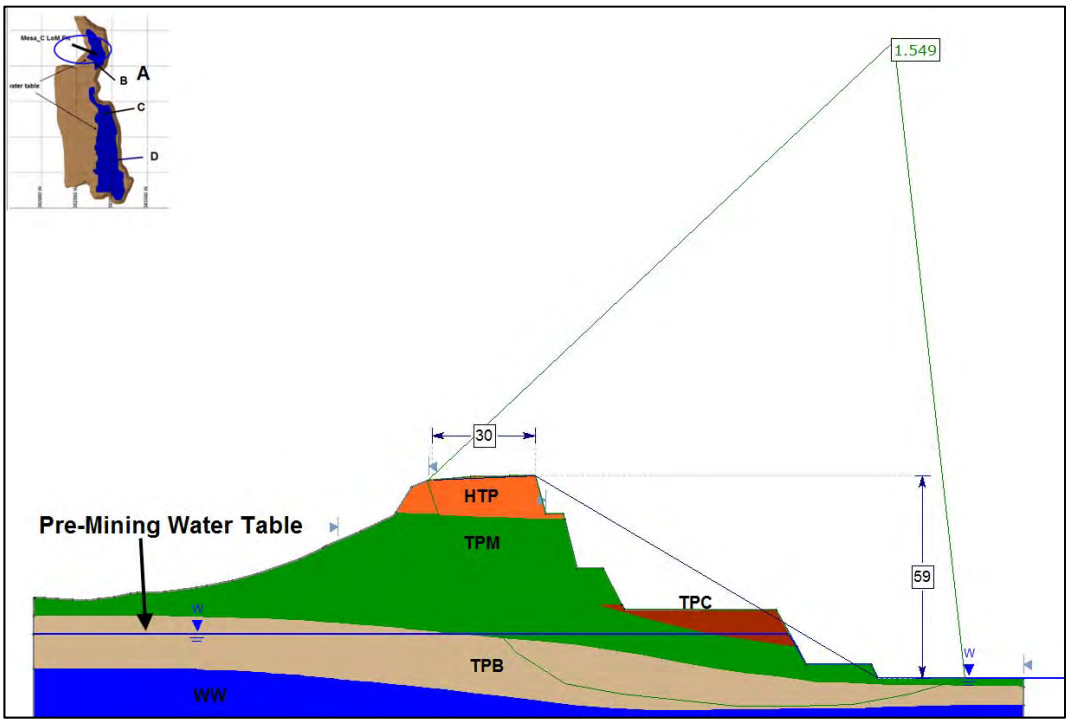


Figure 44. Section A Mesa C Slope Stability after Closure (FoS>1.5).

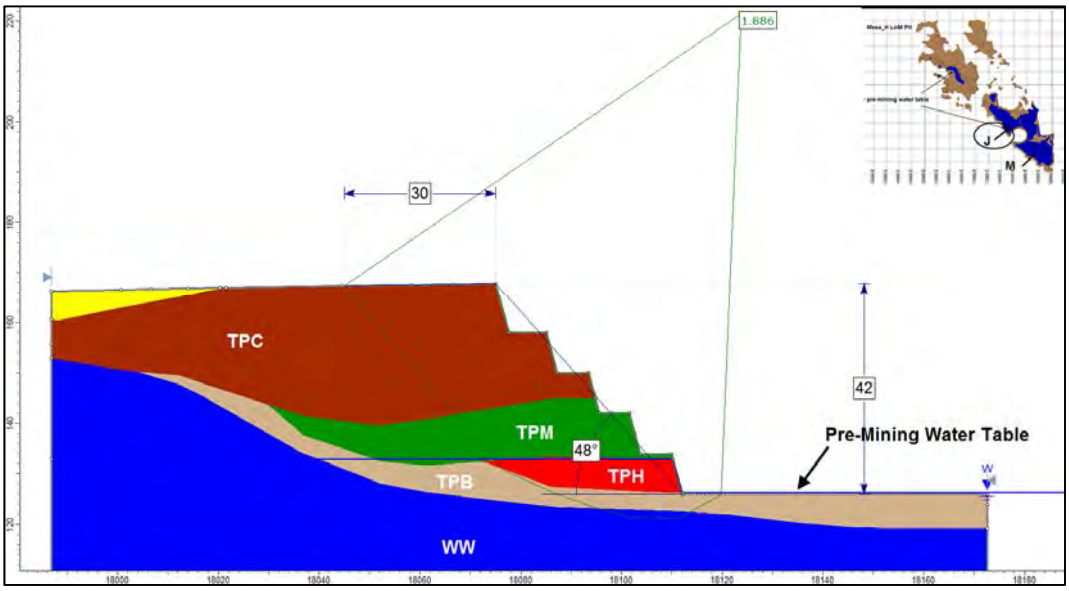


Figure 45.Section J Mesa H Slope Stability after Closure (FoS>1.5).

Both models show that the FoS in area within 30m from the pit crest were higher than Rio Tinto Design Acceptance Criteria (>1.5). Backfilling proposed in the closure plan will increase the wall stability. Therefore, it is concluded that a minimum 30m façade is considered as adequate from a stability perspective and to protect the identified environmental and heritage values.

8 Conclusions

The historical recommendations for the Robe Valley façade stand-off distances are summarized in Table 8.

Table 8. Recommendations for Facade Stand-Off Distance

Robe Valley Façade Stand-Off Distance Recommendation					
Report	**Completed by**	**Year**	**Geotechnical Drilling (m)**	**Number of used holes**	**Minimum Stand-Off Distance (m)**
Mesa A and Warramboo Geotechnical Review	Snowden	2007	507	14	50
Robe Valley Sustaining PFS Geotechnical Design Report	RTIO	2015	NA		15
Mesa H Pit crest/Façade Stand-off Distance Update	RTIO	2016	NA		30
Robe Valley Operational Geotechnical Function Independent Review	Xstract	2017	NA		20
Robe Valley mesa B, C and H Pits Geotechnical Feasibility Study	3rd Rock	2017	2873.2	51	30

Note. Snowden assessed stability for 50m stand-off distance but did not examine smaller distances (less than 50m).

Based on work undertaken in previous studies, and updated information available from new studies including: current wall performance and wall monitoring (with current prism monitoring data at Mesa A); additional drilling data; updated geological models; recent blasting data; and additional laboratory testing (including consideration of the lower quartile rock strength) have contributed to refining a minimum stable stand-off distance to protect the façade during mining operations and into closure.

From the work and studies undertaken to date, it is concluded that a minimum of 30m stand-off distance from the façade to the pit crest is adequate for maintaining the long term stability and integrity of the façade.

Sincerely,

Xuzheng Gao
Geotechnical Engineer
Mine Engineering Geotechnical, OKP

9 Reference:

1. Snowden, 2007. Mesa A/Warramboo Feasibility Study,< RTIO-PDE-0036381>

2. RTIO, 2007. Mesa K Pre-Feasibility Study, <Q:\Resource Planning\Geotechnical\01_Projects\11_Robe_Valley\07_Mesa K\8. Reports>

3. RTIO, 2016. Mesa H Pit crest/Façade Stand-off Distance Geotechnical Recommendations Update, <RTIO-PDE-0131352>

4. RTIO, 2015. Robe Valley Sustaining PFS (Middle Robe, East Deepdale, Mesa B and Mesa C) Geotechnical Design Report, <Q:\Resource Planning\Geotechnical\01_Projects\11_Robe_Valley\00_Robe Valley General\2. Reports\2015_RV_Sustaining_PFS\01_Report>

5. RTIO, 2015, Mesa B and C façade slope stability analyses,< RTIO-PDE-0131352>

6. RTIO, 2016. Mesa H Pit crest/Façade Stand-off Distance Geotechnical Recommendations Update, <Q:\Resource Planning\Geotechnical\01_Projects\11_Robe_Valley\15_Mesa H\8. Reports>

7. 3RD Rock Consulting, 2017. Robe Valley, Mesa B, C and H Pits Geotechnical Feasibility Study, <RTIO-PDE-0154264>

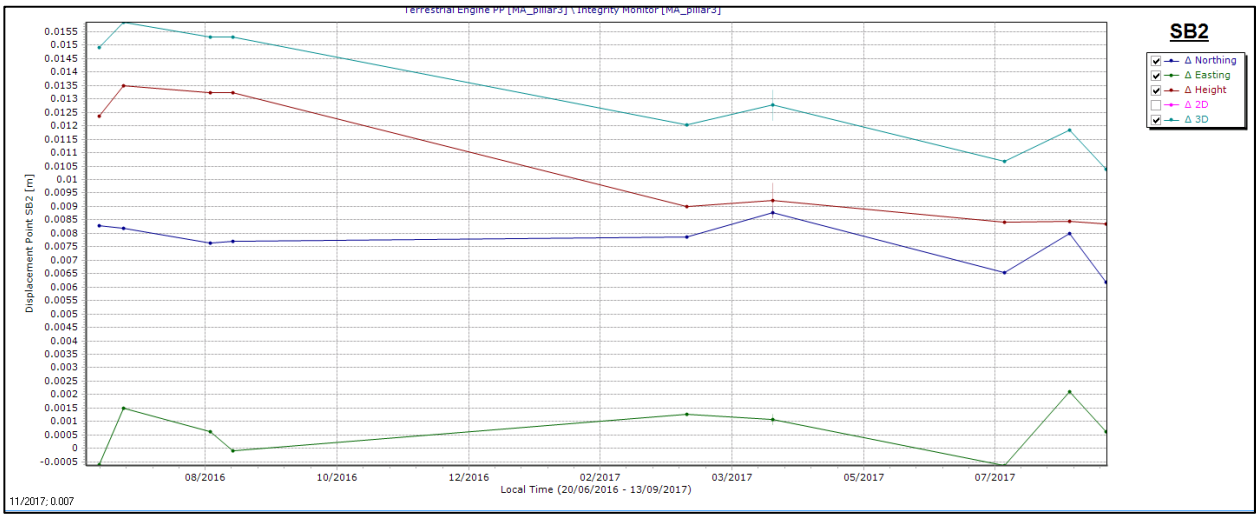
8. Xstract, 2017, Robe Valley Operational Geotechnical Function Independent Review, <RTIO-HSE-0304656>

9. RTIO, 2017, Mesa A Hub Closure Plan, <RTIO-HSE-0307626>

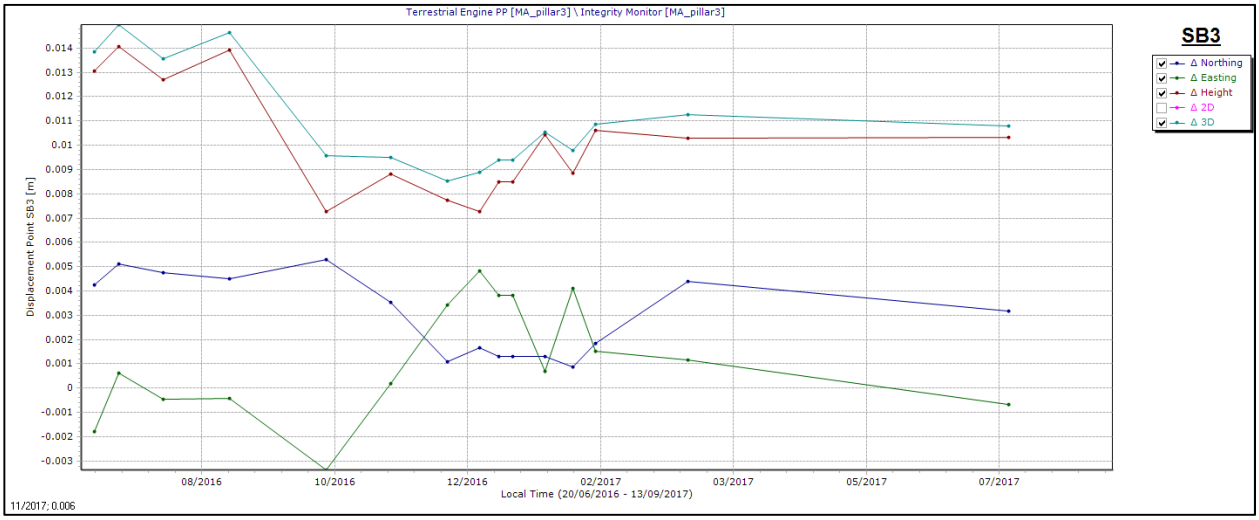
10. RTIO, 2017, Mesa J Hub Closure Plan, <RTIO-HSE-0168839 >

Appendix A – Prisms Displacement Monitoring Charts (Northing, Easting and 2D) vs Time

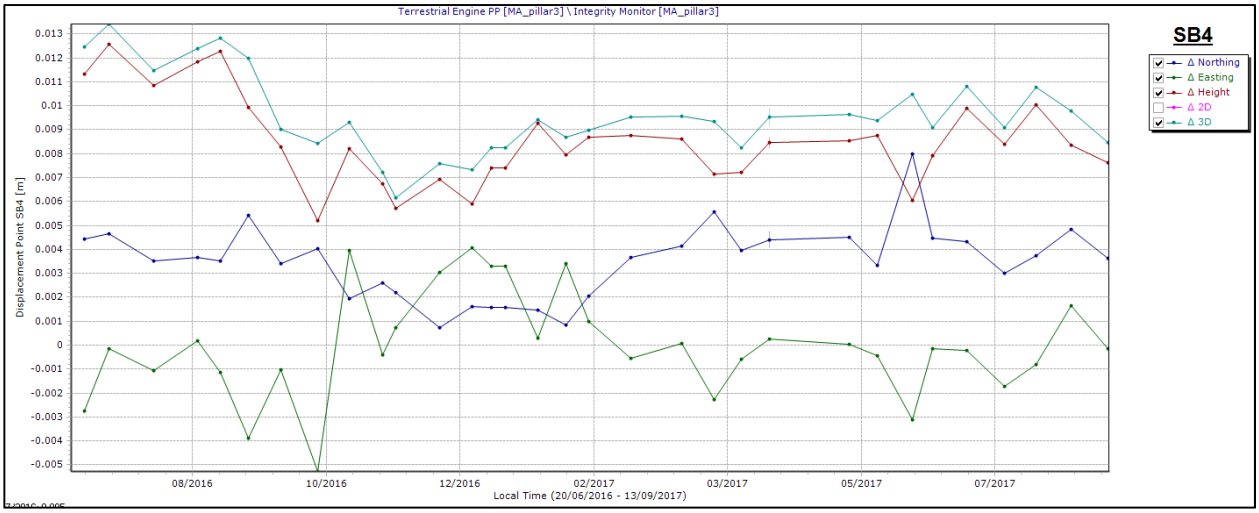
Mesa A Prisms (Breach Area)



Mesa A Prism SB2



Mesa A Prism SB3



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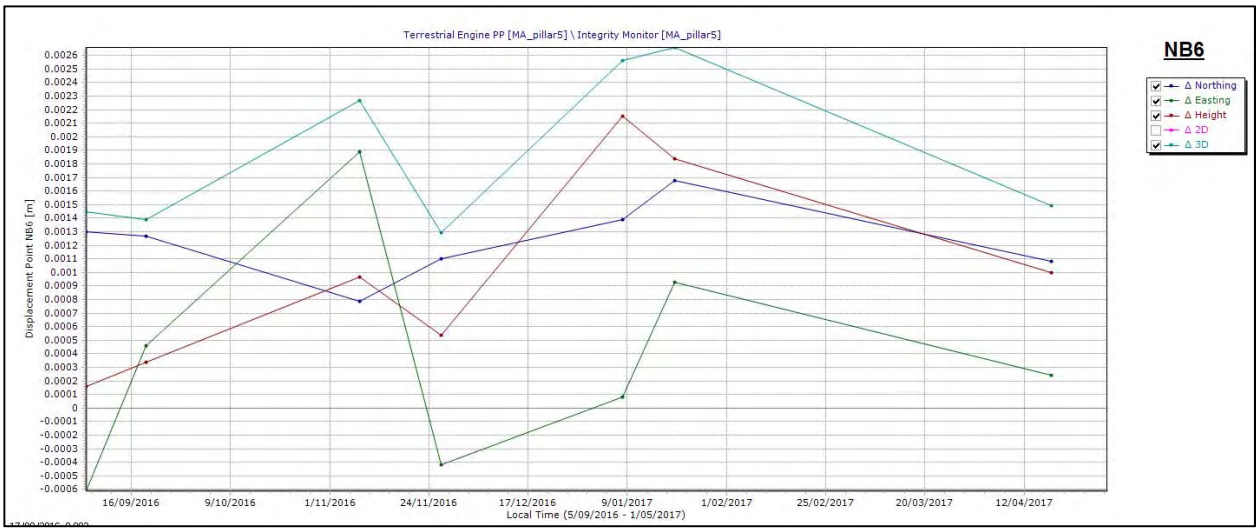
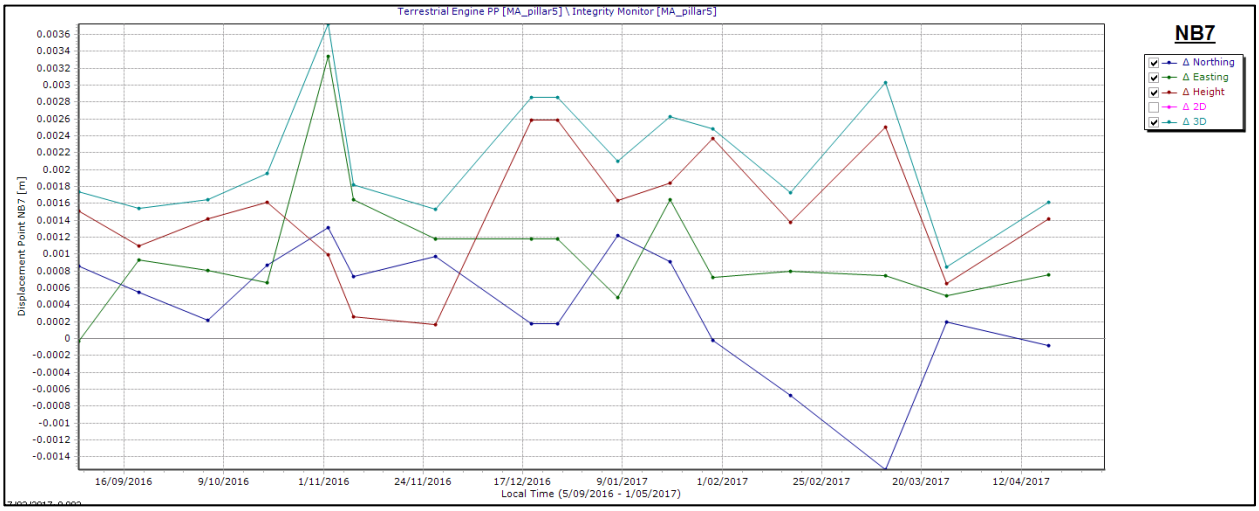


Mesa A Prism NB6



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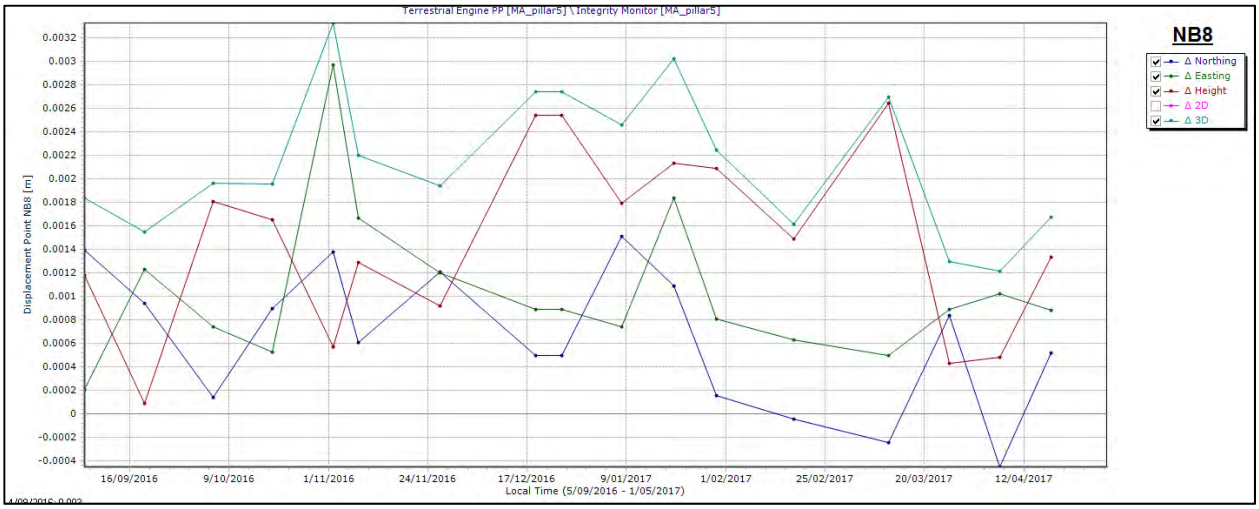

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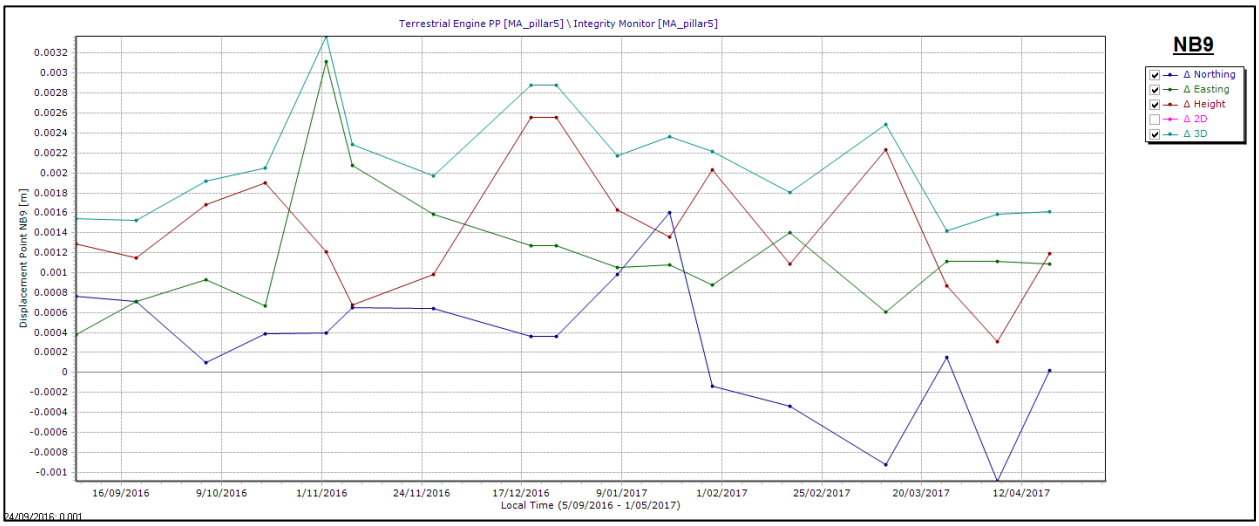
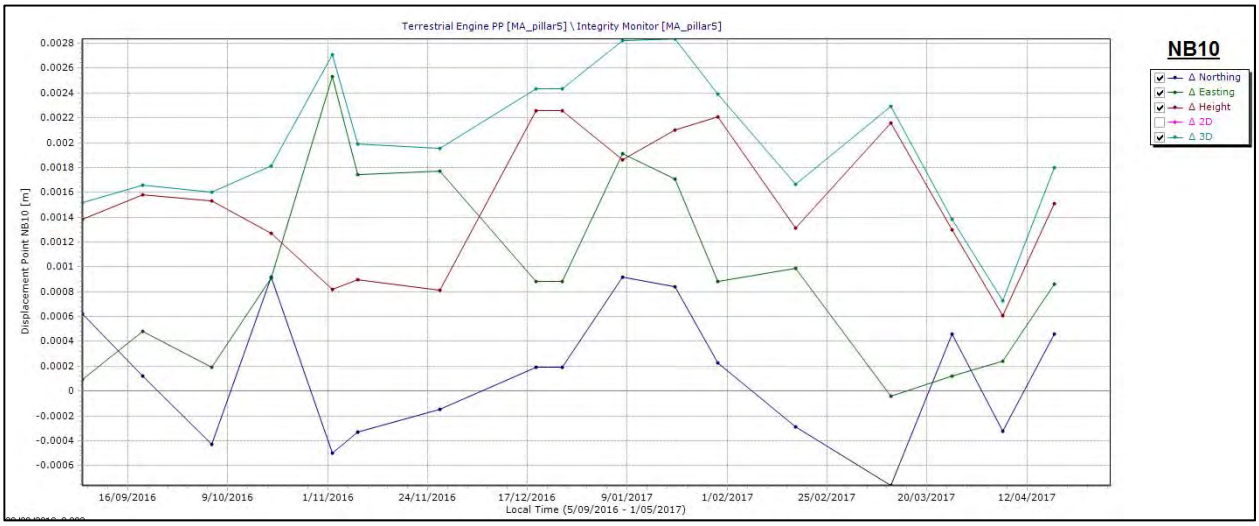
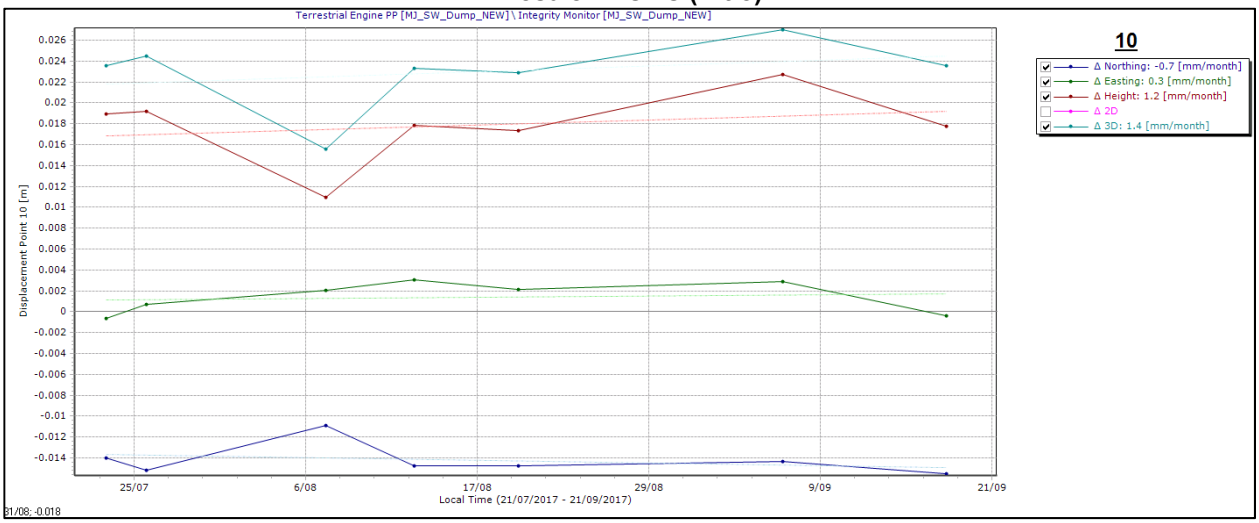


Mesa A Prism NB9

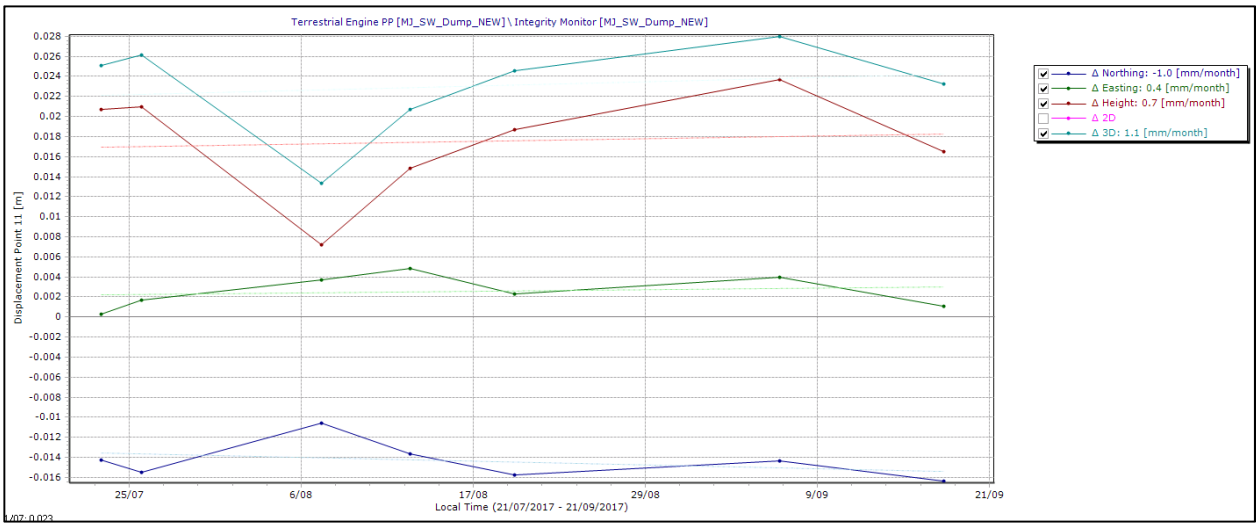


Mesa A Prism NB10

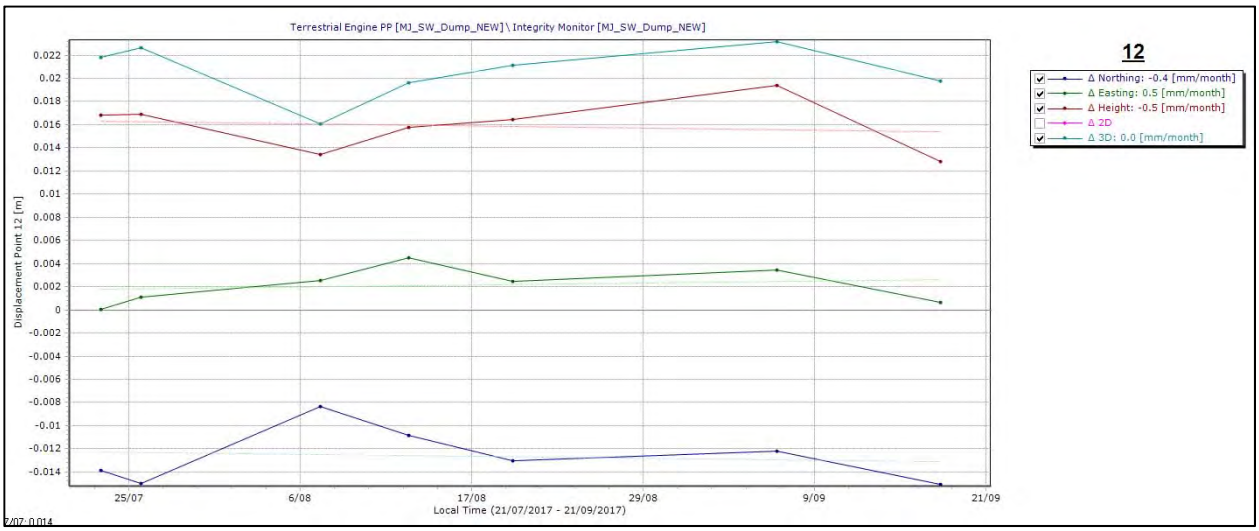
Mesa J Prisms (Pit 8)



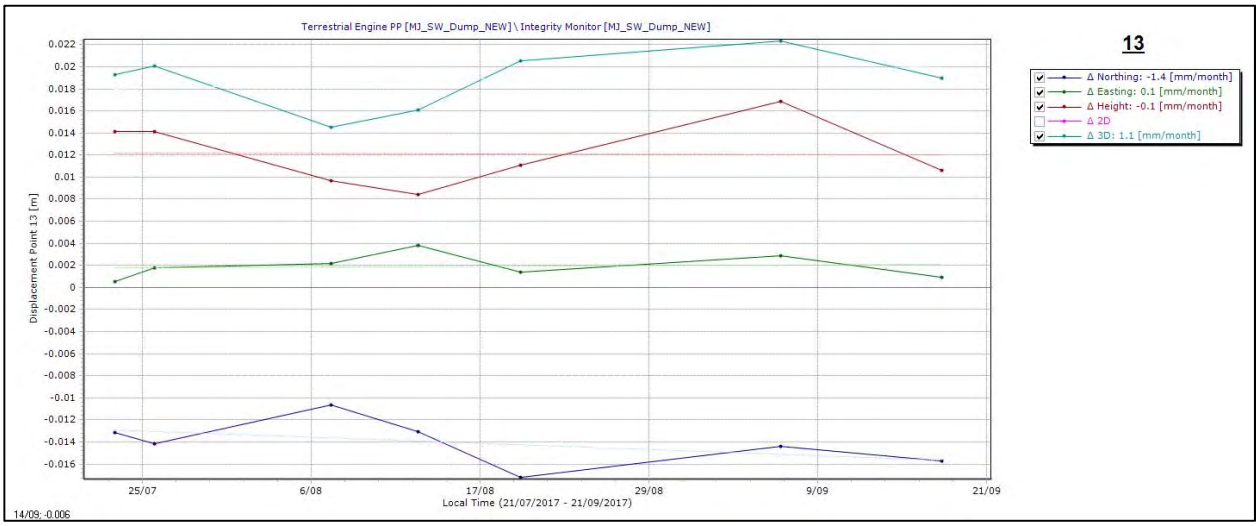
Mesa J Prism 10



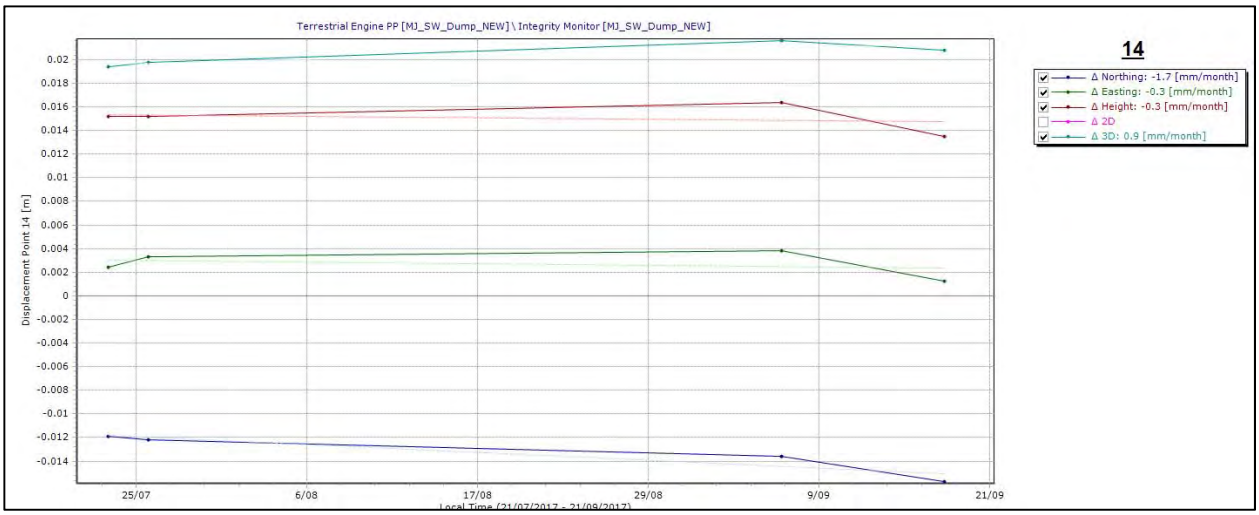
Mesa J Prism 11



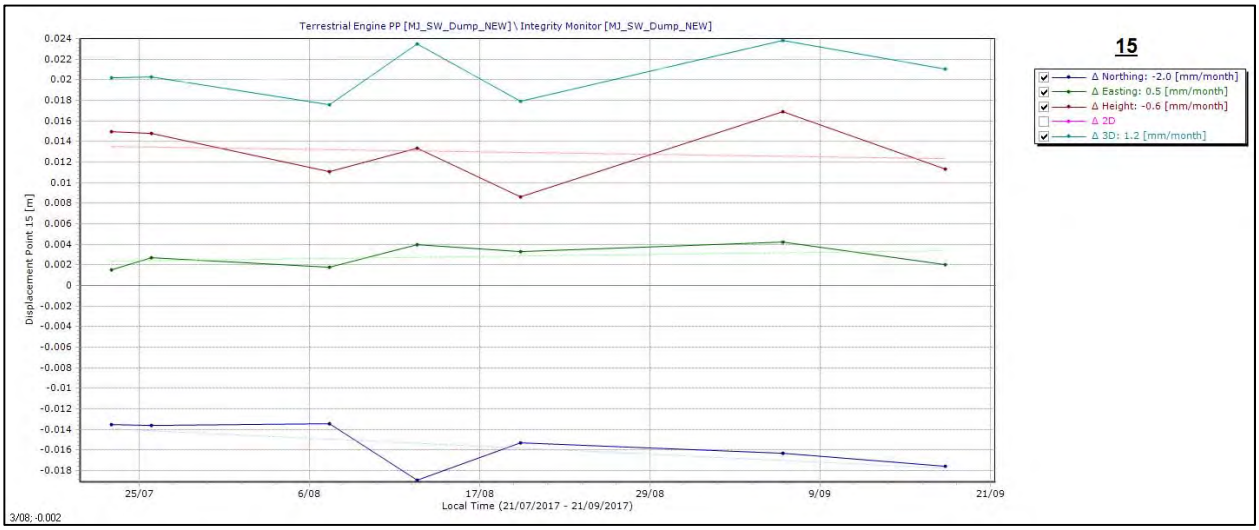
Mesa J Prism 12



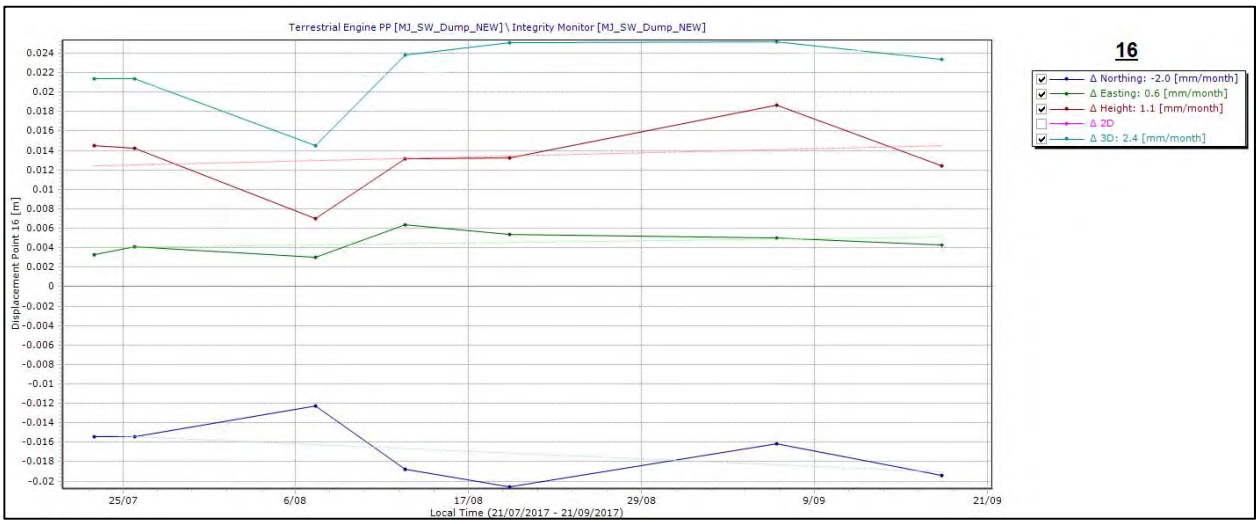
Mesa J Prism 13



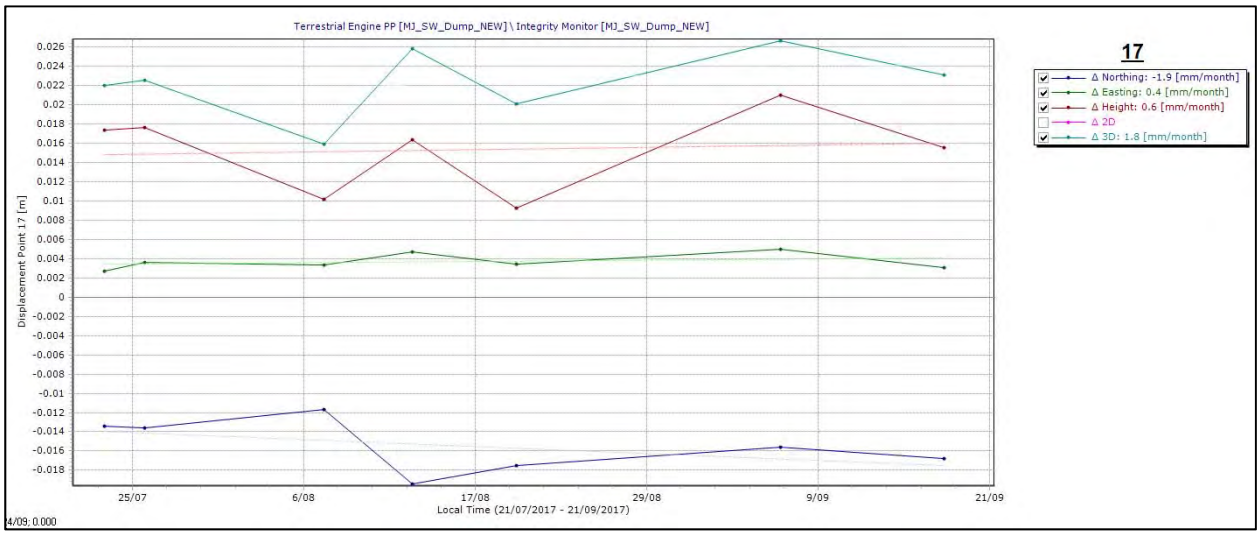
Mesa J Prism 14



Mesa J Prism 15



Mesa J Prism 16



Mesa J Prism 17