Sulphur Dioxide
Environmental Effects Monitoring
for B.C. Works

Wind Correction Addendum to the 2019 Comprehensive Review V.1

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V.1	June 24, 2022	Draft for ENV
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1 Background

Rio Tinto engaged Trinity Consultants to conduct CALPUFF dispersion modelling of SO_2 emissions from the smelter as part of the SO_2 EEM Comprehensive Review (CR, ESSA et al. 2020). The scope of the CR focused solely on total SO_2 emissions from the modernized Kitimat Aluminum Smelter and their associated impacts on human health and the environment. The dispersion modelling was conducted in 2019 and included three years of meteorological data (2016, 2017, and 2018). The model predicted results of SO_2 concentrations and total sulphur deposition. The regional-scale comprehensive review model used gridded meteorological data from Weather Research and Forecasting (WRF) developed by Trinity Consultants and local surface observation station data, including wind data from Kitamaat Village, Haul Road, Whitesail, Terrace Airport, and Yacht Club.

Recent review by the Ministry of Environment and Climate Change Strategy (ENV) and Trinity of wind direction data indicates that the Whitesail station was aligned to magnetic north rather than true north prior to August 2018 and that the Yacht Club station wind direction was also misaligned historically and realigned to true north in early 2019. Therefore, the wind directions recorded at these two stations need correcting for most or all of the CALPUFF model period. In addition, Yacht Club wind speed data was be invalidated by ENV for most of 2018.[1]

Trinity previously conducted a one-year study for 2018 to evaluate whether the wind direction corrections would cause meaningful difference to the results in the CR model. Due to the magnitudes observed in the 2018 study for regional-scale, Trinity and Rio Tinto, in consultation with ENV, determined it was necessary to conduct a study for the 2016 and 2017 years to fully evaluate whether the corrections would cause meaningful difference to the results in the CR model.

This Addendum describes the analysis and presents the results for each line of evidence using the updated CALPUFF results in order to determine if the post-correction CALPUFF results are meaningfully different than the results from the original CR report and whether use of the post-corrected results would lead to different conclusions in the CR.

[1] The details of the wind analysis were provided in a technical letter from Trinity/MSI to Rio Tinto and ENV dated September 29, 2021.

2 CALMET and CALPUFF Sensitivity Study

2.1 Methods

The methods for completing a CALMET and CALPUFF study for Whitesail wind direction and Yacht Club wind corrections include:

1. Update the CALMET input file (SMERGE file) with corrected Whitesail and Yacht Club data
   a. The corrections correspond to the recommendations in the Trinity memo dated September 29, 2021:

Station	Begin Date - Hour	End Date - Hour	Recommendation
Whitesail	12/5/2002 - 10:00 AM	12/31/2011 - 11:00 PM [a]	Correct direction +21.9° (clockwise)
Whitesail	1/1/2012 - 12:00 AM [a]	8/15/2018 - 2:00 PM	Correct direction +19.6° (clockwise)
Yacht Club	6/14/11 - 5:00 PM	1/31/2019 - 11:00 PM [a]	Correct direction +10.7° (clockwise)
Yacht Club	3/1/2018 - 12:00 AM [a]	11/30/2018 - 11:00 PM [a]	Consider whether to invalidate data during months with elevated calm winds

a. First hour of day/month set as start-hour and last hour of month set as end-hour for corrections without an exact date/hour identified.

   b. The correction for 2018 included removing Yacht Club data. Years 2016 and 2017 do not include a similar change to remove Yacht Club, because the elevated calms and wind speed differences were not observed for 2016 and 2017.
2. Rerun CALMET for 2016 - 2018 local-scale and regional-scale with updated Whitesail and Yacht Club wind direction.
3. Run CALPUFF and CALPOST for 2016 - 2018 for local-scale and regional-scale with the updated CALMET for the 42 ton per day scenario and the actual scenario.

Maps are created showing the post-correction model results and the difference between the original CR results and the study results.

Trinity provided a Terms of Reference (TOR) document also describing the methods above on November 23, 2021.

2.2 Summary of Wind Data Corrections

Figure 2-1 shows the 2016, 2017, and 2018 wind rose for Whitesail, before and after the correction. As expected, comparisons for 2017 and 2018 show a distinct shift of 19.6 degrees clockwise of predominant winds. However, since the wind sensor alignment was correct for part of 2018, the 19.6 degree clockwise shift is apparent for the predominant winds (previously from the south-southeast and north-northwest), but the correct predominant winds from the south and north-northeast also show as second-most frequent in the pre-corrected wind rose from the influence of the recordings after the August 2018 re-alignment of the sensor.

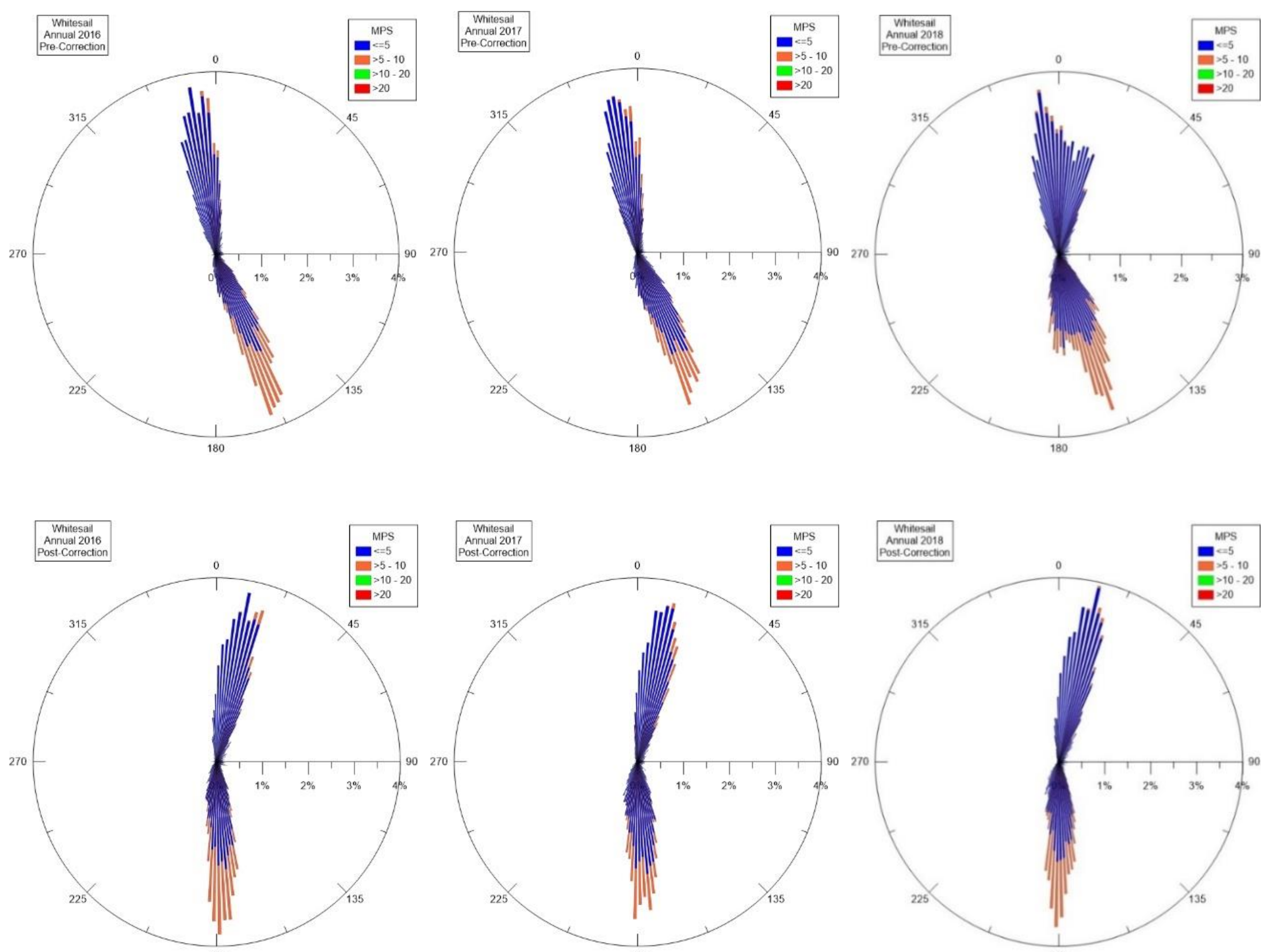

Figure 2-1. Whitesail Wind Rose Comparison.

Figure 2-2 shows the Yacht Club wind roses before and after the corrections for 2018. The wind rose in the upper left is the pre-corrected full year as included in the original CALMET model. The wind rose on the lower left is the post-corrected full year. The wind roses on the top and bottom right are the pre-corrected and post-corrected, respectively, with March – November excluded (because these months were identified as having elevated calm winds). The Yacht Club wind roses indicate that change to remove the March – November data will also remove most of the winds from the south. For this 2018 study, including only Jan, Feb, and December (wind rose on lower right) means the shift to the Yacht Club wind direction will mostly influence the pattern of the plume to the south of the smelter and that removal of the March – November data will remove the Yacht Club influence during months with winds from the south (and plume travel north through the Kitimat Valley) on the CALMET wind fields.

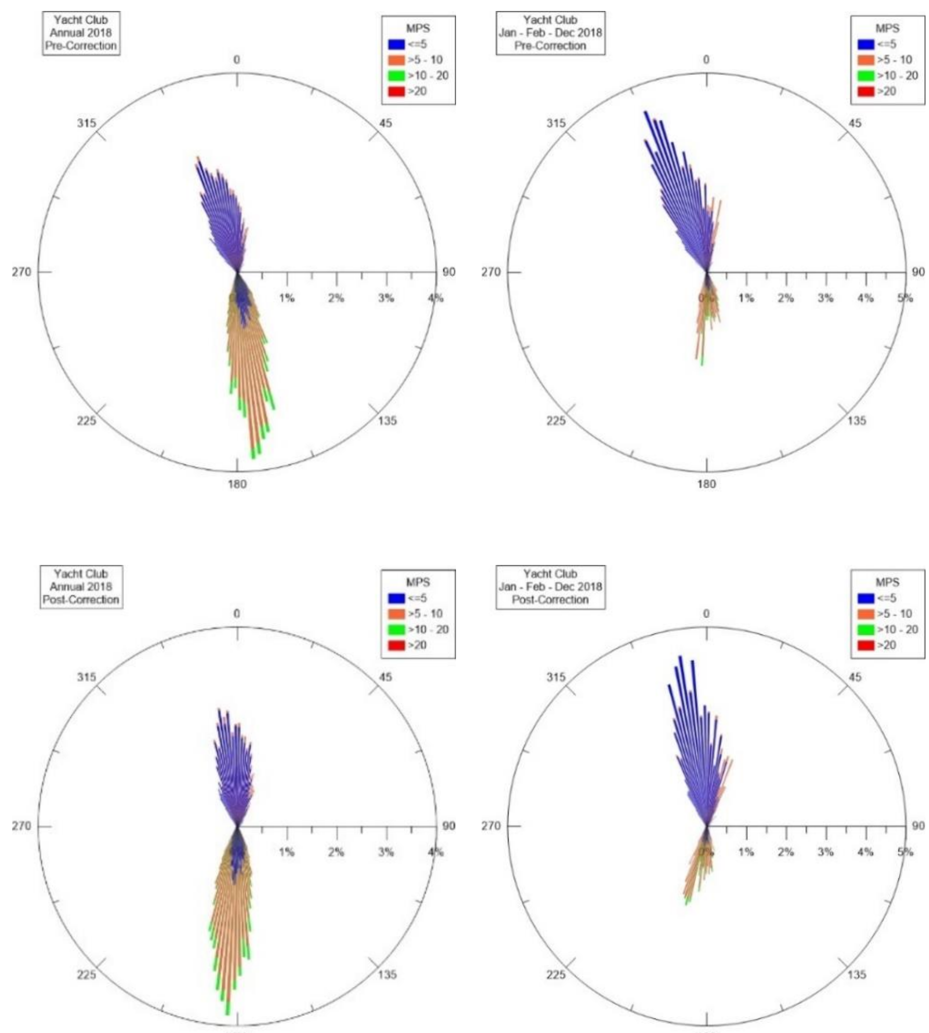

Figure 2-2. Yacht Club Wind Rose Comparison for 2018.

Figure 2-3 shows the Yacht Club wind roses before and after the corrections for 2016 and 2017. Since the calm wind correction is not performed for 2016 and 2017, these comparisons are similar to those for Whitesail, showing an approximate 10 degree shift and no other notable differences.

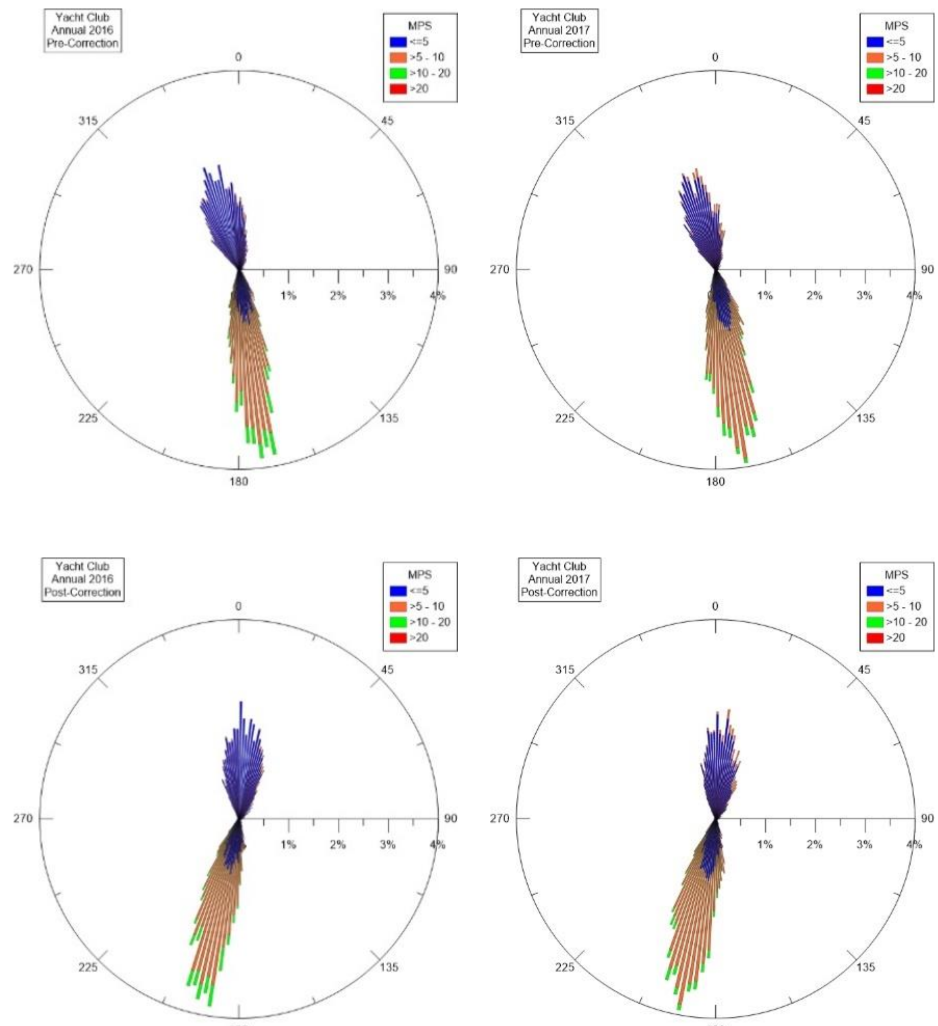

Figure 2-3. Yacht Club Wind Rose Comparison for 2016 and 2017.

2.3 Preliminary Results and Conclusions for 2018 Sensitivity Study

Attachment 1 shows plots of the increase and decrease in annual average sulphur deposition and SO_2 concentration for the annual and 1-hour averaging periods for 2018. Based on the annual comparison of sulphur deposition and SO_2 concentrations, a distinct shift is observed. The location of the decrease occurs due north of the smelter (centered at zero degrees), and the increase occurs north-northeast of the smelter (at direction of approximately 24 degrees, see Attachment 2). This shift of approximately 24 degrees corresponds fairly closely to the corrections to wind direction at the Whitesail station of approximately 19.6 degrees for the period modelled. However, the shift at Yacht club is only 10.7 degrees. The two wind direction changes alone are expected to result in an 11 to 20 degree shift in the CALPUFF plume path results, not the 24 degree shift observed. This discrepancy could indicate:

- Whitesail wind data has an outsized influence on the CALPUFF results patterns, or
- The absence of Yacht club data in March – November removed an influence on the wind fields that causes a more pronounced effect on model results.

This second reason would be the case if the previous Yacht Club dataset caused winds from the south-southwest in the WRF model to shift to be more directly from the south in the final CALMET model. Based on a previous study conducted by Trinity, this second reason is most likely. In 2019, Trinity completed a comparison study of preliminary CR results result using the no-obs CALMET option (WRF data only) and another using the hybrid option (WRF and surface whether station data).[2] As shown in Figure 2-4 below, the highest no-obs deposition results occur to the north-northeast, while the hybrid results occur to the north. The results from the current study are presented in the center of the figure and align much more closely with the no-obs (WRF-only case).

The removal of the Yacht Club dataset for March – November appears to have caused a more pronounced change than the correction to Whitesail and Yacht Club wind direction. This change from the Yacht Club removal is substantial enough to affect critical loads results and to *possibly* affect conclusions. However, the post-adjusted CALMET and CALPUFF results appear to be less representative of actual meteorological conditions in the Kitimat Valley. As such, testing CR conclusions based on this 2018 study would not provide a test of a possibly more accurate effects assessment. Therefore, Trinity also updated the 2016 and 2017 CALMET and CALPUFF for both regional-scale and local-scale assessments to use the post-corrected wind data from the two stations.

2.4 Results for 2016 and 2017 Sensitivity Study

Figure 2-4 through Figure 2-12 below present the results of the 2016 and 2017 CALPUFF update for the wind direction correction at Whitesail and Yacht Club for the regional scale model. Based on initial observations from the 2018 study, the updated 2016 and 2017 results were expected to align more closely with the original CR model. While the pattern change and overall differences are slightly lower for 2016 and 2017 than for 2018, the patterns are generally similar, indicating other factors influence results as much as or more-so than the absence of the Yacht Club data. One possible explanation for

[2] Trinity completed initial regional-scale CALPUFF models using the no-obs CALMET dataset. These preliminary no-obs models resulted in an unexpected spatial distribution of the deposition and concentration results. The initial results did not align with expectations based on terrain and monitoring data. In particular, the no-obs model results are highest to the northeast of the smelter, whereas terrain and ambient SO_2 monitoring indicate highest concentrations are expected to the north of the smelter. Therefore, Trinity tested an alternative option to run CALMET using the hybrid option.

the near 20 degree difference between the decreases and increases (Figure 2-6 and Figure 2-7, Figure 2-10 and Figure 2-11, and Figure 2-13 and Figure 2-14) rather than the expected ~15 degrees could be that the format of the observation wind direction data rounds to the nearest 10 degrees. While the differences between the two models are notable in these figures, the overall spatial pattern is fairly similar to the original CR model (Figure 2-1, Figure 2-2, Figure 2-3, Figure 2-4, Figure 2-8, Figure 2-9, and Figure 2-12).

The plots for actual scenario and local scale are included in Attachment 1. Further evaluation of the changes to the local scale results and how they may affect the network analysis study will be included in a report specific to the network optimization.

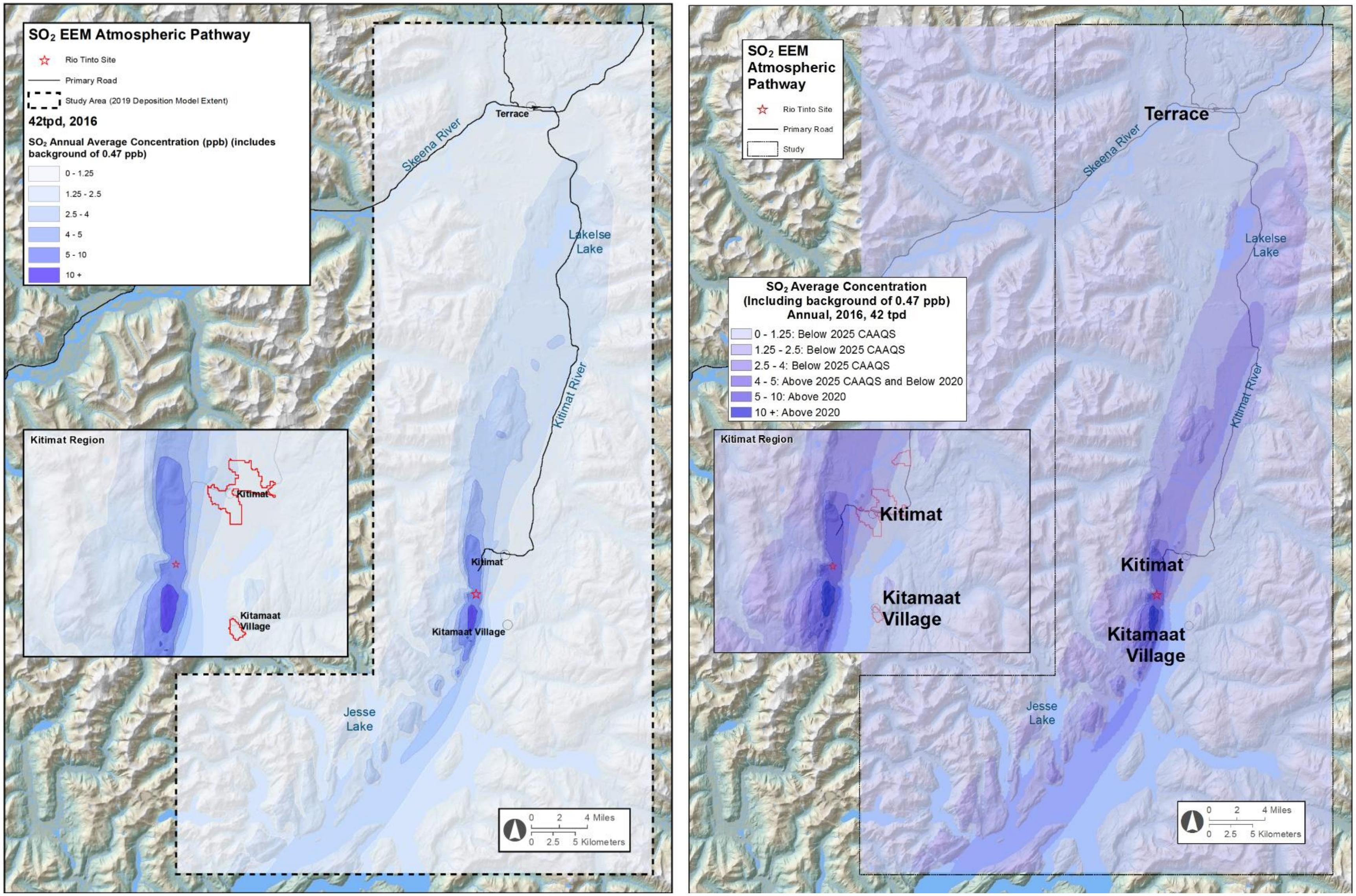

Figure 2-4. SO_2 Annual Concentration Comparison – 2016. The map on the left is pre-correction, the map on the right is post-correction.

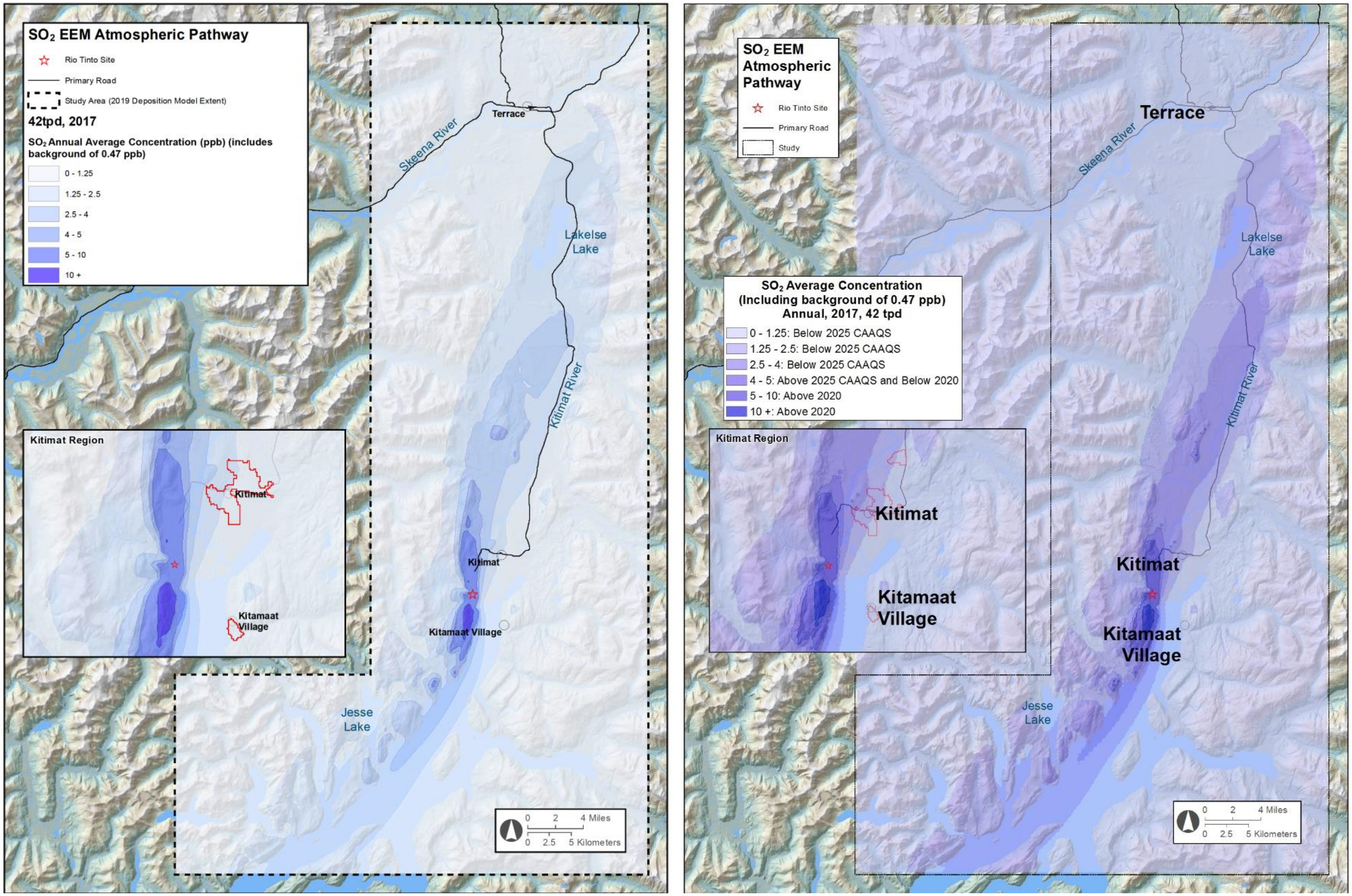

Figure 2-5. SO_2 Annual Concentration Comparison – 2017. The map on the left is pre-correction, the map on the right is post-correction.

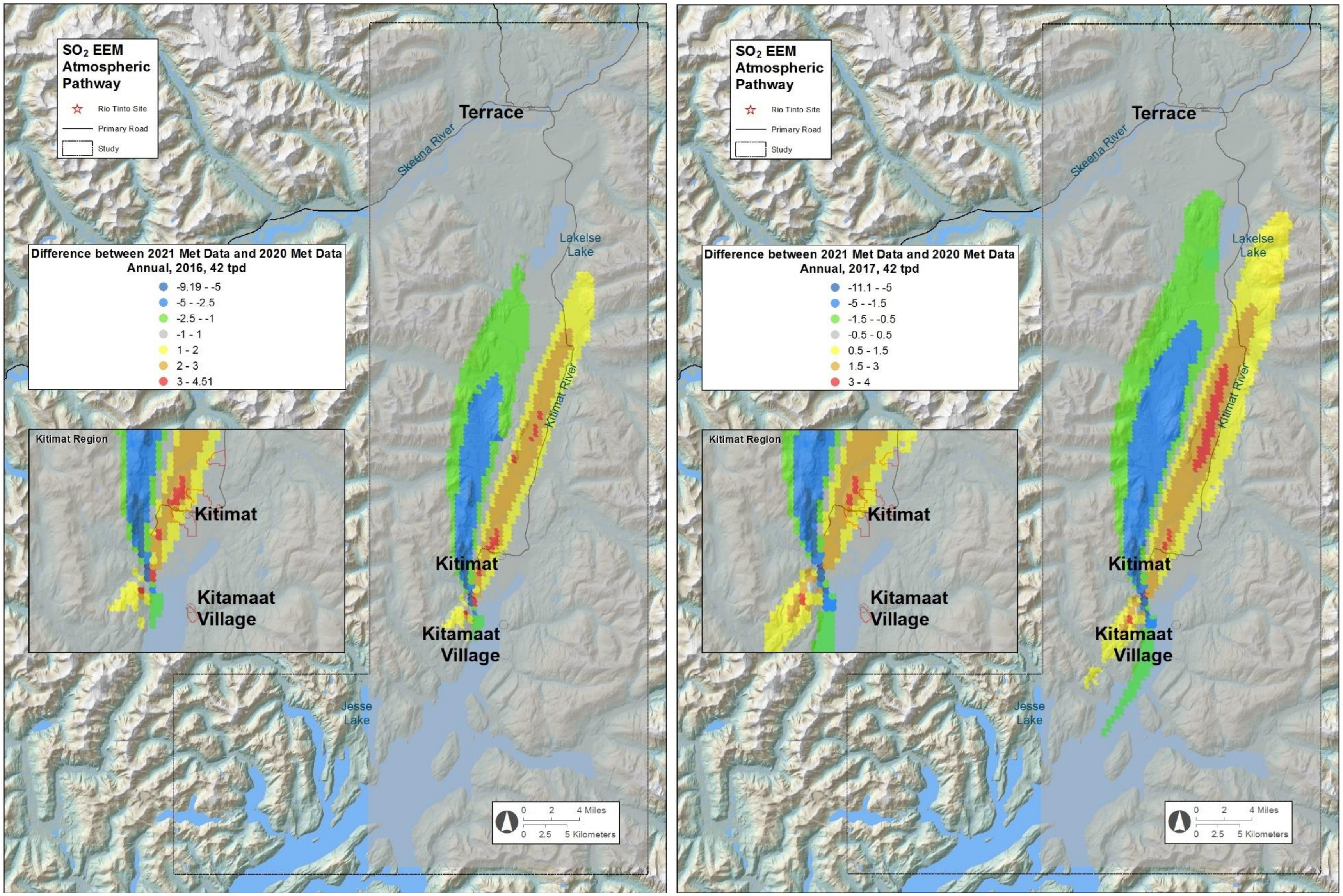

Figure 2-6. SO_2 Annual Difference – 2016 and 2017.

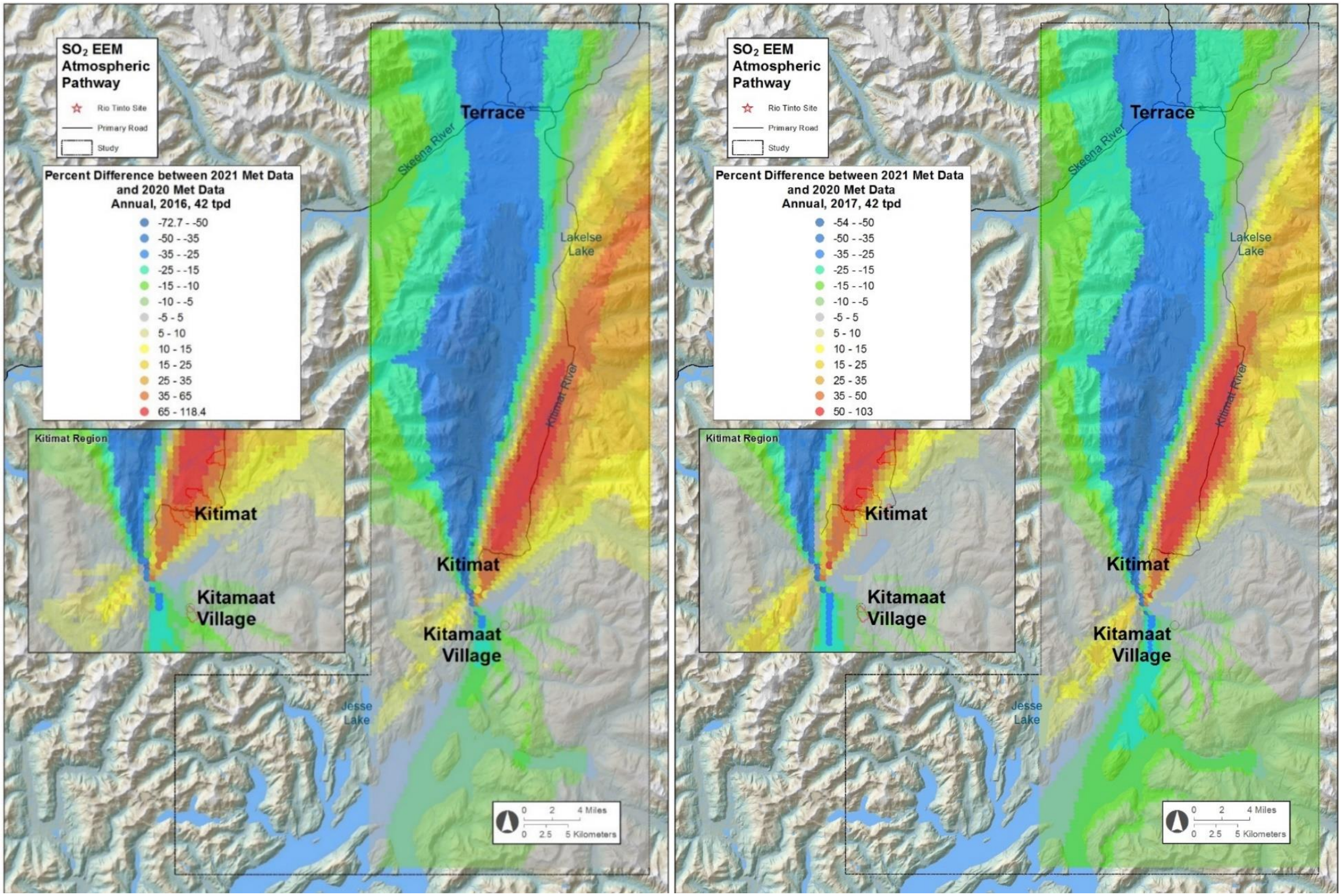

Figure 2-7. SO_2 Annual Percent Difference – 2016 and 2017.

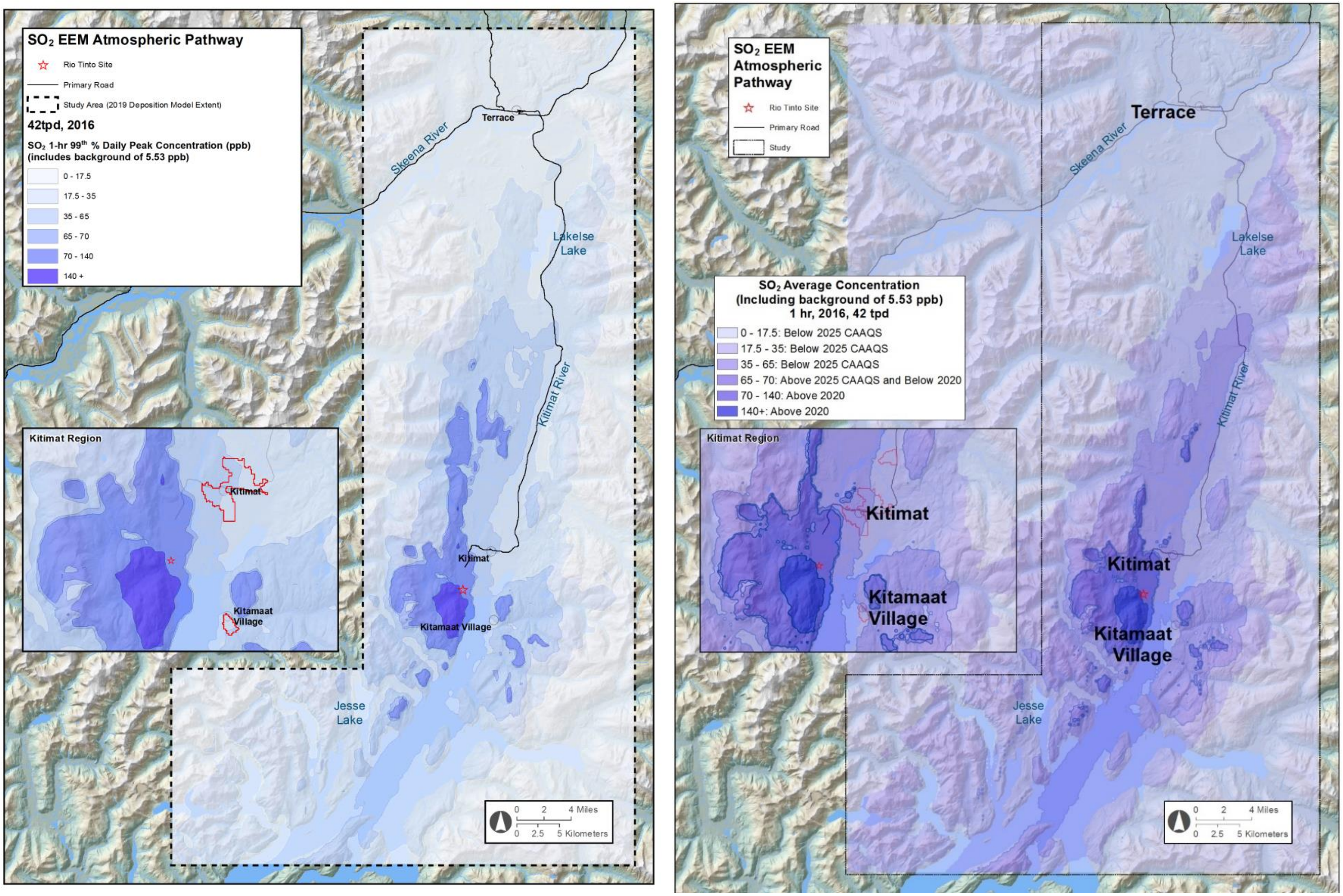

Figure 2-8. SO_2 99% Daily 1hr Peak Concentration Comparison – 2016. The map on the left is pre-correction, the map on the right is post-correction.

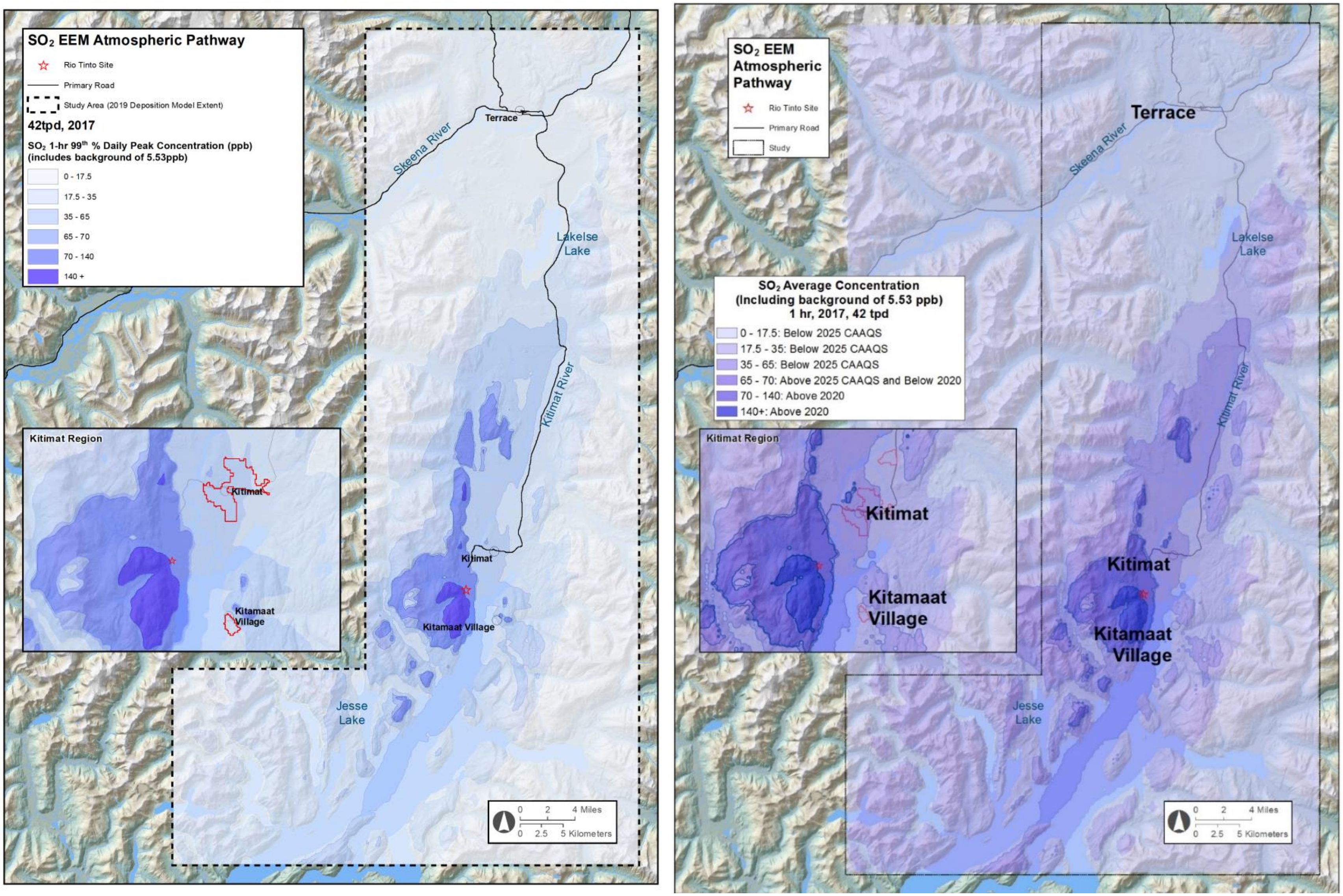

Figure 2-9. SO_2 99% Daily 1hr Peak Concentration Comparison – 2017. The map on the left is pre-correction, the map on the right is post-correction.

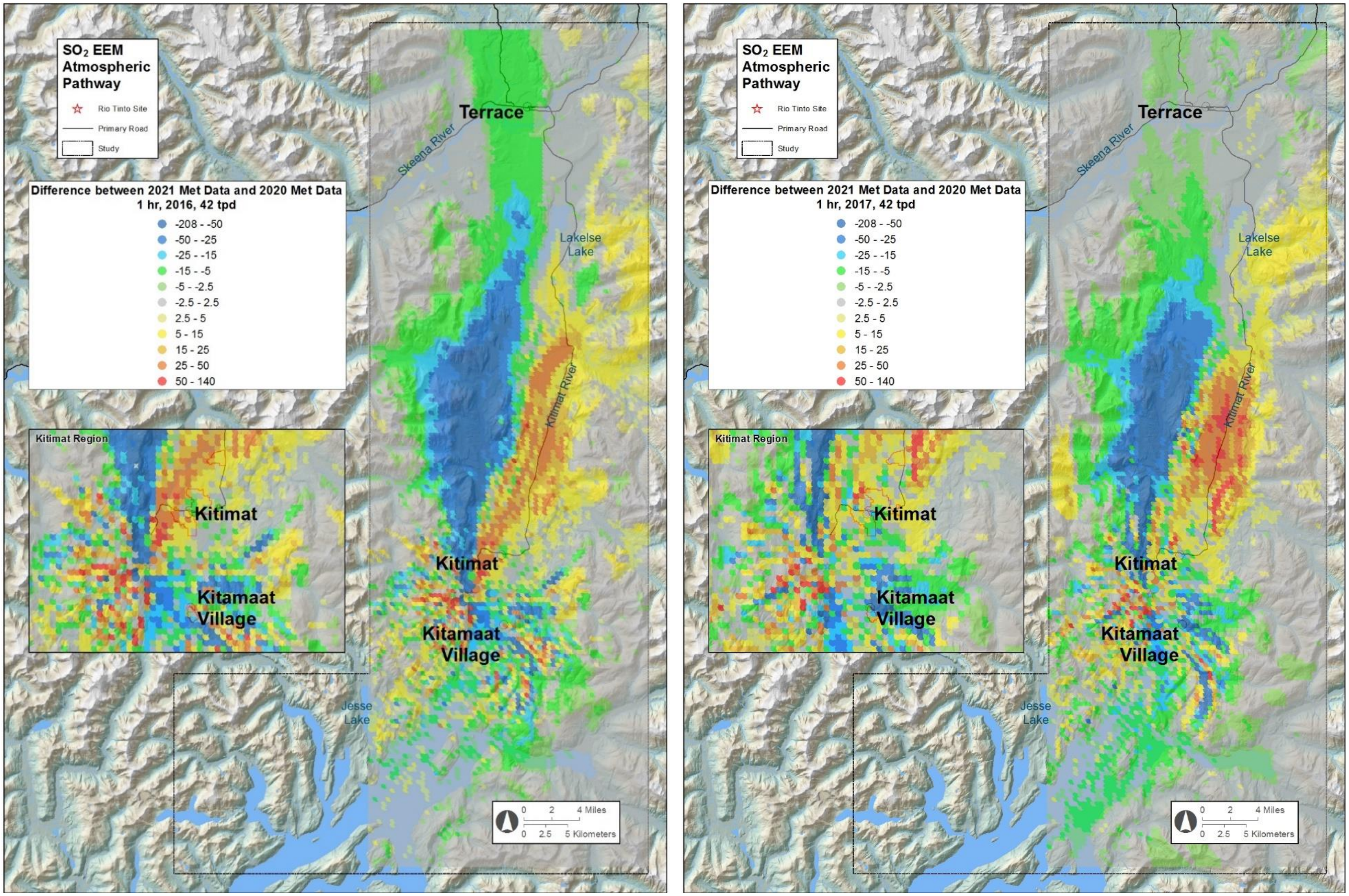

Figure 2-10. SO_2 99% Daily 1hr Peak Difference – 2016 and 2017.

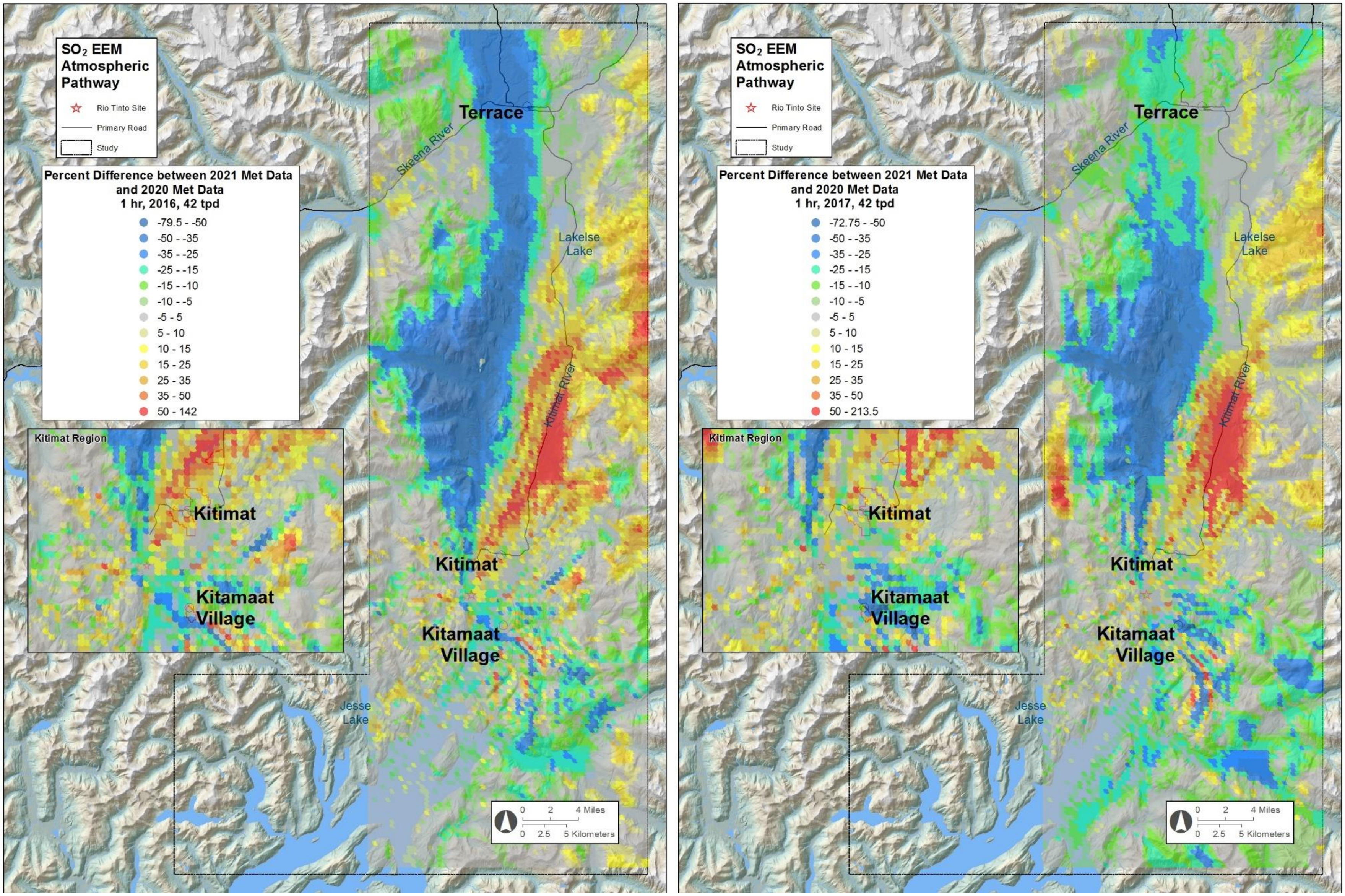

Figure 2-11. SO_2 99% Daily 1hr Peak Percent Difference – 2016 and 2017.

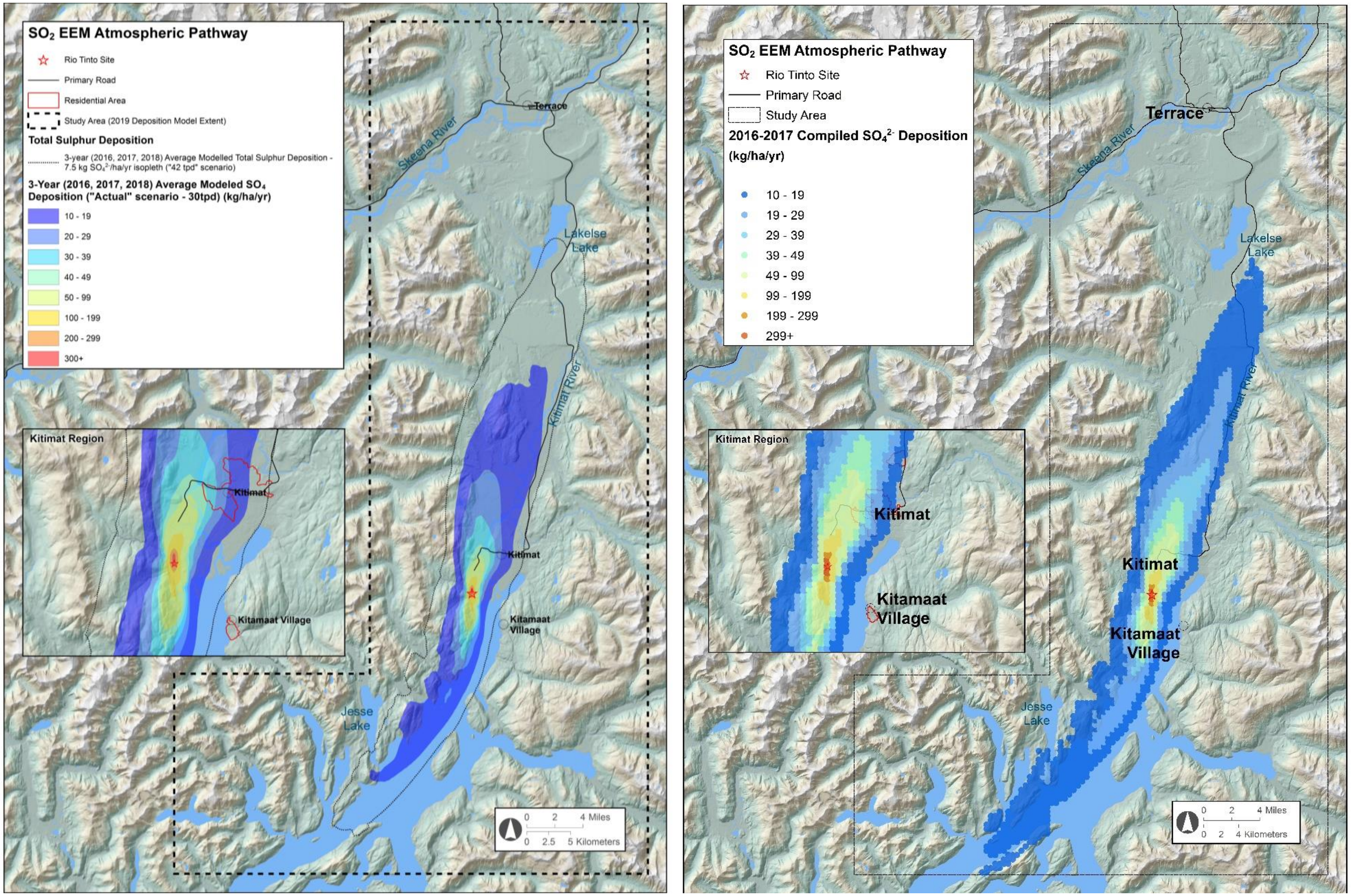

Figure 2-12. Sulfur Deposition Comparison – CR 2016-2018 (map on the left) v. updated 2016-2017 (map on the right).

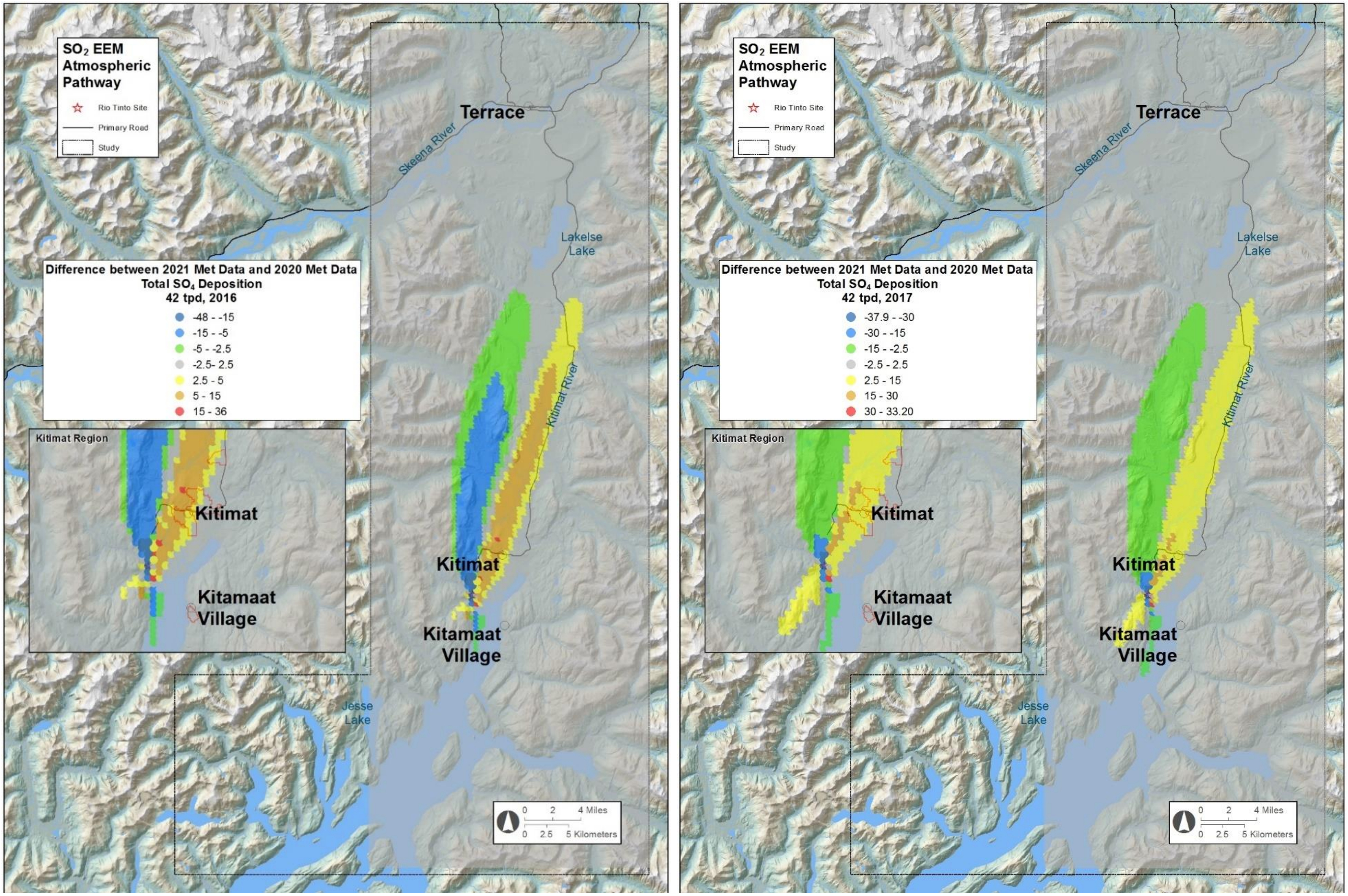

Figure 2-13. Sulfur Deposition Difference – 2016 and 2017.

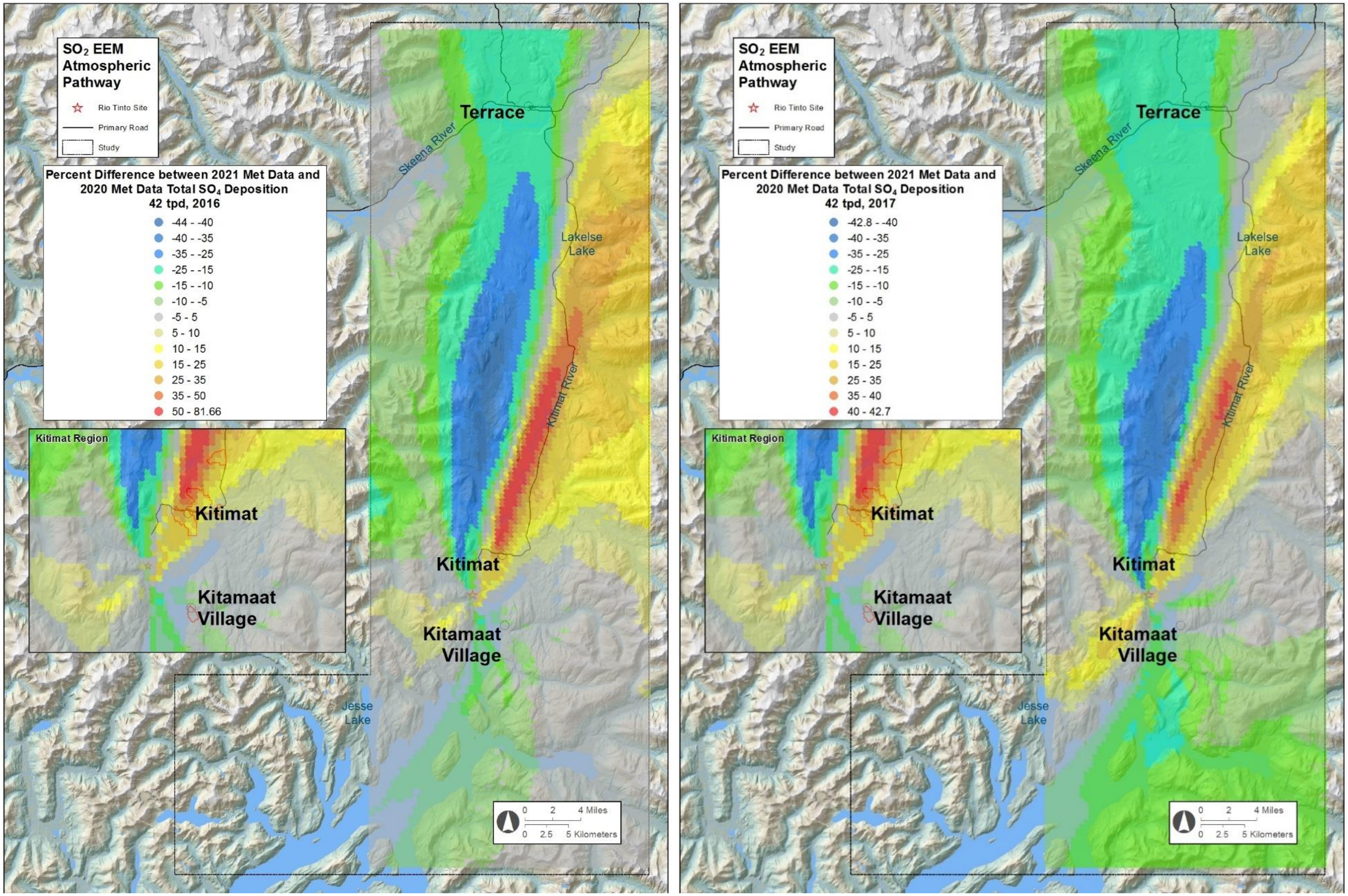

Figure 2-14. Sulfur Deposition Percent Difference – 2016 and 2017.

2.5 Sensitivity Study Conclusion

Initial 2018 study results indicated that the removal of the Yacht Club dataset for March – November may have caused a more pronounced change than the correction to Whitesail and Yacht Club wind direction. The subsequent 2016 – 2017 studies found similar changes as the 2018 study, though somewhat less pronounced, indicating the Yacht Club removal was not as critical of a factor as initially suspected. Therefore, 2018 was also included in the model evaluation included in Attachment 3 for possible use in the review of CR conclusions for the various lines of evidence.

As detailed in Attachment 3, the model performance using the corrected wind data is similar to the CR model performance when considering 2017-2017 only and when considering 2016-2018. The updated model reduced over-prediction at some locations such as Haul Road and other locations due north of the smelter, while over-prediction increased in the Kitimat residential area and other areas to the northeast of the smelter.

Overall differences between the two models are moderate, but the changes in model results may not affect CR conclusions because areas with higher predicted concentrations do not appear to coincide with any sensitive locations identified in the vegetation, terrestrial ecosystems and aquatic ecosystems lines of evidence. Sections 3 through 5 below review the CR results and conclusions for each of these lines of evidence when using the corrected wind data model results.

For the human health line of evidence, the model results were not used directly in the CR. Rather, the model results were used to perform a monitoring network evaluation, and the continuous SO_2 monitoring data is the direct indication of human health impacts. While the model changes do not affect SO_2 measurements, the network evaluation is revisited in a separate report to assess whether any conclusions could change as a result of the updates to the model.

3 Vegetation

3.1 Approach

We conducted the following steps:

1. Using the wind corrected modelled SO_4^{2-} deposition, we recalculated the *Estimated 3-year average SO_4^{2-} deposition from CALPUFF near reported sites with listed species or ecological communities* (Table 5-8 on page 126 of the CR).
2. Using the wind corrected modelled SO_4^{2-} deposition we recalculated *Estimates of the area in the study domain subject to SO_4^{2-} deposition with and without 3.6 kg SO_4^{2-}/ha/yr background* (Table 5-9 on page 127 of the CR).
3. Using the wind corrected modelled air concentrations of SO_2, we recalculated predictions of *Land areas by vegetation type under the actual and 42 tpd emission scenarios that fall within the 10 and 20 µg/m³ SO_2 isopleths* (Table 5-10 on page 128 of the CR).
4. Using the wind corrected modelled SO_4^{2-} deposition, we recreated a map of *Overlap of old growth management areas and average modelled SO_4 deposition for 2016-2018* (Figure 5-16 on page 129 of the CR).

Based on the results of steps 1-4, we reviewed *Section 5.3.1.2 Summary and interpretation of post-KMP CALPUFF air concentration and deposition modelling with regard to vegetation thresholds.*

3.2 Results

Step 1. Table 3-1 reproduces Table 5-8 on page 126 of the CR using wind corrected modelling and shows both the original estimated SO_4^{2-} deposition near reported sites with listed species or ecological communities. As stated in the CR, the exact locations of the sites are not available, so we chose the location identified on the map from the British Columbia Conservation Data Centre (accessed February 14, 2020).

In four of the six cases, the modelled SO_4^{2-} deposition using corrected wind data was less than reported in the CR. In the two cases where modelled SO_4^{2-} deposition increased, the increases were small. For *Lobaria retigera*, estimated SO_4^{2-} deposition increased by 0.23 kg SO_4^{2-}/ha/yr (3.4%) and for the Black cottonwood-red alder-salmonberry community, estimated deposition increased 0.16 kg SO_4^{2-}/ha/yr (9.3%). Both predicted increases are small in absolute terms and in neither case would the conclusions drawn in the CR change. Since the modelled SO_4^{2-} deposition using wind corrected data is less than originally reported in the CR, the conclusions drawn there would not change.

Table 3-1. Estimated 3-year average SO42- deposition from CALPUFF near reported sites with listed species or ecological communities. Deposition rates do not include a background of 3.6 kg SO42-/ha/yr. The values within brackets refer to pre-corrected values.

Species	Common Name	Conservation Status[1]	Actual Emissions	42 tpd
			SO_4^{2-} (kg/ha/yr)	
Nephroma occultum (Kitamaat vicinity)	Cryptic paw	Blue List Threatened/Special Concern	(5.83)	5.32 (7.65)
Nephroma occultum (Bish Cove vicinity)	Cryptic paw	Blue List Threatened/Special Concern	(20.5)	22.8 (27.0)
Pseudocyphellaria rainierensis	Old growth specklebelly	Blue List Special Concern	(3.84)	4.88 (5.53)
Lobaria retigera	Smoker's lung	Blue List Threatened	(4.37)	6.91 (6.68)
Arctopoa eminens	Eminent bluegrass	Red List Not listed	(0.26)	0.33 (0.38)
Populus trichocarpa-Alnus rubra-Rubus spectabilis	Black cottonwood-red alder-salmonberry	Blue List None	(1.16)	1.88 (1.72)

[1]Provincial designations of Blue or Red List followed by national designation.

Step 2. Table 3-2 reproduces Table 5-9 on page 127 of the CR using wind corrected modelling and shows estimates of the area in the study domain subject to SO_4^{2-} deposition. Both the original CR values and the new estimates are shown for the 42 tpd case, with and without background deposition. In the case of predicted deposition without background, shifts in the areas within the SO_4^{2-} deposition categories occur, but in all cases, the shifts are small given the uncertainties in modelling and the conservative nature of the model design. In the lowest deposition category, the percent of the total area increased by 2.5% (9,225 ha). The land area in the categories from 3.7 to 10 kg SO_4^{2-}/ha/yr essentially remained unchanged, differing by less than 0.2%. The only category in that range that increased was 3.7-5, and then by only 50 ha. The area subject to predicted SO_4^{2-} deposition of greater than 10 kg SO_4^{2-}/ha/yr increased by less than 1%. The only category with an increase greater than 1% of the land area was in the 2.5-3.7 where the predicted area increased by 1.5%.

Where background SO_4^{2-} deposition of 3.6 kg SO_4^{2-}/ha/yr is included, the areas increased over those reported in the CR in the categories ranging from 3.7 to 10 kg SO_4^{2-}/ha/yr. The area predicted to be subject to >10 kg SO_4^{2-}/ha/yr decreases. Once again, the increases are small, ranging from 0.1 to 2.1% of the land area, with a decrease of 1.2% in the >10 kg SO_4^{2-}/ha/yr category.

Based on these small changes under the maximum emissions scenario, and particularly the decreased area of the study domain predicted to be subject to the greatest deposition of SO_4^{2}, there are no changes warranted to the conclusions in the CR.

Table 3-2. Estimates of the area in the study domain subject to SO_4^{2-} deposition with and without 3.6 kg SO_4^{2-}/ha/yr background. Approximately 1% of the area with deposition greater than 5 kg SO_4^{2-}/ha/yr and less than 15 kg SO_4^{2-}/ha/yr is in Minette Bay. The values within brackets refer to pre-corrected values.

SO_4^{2-} Deposition (kg/ha/yr)	Actual Emissions Case	% of Total Area	Actual Emissions Case + Background 3.6 kg SO_4^{2-}/ha/yr	% of Total Area	42 tpd Case	% of Total Area	42 tpd Case+ Background 3.6 kg SO_4^{2-}/ha/yr	% of Total Area
	ha	%	ha	%	ha	%	ha	%
0-2.5	234,925	64.3	0	0.0	190,000 (180,775)	52.0 (49.5)	0	0
2.5-3.7	45,250	12.4	875	0.2	51,525 (57,075)	14.1 (15.6)	0	0
3.7-5	24,050	6.6	156,150	42.7	35,050 (35,000)	9.6 (9.6)	116,425 (108,775)	31.9 (29.8)
5-7.5	21,650	5.9	128,475	35.2	34,475 (34,675)	9.4 (9.5)	131,525 (135,350)	36.0 (37.0)
7.5-10	12,375	3.4	33,550	9.2	15,525 (16,025)	4.2 (4.4)	51,950 (51,625)	14.2 (14.1)
>10	27,100	7.4	46,300	12.7	38,750 (41,800*)	10.6 (11.4)	65,475 (69,600)	17.9 (19.1)

* The original CR included a value of 57,825 in this cell. However, underlying data confirmed 41,800 hectares is the correct value representing deposition > 10 SO_4^{2-} (kg/ha/yr) for the original 42 tpd case CALPUFF results (pre-wind correction).

Step 3. Table 3-3 shows the land area by vegetation type that is predicted to fall within the 10 and 20 µg SO_2/m^3 isopleths using wind corrected modelling output. Table 3-4 shows the difference in area within the 10 and 20 µg/m^3 isopleths between the wind-corrected modelling and the original CR modelling. Under the actual scenario, the maximum increase in land area was about 109 ha of forested land moving into the 20 µg/m^3 isopleth. Under the 42 tpd scenario, increases in land area within classifications were small with only 1 increase of 41.8 ha of wetland exposed to 10 µg/m^3 in 2017 and 3 increases (one occurring in each modelled year with a maximum of 71 ha) in forest land and 1 increase of 6.7 ha in herb lands in model year 2016. In some cases, there were relatively large decreases in areas within the 10 µg/m^3 isopleth as the plume moved away from forested land. Still, under the wind-corrected 42 tpd modelling, less than 3% of the study area fell within the 10µg/m^3 isopleth and about 0.6% fell within the 20µg/m^3 isopleth. Under the actual scenario, about 1.4% fell within the 10 µg/m^3 isopleth and less than 0.5% fell within the 20 µg/m^3 isopleth.

Table 3-3. Land areas by vegetation type under the actual and 42 tpd emission scenarios that fall within the 10 and 20 μg/m³ SO_2 isopleths. Land cover classifications are based on the Canadian Land Use Cover data (circa 2000) used in the SO_2 EEM Program and comprehensive review.

Scenario	SO_2 Isopleth	2016				2017				2018			
		Forest	Herb	Wetland	Shrub	Forest	Herb	Wetland	Shrub	Forest	Herb	Wetland	Shrub
		Hectares											
Actual	10	1082.1	428.9	47.0	77.5	1278.5	480.9	47.3	90.9	1171.1	338.1	29.4	69.7
	20	261.6	113.1	0	15.1	353.3	122.1	0	14.9	302.6	102.1	0	14.9
42 tpd	10	1879.7	694.6	85.6	175.5	2396.3	782.9	139.8	450.9	2642.7	673.8	61.2	148.8
	20	459.6	154.1	0	19.6	527.8	159.4	0	25.4	561.3	168.7	0	27.3

Table 3-4. Difference in land areas by vegetation type under the actual and 42 tpd emission scenarios that fall within the 10 and 20 μg/m³ SO_2 isopleths. Land cover classifications are based on the Canadian Land Use Cover data (circa 2000) used in the SO_2 EEM Program and comprehensive review. Positive values are increases in area and negative values are decreases in area.

Scenario	SO_2 Isopleth	2016				2017				2018			
		Forest	Herb	Wetland	Shrub	Forest	Herb	Wetland	Shrub	Forest	Herb	Wetland	Shrub
		Hectares											
Actual	10	-28.6	-79.8	4.5	-25.4	-177.4	-75.5	3.3	-58.2	-422.4	-211.7	-17.6	-81.4
	20	55.5	18.6	-5.2	1.43	108.8	41.4	-17	-3.9	23.8	23.2	-13.2	-5.1
42 tpd	10	-763.1	-63	-6.5	-157.2	-905.9	-8.2	41.8	-14.3	-1045.7	-129.9	-29.6	-307.6
	20	71	6.7	-21.6	-15.7	51.7	-67.7	-23.9	-23.3	33.1	-55.4	-22.5	-23.5

Step 4. Figure 3-1 shows the position of old growth management areas in the study area that fall within estimated SO_4^{2-} deposition ranges. The panel on the left is the original Figure 5-16 (page 129 in the CR) while the panel on the right uses the modelled wind-corrected estimates of SO_4^{2-} deposition. Using the CR-modelled deposition, we found that all or parts of 17 old growth management areas fell within the >5 kg SO_4^{2-}/ha/yr isopleth. Using the wind-corrected modelling, all or parts of 24 old growth management areas fell within the >5 kg SO_4^{2-}/ha/yr isopleth. An inspection of the two maps shows that the additional parts of old growth management areas that are included in the wind-corrected analysis are small tracts that fell into the area due to the shift in direction of the modelled plume path. We also note that the focus of vegetation monitoring shifted because of the CR to measure biodiversity of vascular plants and cyanolichens, so, to a large extent, the program is now focussed on mature and old growth forest.

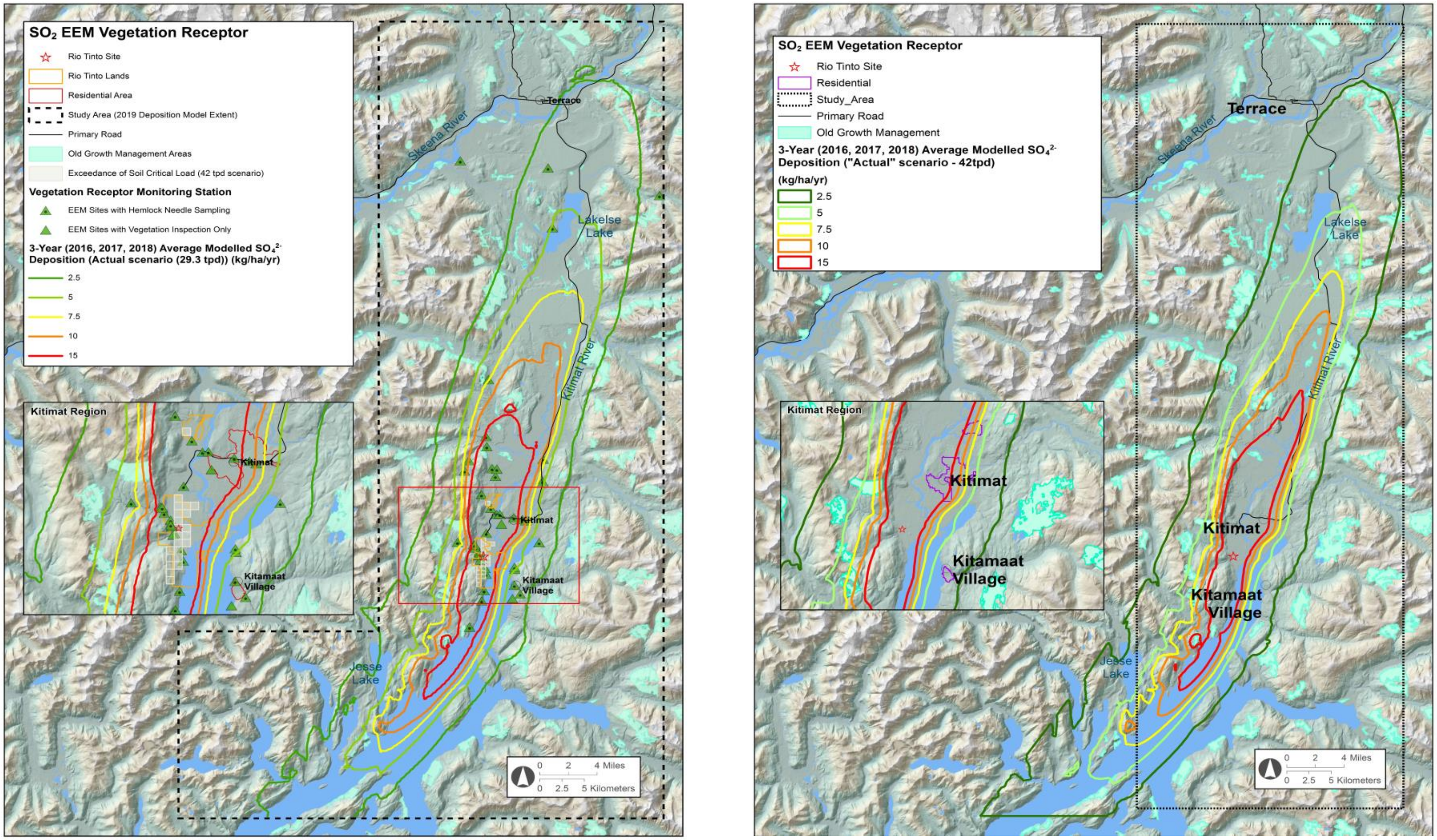

Figure 3-1. The map on the left shows the CR-modelled SO_4^{2-} deposition and the location of old growth management areas. The map on the right shows the wind-corrected modelled SO_4^{2-} deposition and the location of old growth management areas.

3.3 Conclusions and Recommendations

Based on the results of Steps 1-4, we believe there is no reason to change the conclusions drawn in the CR. A major recommendation of the CR was to shit the focus of vegetation monitoring to detect subtle and long-term effects of SO_4^{2-} deposition on vascular plant and cyanolichen biodiversity which addresses potential impacts on old growth management areas.

4 Terrestrial Ecosystems (Soils)

4.1 Approach

We conducted the following steps:

1. Obtained revised estimates of total sulphate deposition for 2016-2017 for each 0.5 x 0.5 km^2 grid square in the study area
2. Overlaid revised estimates of 2016-2017 and 2016-2018 deposition on estimated critical loads (CLs) for each grid square (CLs unchanged from those estimated in the CR)
3. Computed revised estimates of exceedance for each grid square
4. Compared revised estimates of exceedance to prior estimates in the Comprehensive Report
5. Developed revised maps of areas of CL exceedance (i.e., revised Figure 6-5, pg. 163 in CR report) and various metrics related to CL exceedance (i.e., revised Table 6-4, pg. 164 in CR report)
6. Compared revised estimates of 2016-2017 and 2016-2018 deposition at long-term soil plots with prior estimates of deposition in the STAR (ESSA et al. 2013) and CR.
7. Reviewed and if required revised conclusions and recommendations (CR report sections 6.3.3 and 6.4, pg. 170-171)
8. Addressed the question: "*Given these results and conclusions, is the SO_2 EEM soils work still looking in the right areas*?"

4.2 Results

The results of steps 1-5 are shown in Table 4-1 and Figure 4-1. Changes from the CR are small and not ecologically significant. We first compare results in the CR using deposition for 2016-2018 meteorological years (column C of Table 4-1) with results using the revised estimates of deposition for 2016 and 2017 (column D of Table 4-1):

- there was a *slight decrease in the mapped receptor area* (area with deposition ≥ 7.5 kg/ha/yr, row 6 of Table 4-1) from results in the CR (398.4 km^2, column C) to results with the revised estimates of 2016-2017 deposition (387.8 km^2, column D);
- there was a *small increase in the total area with exceedance* (row 2 of Table 4-1), from 2.33 km^2 in the CR (column C) to 2.58 km^2 with the revised estimates for 2016-2017 (column D), representing, respectively, 0.58% and 0.61% of the mapped receptor area (row 4 of Table 4-1);
- the *area of wetlands with exceedance* (row 3 of Table 4-1) decreased from 0.58 km^2 in the CR to 0.47 km^2 with revised estimates of 2016-2017 deposition (column D);
- the *number of grids with exceedance* (row 5 of Table 4-1) was similar (23 grids in the CR (column C) and 24 with revised estimates of 2016-2017 deposition (column D));
- *average exceedance in grids with exceedance* (row 1 of Table 4-1) increased slightly (from 149.6 meq/m^2/yr in the CR (column C) to 154.1 with revised estimates of 2016-2017 deposition (column D); and

- the *spatial distribution of grids with exceedance* was very similar to that in the CR (Figure 4-1), in a column roughly 3 km wide, from 6 km south to 4 km north of the smelter.

Compared to the CR (column C), revised results for 2016-2018 deposition (column E) show decreases in the mapped receptor area (from 398.4 in the CR to 374.8 km^2, number of grids with exceedance (from 24 to 22), average exceedance within those grids (from 149.6 to 140.7 $meq/m^2/yr$), total exceeded area (from 2.33 to 2.31 km^2), and exceeded area of wetlands (from 0.58 to 0.47 km^2). There was a slight increase in the percent of mapped receptor area with exceedance (from 0.58% to 0.62%), due to the decrease in the mapped receptor area.

Table 4-1. Comparison of exceedance of CLs for forest soils and wetlands under 42 tpd of SO_2 emissions and deposition estimates for: 2016-2018, as reported in the CR (column C), revised estimates of 2016-2017 deposition (column D), and revised estimates of 2016-2018 deposition (column E). The values within brackets refer to areas outside of the Rio Tinto fence line.

Exceedance	Sulphate deposition (2016-2018 meteorological years) in the Comprehensive Review report			Revised 2016-2017 sulphate deposition	Revised 2016-2018 sulphate deposition
	A) Actual	B) 35 tpd	C) 42 tpd	D) 42 tpd	E) 42 tpd
1.Average exceedance ($meq/m^2/yr$)	119.9 (97.9)	140.0 (116.13)	149.6 (97.9)	154.1 (105.0)	140.7 (93.7)
2.Exceeded area (km^2)	0.97 (0.20)	1.26 (0.40)	2.33 (1.26)	2.58 (1.26)	2.31 (1.24)
3.Exceeded area wetland (km^2)	0.40 (0.16)	0.44 (0.16)	0.58 (0.30)	0.47 (0.19)	0.47 (0.19)
4.Exceeded area (%) *	0.36 (0.07)	0.39 (0.13)	0.58 (0.32)	0.67 (0.33)	0.62 (0.33)
5.Exceeded grids (n)	12 (5)	15 (6)	23 (11)	24 (13)	22 (12)
6.Mapped receptor area (km^2)	271.1	321.4	398.4	387.8	374.8

* as a percentage of the mapped receptor area under the 7.5 kg SO_4^{2-}/ha/yr deposition isoline

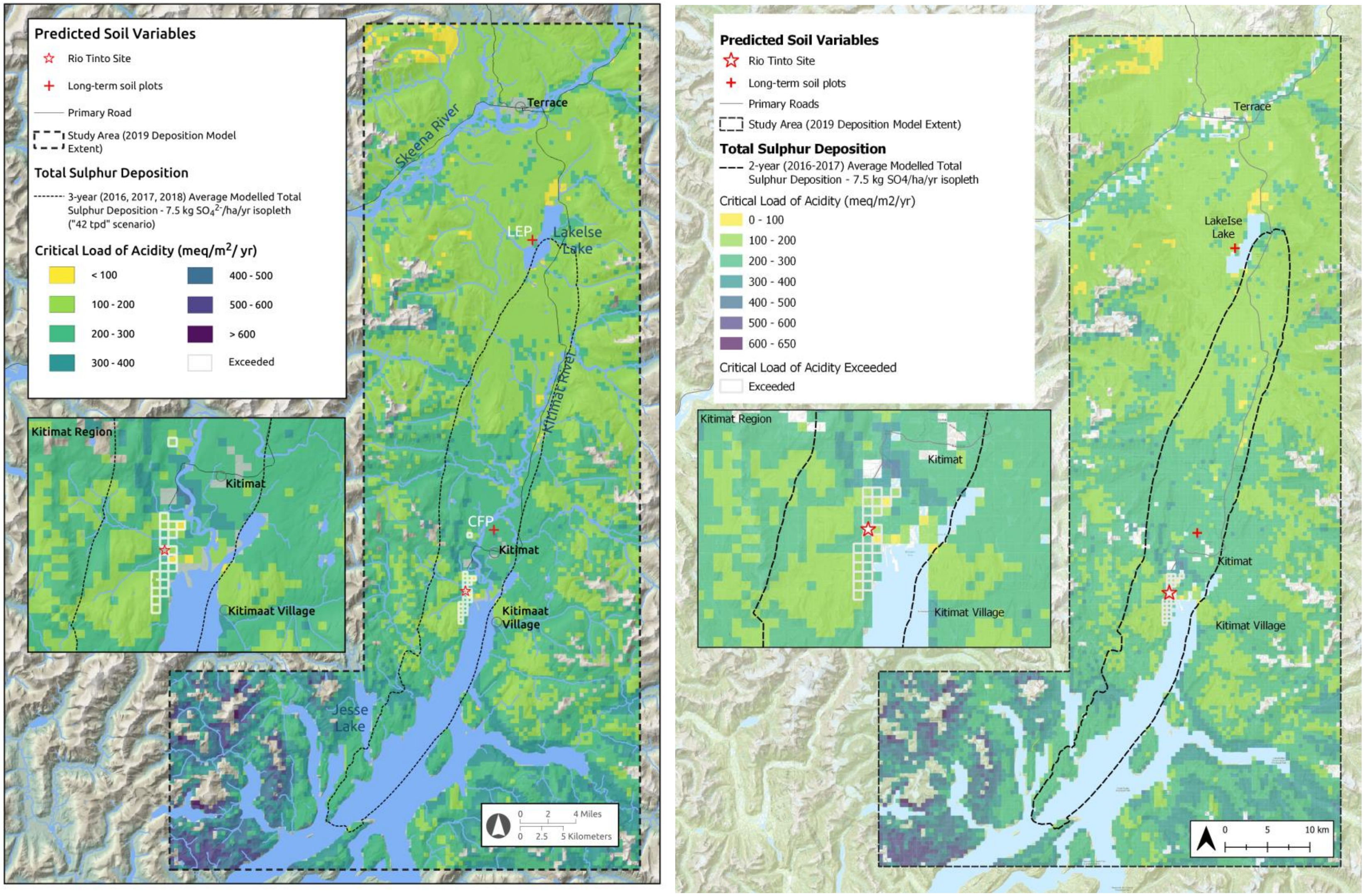

Figure 4-1. Comparison of grid squares with CL exceedance (white squares) under the original CR estimates of deposition for 2016-2018 (left, CR Figure 6-5) vs the revised deposition estimates for 2016-2017 (right). The same estimated CLs are used for both maps.

Modelled sulphate deposition to the long-term soil plots (step 6) are shown in Table 4-2. The revised deposition estimates show more deposition close to the smelter at Coho Flats, and less deposition at Lakelse Lake, relative to the CR. These differences are visually apparent in Figure 4-2, with ~50% increases in deposition near Coho Flats, and ~15% decreases in deposition in the vicinity of Lakelse Lake. Estimated deposition to Coho Flats was significantly higher with both the 2016-2017 and 2016-2018 revised deposition estimates (40.0 and 37.5 kg/ha/yr, respectively) than with the 2016-2018 deposition estimates used in the CR (26.8 kg/ha/yr). Conversely, the 2016-2017 deposition estimates were lower at Lakelse Lake with both the 2016-2017 and 2016-2018 revised estimates (6.12 and 5.79 kg/ha/yr) than with the deposition estimates used in the CR (7.26 kg/ha/yr).

Table 4-2. Comparison of modelled sulphate deposition to the long-term soil plots under emissions of 42 tpd.

Soil Plot	Latitude	Longitude	SO_4 (kg/ha/yr)			
			STAR	CR	2016–2017 revised	2016–2018 revised
Coho Flats	54.0766	-128.6512	20.4	26.8	40.0	37.5
Lakelse Lake	54.37827	-128.5799	16.7	7.26	6.12	5.79

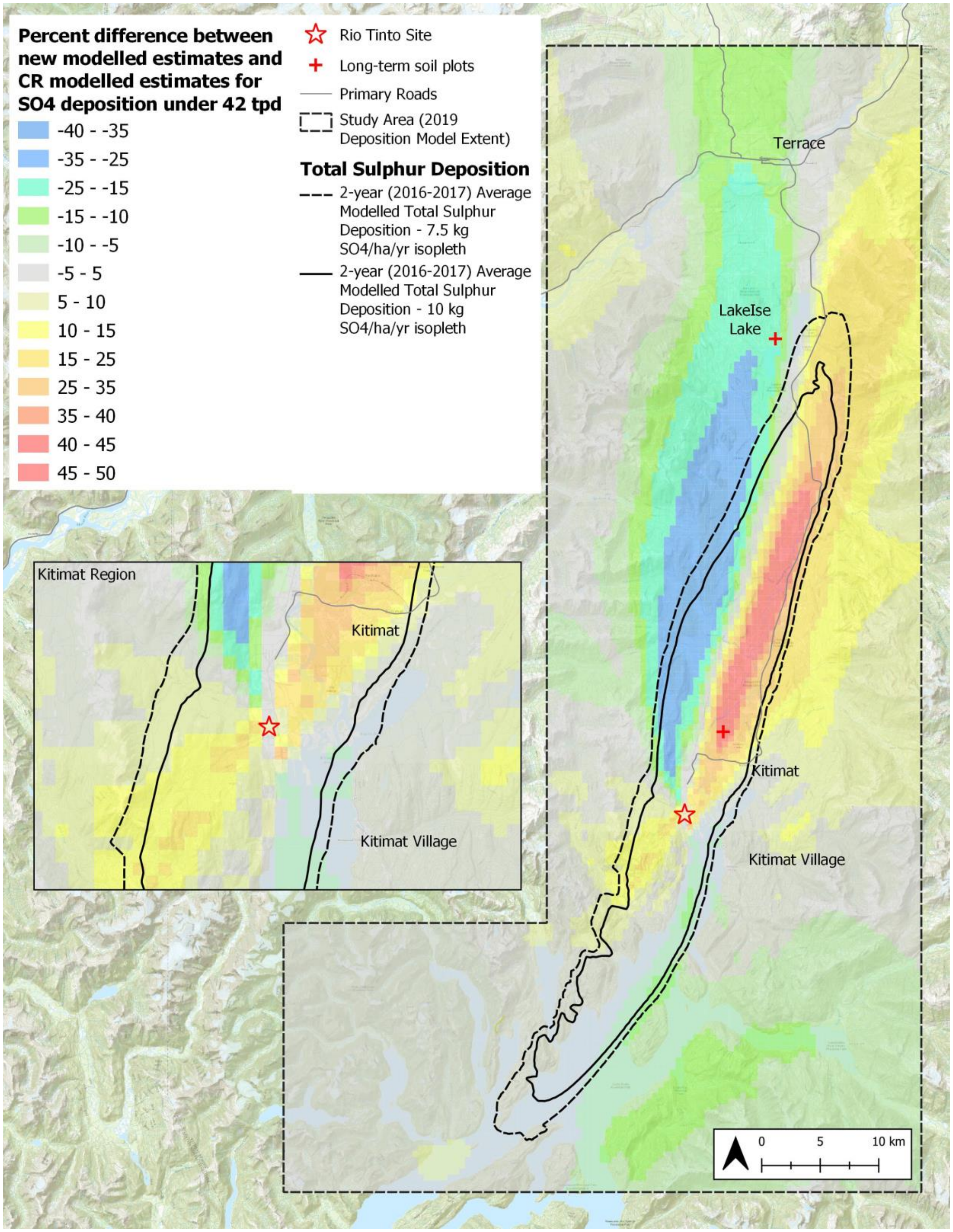

Figure 4-2. Percent difference between revised estimates of sulphate deposition under 42 tpd for meteorological years 2016-2017 and the estimates in the CR for meteorological years 2016-2018. The revised deposition isopleths (7.5 kg/ha/yr and 10 kg/ha/yr) are also shown.

4.3 Conclusions

The revised estimates of deposition do not result in any changes in the conclusions of the CR for terrestrial ecosystems. Under both the 2016-2018 deposition estimates used in the CR and the revised deposition estimates for both 2016-2017 and 2016-2018, the threshold for the first terrestrial KPI was not reached, (i.e., the area of critical load exceedance was < 1%). The areal extent of exceedance was similar to what was found in the STAR and CR, a small area close to the smelter, and this area showed high levels of exceedance similar to those reported in the CR. The second terrestrial KPI (change in soil base cations at the long-term soil plots between 2015 and 2018) is based on empirical measurements of soil physical and chemical attributes. These empirical measurements are unaffected by the revised estimates of modelled deposition to long-term soil plots; the plots integrate the cumulative effects of all years of actual deposition. As reported in the CR, the long-term soil plots at Coho Flats and Lakelse Lake showed no statistically significant decrease in exchangeable base cations or base saturation between 2015 and 2018 in the 0–30 cm depth.

4.4 Recommendations

The recommendations in section 6.4 of the CR generally remain unchanged. There were only marginal changes in the analysis of critical load exceedance (Table 4-1); the new results do not change any of the recommendations in the CR pertaining to critical load calculations. Comparing the two maps in Figure 4-1 shows that there were only very minor changes in the isopleth of 7.5 kg/ha/yr of deposition, despite noticeable changes in some parts of the study area (Figure 4-2). The long-term soil plots at Coho Flats (higher deposition site) and Lakelse Lake (lower deposition site), as well as Kemano (control site) remain appropriate locations for monitoring gradual changes in soil chemistry. Higher predicted levels of deposition at Coho Flats (Table 4-2) make that site an even better early warning indicator of potential changes to soils.

It is worth considering moving the NADP site from Haul Road to an air monitoring station closer to Coho Flats long-term soil plot. Deposition monitoring at the closer station would provide empirical measurements of changes in sulphate deposition over time to compare with observed changes in soil chemistry at Coho Flats, using statistical approaches and possibly dynamic modelling. Forest cover at the Coho Flats site is too extensive to fulfill NADP siting criteria.

5 Aquatic Ecosystems

5.1 Approach

Deposition Sensitivity Analyses

Overview

We expanded the sensitivity analyses on deposition rates, as conducted in the 2019 Comprehensive Review, to a finer scale to understand the degree to which the new deposition data values would change the original predictions for critical load exceedances, future steady-state pH, and future steady-state ANC.

Rationale

The benefits of taking the approach of extending the sensitivity analyses rather than conducting singular analyses with the new modelled deposition estimates, include:

- Expanding the existing analyses is most efficient because it does not require GIS-processing of the new data for watershed-specific estimates of deposition
- This approach is more resilient to potential future modifications of deposition estimates – i.e., the specific result (at a particular level of deposition) may change but the "response surface" will not change
- It provides a clearer, more comprehensive perspective on the bigger picture - i.e., understanding both the estimated effect under the new deposition modelling *and* the proximity of that result to the relevant thresholds of interest

Methods – SSWC and ESSA-DFO models

To determine how the revised results from the CALPUFF model affect the estimates of critical load exceedances and future changes in pH and Gran ANC that we modelled in the CR, we expanded the sensitivity analyses on deposition rates, as conducted in the CR (See CR Appendix 7.7: Aquatic Appendix G).

We applied the SSWC model and ESSA-DFO model (see CR Aquatic Appendix G for details on the models and their implementation) to estimate critical load exceedances, future pH and future Gran ANC under varying deposition levels. The deposition input values applied in the CR were varied from 50% to 200%, at 10% increments (i.e., from a halving to a doubling of deposition). For the SSWC model, which predicts the potential exceedances of aquatic critical loads based on the predicted level of future deposition, the deposition input value that was modified was the watershed deposition estimate under the maximum future emissions scenario of 42 tpd. For the ESSA-DFO model, which predicts the future pH and Gran ANC based on the predicted *change* in deposition between two time periods, the deposition input value that we modified was the *change* in deposition between "current" (i.e., post-KMP average, as per CR; 29.3 tpd) and future deposition.

Results from these models provide estimates of critical load exceedances (Ex(A)), changes in future acidity (Δ pH), and changes in future Gran ANC under varying deposition levels. As done in the CR, we implemented these analyses with two data sets: a) the full set of STAR and KAA lakes within study area (herein referred to as "all lakes"), and b) the EEM lakes. As per the approach applied in the CR, we used these two data sets to recognize that for the full set of all lakes, we can apply analyses that utilize newer deposition data but use the original lake chemistry data whereas for the EEM lakes we have much more comprehensive lake chemistry data over many years. The CR Aquatic Appendix G explains the limitations of the analyses and sensitivity analyses. Of particular note in this addendum is the fact that we cannot run the ESSA-DFO model on the full set of lakes because the deposition estimates that are concurrent with the lake chemistry data for those lakes (i.e., the "pre-KMP" emissions scenario in the STAR) were not generated within the same atmospheric modeling framework as the newer (CR / current) deposition estimates for the future emissions scenarios. This means it is not possible to generate a valid estimate of the *change* in deposition between the initial conditions and the future scenario.

Key outputs from these analyses are: 1) critical load exceedances for all lakes and EEM lakes; 2) future steady-state pH and the change from 2012 for EEM lakes; and 3) future steady-state Gran ANC and the change from 2012 for EEM lakes.

Methods – Relative Difference in Deposition

We compared the new deposition modelling estimates under the 42 tpd emissions scenario to the CR deposition modelling estimates under the same scenario to determine the % difference for every grid cell. We used these results for the sensitivity analyses for both the SSWC and ESSA-DFO models. These results are explicitly relevant to the SSWC model (critical loads exceedance), which uses future deposition as an input. However, the ESSA-DFO model (future pH, future Gran ANC) uses the *change in deposition* (i.e., the difference between future and current deposition) as an input – i.e., the difference between a) the CR-modelled change in deposition from 29.3 tpd to 42 tpd, and b) the newly-modelled change in deposition from 29.3 tpd to 42 tpd. We were unable to calculate the difference in the change because the compiled results from the "current" scenario (29.3 tpd) were not available in a timely manner and therefore we used the difference between the two sets of modelling estimates for 42 tpd as a proxy. Relying on this proxy is conservative – i.e., the % difference between the CR-modeled 42 tpd scenario and the newly-modelled 42 tpd scenario will *overestimate* the % difference as compared to the difference in the *change* in deposition and therefore **the actual changes in the future pH and Gran ANC predictions will be less than our results show.**

Mapping Location of New Plume

We calculated the 10 kg/ha/yr SO_4 deposition isopleth based on the revised CALPUFF modelling. The 10 kg/ha/yr isopleth modelled in the STAR was critically important both in terms of identifying the lakes that were sampled in the STAR as well as providing a foundation for defining the spatial boundaries of the STAR study area. Table 5-1 shows the lake selection and exclusion criteria applied in the STAR.

We mapped all lakes (>1 ha, as per STAR) within the current study area (expanded in the CR from the original STAR boundaries), including identification of the full suite of STAR and KAA lakes, with respect to the location of the revised deposition plume. We examined the locations of lakes with respect to the original and revised version of the 10 kg/ha/yr deposition isopleth. In particular, we assessed whether there were any lakes that are located within the new isopleth but not the original – i.e., lakes that were *not sampled* in the STAR but *would have been considered* for inclusion (i.e., pending review of other exclusion criteria) if we had the current deposition modelling data at the time of the STAR. We also assessed whether there were any lakes that no longer meet the STAR selection criteria under the revised deposition estimates – i.e., lakes that *were sampled* in the STAR but *would not have been* based on current data.

Table 5-1. Lake selection criteria applied in the STAR.

STAR Lake Selection Criteria

Sampling Regions (p.225)

The sampling design began with a set of 57 candidate lakes, made up of all 57 lakes greater than 1 ha in area in the study area, distributed across the following four *sampling regions of interest*:

- 31 lakes entirely within the three year average 10 kg SO4·/ha/yr isopleth of total sulphate deposition;
- nine lakes north of the isopleth that would be potentially exposed to total sulphate deposition of more than 7.5 kg SO4·/ha/yr based on meteorological conditions in 2008;
- five lakes south of the smelter that potentially receive SO4 deposition during wind outflows; and
- 12 lakes within ASC class 1 and 2 water bodies that could potentially receive acid deposition from the smelter.

Exclusion Criteria (p. 227)

To reduce uncertainty about the suitability of lakes for sampling, access, and safety, a field reconnaissance was completed by helicopter on July 11, 2012, as described in Limnotek (2012b) (Appendix 8.6-1). Following criteria applied in the U.S. EPA National Surface Water Survey (Eilers et al. 1987; Landers et al. 1987), a candidate lake (any water body >1 ha in size) was omitted from sampling if any one of the following conditions was found during the reconnaissance:

1. the lake could not be safely accessed;
2. the lake was disturbed by human activity such as runoff from industrial works and roads (the presence of small septic fields was considered acceptable because critical load models have previously been applied to regions where septic fields are present, such as in the studies of Henriksen et al. 2002 and Dupont et al. 2005);
3. the maximum depth of a lake was <0.75 m (water depths were not measured during the reconnaissance but if extensive littoral development and emergent vegetation was present throughout the wetted areas, water depths were considered to be <0.75 m);
4. a lake found in the watershed atlas was not present;
5. a lake found in the watershed atlas was a wetland or stream, meaning that it did not have an open water pelagic zone;
6. a lake found in the watershed atlas was a side channel of a large river; or
7. a lake found in the watershed atlas had open water but was not a natural lake (e.g., town of Kitimat sewage treatment ponds).

5.2 Results

Deposition Sensitivity Analyses

For each lake's watershed, we assed the difference between the results of the new deposition modelling and the deposition modelling estimates applied in the CR in order to determine the relative different between the two sets of results (Figure 5-1, Table 5-2). We then compared those watershed-specific percent changes to the results of the sensitivity analyses to determine the extent to which the difference in deposition affected the results reported in the CR.

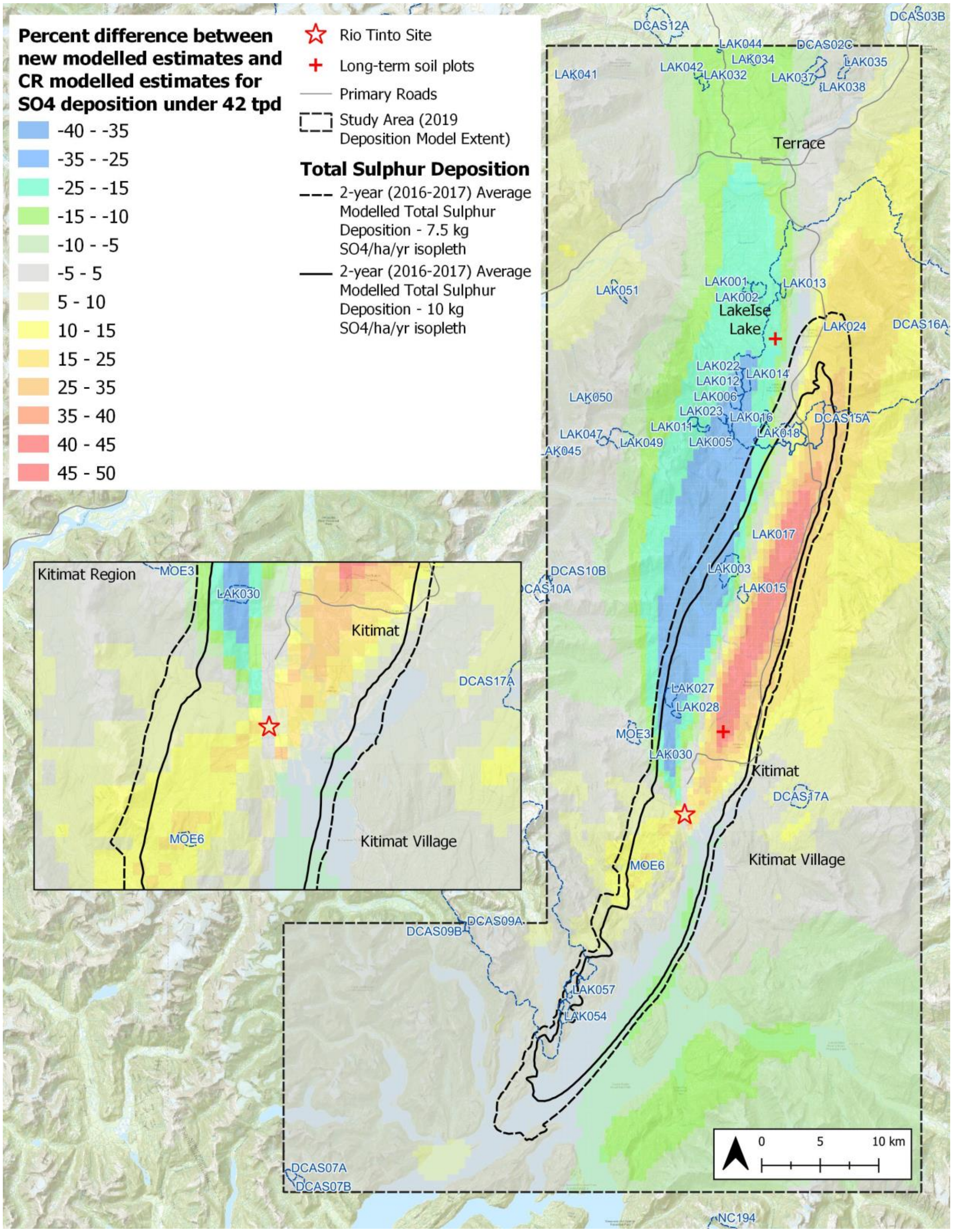

Figure 5-1. Percent difference between new modelled estimates and CR modelled estimates for SO_4 deposition under 42 tpd. The watersheds of all STAR and KAA lakes within the study area are shown. The results in the SW "toe" of the study area are not shown due to data issues.

Table 5-2. Watershed-specific differences in deposition estimates (from CR modelling to revised modelling). The green and blue highlighting indicates EEM sensitive lakes and less sensitive lakes, respectively).

Lake	Watershed Area (ha)	% Difference in Deposition
DCAS02C	0.6	-4%
DCAS07A	57.9	-4%
DCAS07B	142.1	-4%
DCAS09A	17.4	1%
DCAS09B	33.1	1%
DCAS10A	48.9	-4%
DCAS10B	11.1	-4%
DCAS15A	543.5	26%
DCAS17A	239.5	5%
LAK001	55.8	-22%
LAK002	141.6	-21%
LAK003	319.3	-26%
LAK004	108.6	-22%
LAK005	18.4	-31%
LAK006	97.0	-27%
LAK007	324.6	8%
LAK008	382.4	-15%
LAK011	55.1	-21%

Lake	Watershed Area (ha)	% Difference in Deposition
LAK012	73.8	-27%
LAK013	50.4	-14%
LAK014	115.6	-26%
LAK015	81.7	6%
LAK016	41.4	-30%
LAK017	27.6	31%
LAK018	182.8	11%
LAK022	50.3	-26%
LAK023	42.5	-28%
LAK024	24470.8	8%
LAK027	139.1	-34%
LAK028	33.6	-30%
LAK030	61.2	-27%
LAK032	62.0	-11%
LAK034	67.0	-14%
LAK035	89.5	0%
LAK037	269.3	-5%

Lake	Watershed Area (ha)	% Difference in Deposition
LAK038	22.3	-3%
LAK039	58.1	-4%
LAK041	63.3	3%
LAK042	33.9	-11%
LAK044	8.0	-13%
LAK045	50.9	0%
LAK047	47.5	-1%
LAK049	215.1	-5%
LAK050	56.2	1%
LAK051	90.5	5%
LAK053	6483.0	1%
LAK054	137.6	0%
LAK055	133.1	2%
LAK056	28.8	0%
LAK057	150.9	1%
MOE3	151.2	-3%
MOE6	26.3	15%

Critical Load Exceedances:

The results from the expanded sensitivity analysis for the exceedances of critical loads are shown in Table 5-3 for all lakes and Table 5-4 for EEM lakes.

For the original STAR scenario (Table 5-3), the majority of the lakes showed a reduction, albeit slight in some cases, in deposition and therefore less exceedance (or more negative exceedance). The most notable reductions are visible in LAK005 and LAK027. Lakes that were predicted to exceed their critical load threshold are still predicted to exceed their critical load threshold under the revised deposition estimates, except LAK028. Based on the deposition modelling in the CR, LAK028 was predicted to show a positive exceedance of 6.5 $meq/m^2/year$; however, the revised deposition estimate for LAK028 under 42 tpd is 30% less than in the CR and the lake is no longer is predicted to exceed its critical load

For the EEM Lakes under the CR best case estimates (Table 5-4), all lakes except LAK007 and LAK024 showed a reduction in deposition and therefore less exceedance. **In none of the cases did the results for any lakes change from a non-exceedance to an exceedance of their critical load.** LAK044 was already predicted to exceed its critical load, and the new deposition data did not change this.

Table 5-3. Sensitivity of exceedances (under 29.3 tpd) of original STAR/KAA critical loads for all lakes within the study area to varying levels of deposition. The outlined cells show the results that are relevant to the new deposition estimates (based on the relative difference from the CR estimates). Red cells indicate positive exceedances of the lake's critical load.

			Exceedance of Original CLs under "Current" Emissions (30 tpd)															
	Area (ha)	% Change in Deposition	0.5x Dep	0.6x Dep	0.7x Dep	0.8x Dep	0.9x Dep	1.0x Dep	1.1x Dep	1.2x Dep	1.3x Dep	1.4x Dep	1.5x Dep	1.6x Dep	1.7x Dep	1.8x Dep	1.9x Dep	2.0x Dep
LAK006	97.0	-27%	-16.3	-15.4	-14.5	-13.6	-12.7	-11.9	-11.0	-10.1	-9.2	-8.3	-7.4	-6.5	-5.6	-4.7	-3.9	-3.0
LAK012	73.8	-27%	-67.4	-66.5	-65.7	-64.8	-64.0	-63.1	-62.3	-61.4	-60.5	-59.7	-58.8	-58.0	-57.1	-56.3	-55.4	-54.6
LAK022	50.3	-26%	-42.1	-41.3	-40.5	-39.7	-38.9	-38.0	-37.2	-36.4	-35.6	-34.8	-34.0	-33.2	-32.4	-31.6	-30.7	-29.9
LAK023	42.5	-28%	-20.2	-19.4	-18.6	-17.8	-17.0	-16.1	-15.3	-14.5	-13.7	-12.9	-12.1	-11.3	-10.5	-9.7	-8.9	-8.1
LAK028	33.6	-30%	-15.9	-11.2	-6.5	-1.8	2.9	7.6	12.3	17.0	21.7	26.5	31.2	35.9	40.6	45.3	50.0	54.7
LAK042	33.9	-11%	-6.8	-6.6	-6.3	-6.1	-5.9	-5.6	-5.4	-5.1	-4.9	-4.7	-4.4	-4.2	-3.9	-3.7	-3.5	-3.2
LAK044	8.0	-7%	8.7	8.9	9.2	9.4	9.6	9.8	10.0	10.2	10.5	10.7	10.9	11.1	11.3	11.5	11.8	12.0
LAK007	324.6	8%	-1377.7	-1376.1	-1374.5	-1373.0	-1371.4	-1369.8	-1368.3	-1366.7	-1365.1	-1363.6	-1362.0	-1360.4	-1358.9	-1357.3	-1355.7	-1354.2
LAK016	41.4	-30%	-103.0	-102.1	-101.1	-100.1	-99.2	-98.2	-97.2	-96.3	-95.3	-94.4	-93.4	-92.4	-91.5	-90.5	-89.6	-88.6
LAK024	24470.8	8%	-358.1	-357.2	-356.4	-355.6	-354.7	-353.9	-353.0	-352.2	-351.4	-350.5	-349.7	-348.9	-348.0	-347.2	-346.4	-345.5
LAK034	67.0	-14%	-115.3	-114.9	-114.6	-114.3	-114.0	-113.7	-113.3	-113.0	-112.7	-112.4	-112.1	-111.7	-111.4	-111.1	-110.8	-110.4
LAK001	55.8	-22%	-591.7	-591.1	-590.4	-589.8	-589.1	-588.5	-587.8	-587.2	-586.5	-585.9	-585.3	-584.6	-584.0	-583.3	-582.7	-582.0
LAK002	141.6	-21%	-101.7	-101.0	-100.3	-99.5	-98.8	-98.1	-97.3	-96.6	-95.9	-95.1	-94.4	-93.7	-92.9	-92.2	-91.5	-90.7
LAK003	319.3	-26%	-483.5	-480.9	-478.3	-475.7	-473.1	-470.5	-467.9	-465.3	-462.7	-460.1	-457.5	-454.9	-452.3	-449.7	-447.1	-444.5
LAK004	108.6	-22%	-194.6	-194.1	-193.6	-193.0	-192.5	-192.0	-191.4	-190.9	-190.4	-189.8	-189.3	-188.8	-188.2	-187.7	-187.1	-186.6
LAK005	18.4	-31%	-100.6	-99.5	-98.5	-97.4	-96.3	-95.3	-94.2	-93.1	-92.0	-91.0	-89.9	-88.8	-87.7	-86.7	-85.6	-84.5
LAK008	382.4	-15%	-1681.4	-1679.9	-1678.4	-1676.9	-1675.4	-1673.9	-1672.4	-1670.9	-1669.4	-1667.9	-1666.4	-1664.9	-1663.4	-1661.9	-1660.4	-1658.9
LAK011	55.1	-21%	-89.3	-88.8	-88.3	-87.8	-87.3	-86.8	-86.3	-85.9	-85.4	-84.9	-84.4	-83.9	-83.4	-82.9	-82.5	-82.0
LAK013	50.4	-14%	-708.3	-707.3	-706.4	-705.5	-704.5	-703.6	-702.7	-701.7	-700.8	-699.8	-698.9	-698.0	-697.0	-696.1	-695.2	-694.2
LAK014	115.6	-26%	-98.6	-97.7	-96.8	-95.9	-95.0	-94.0	-93.1	-92.2	-91.3	-90.4	-89.5	-88.5	-87.6	-86.7	-85.8	-84.9
LAK015	81.7	6%	-203.3	-200.7	-198.0	-195.4	-192.7	-190.1	-187.4	-184.8	-182.1	-179.5	-176.8	-174.2	-171.5	-168.9	-166.2	-163.6
LAK017	27.6	31%	-212.6	-210.4	-208.3	-206.1	-203.9	-201.8	-199.6	-197.4	-195.3	-193.1	-190.9	-188.8	-186.6	-184.4	-182.3	-180.1
LAK018	182.8	11%	-1457.3	-1455.7	-1454.1	-1452.5	-1450.8	-1449.2	-1447.6	-1446.0	-1444.4	-1442.8	-1441.2	-1439.6	-1437.9	-1436.3	-1434.7	-1433.1
LAK027	139.1	-34%	-230.2	-226.9	-223.7	-220.5	-217.3	-214.0	-210.8	-207.6	-204.4	-201.1	-197.9	-194.7	-191.4	-188.2	-185.0	-181.8
LAK030	61.2	-27%	-754.4	-749.5	-744.6	-739.7	-734.8	-730.0	-725.1	-720.2	-715.3	-710.5	-705.6	-700.7	-695.8	-690.9	-686.1	-681.2

			Exceedance of Original CLs under "Current" Emissions (30 tpd)															
	Area (ha)	% Change in Deposition	0.5x Dep	0.6x Dep	0.7x Dep	0.8x Dep	0.9x Dep	1.0x Dep	1.1x Dep	1.2x Dep	1.3x Dep	1.4x Dep	1.5x Dep	1.6x Dep	1.7x Dep	1.8x Dep	1.9x Dep	2.0x Dep
LAK032	62.0	-11%	-939.7	-939.5	-939.2	-939.0	-938.7	-938.5	-938.2	-938.0	-937.7	-937.4	-937.2	-936.9	-936.7	-936.4	-936.2	-935.9
LAK035	89.5	0%	-81.0	-80.5	-80.1	-79.6	-79.2	-78.7	-78.2	-77.8	-77.3	-76.8	-76.4	-75.9	-75.4	-75.0	-74.5	-74.0
LAK037	269.3	-5%	-124.4	-123.9	-123.5	-123.0	-122.6	-122.1	-121.6	-121.2	-120.7	-120.2	-119.8	-119.3	-118.9	-118.4	-117.9	-117.5
LAK038	22.3	-3%	-168.1	-167.6	-167.1	-166.6	-166.1	-165.7	-165.2	-164.7	-164.2	-163.7	-163.2	-162.7	-162.2	-161.7	-161.2	-160.7
LAK039	58.1	-4%	-88.3	-87.8	-87.3	-86.9	-86.4	-85.9	-85.5	-85.0	-84.5	-84.1	-83.6	-83.1	-82.7	-82.2	-81.7	-81.2
LAK041	63.3	3%	-44.9	-44.8	-44.7	-44.6	-44.4	-44.3	-44.2	-44.1	-44.0	-43.8	-43.7	-43.6	-43.5	-43.4	-43.2	-43.1
LAK045	50.9	0%	-216.6	-216.5	-216.3	-216.2	-216.0	-215.9	-215.7	-215.6	-215.5	-215.3	-215.2	-215.0	-214.9	-214.7	-214.6	-214.5
LAK047	47.5	-1%	10.5	10.6	10.8	11.0	11.2	11.4	11.5	11.7	11.9	12.1	12.3	12.4	12.6	12.8	13.0	13.2
LAK049	215.1	-5%	-224.1	-223.9	-223.7	-223.5	-223.3	-223.1	-222.9	-222.7	-222.5	-222.3	-222.1	-221.9	-221.7	-221.5	-221.3	-221.1
LAK050	56.2	1%	-104.4	-104.3	-104.1	-104.0	-103.8	-103.7	-103.5	-103.4	-103.2	-103.1	-102.9	-102.7	-102.6	-102.4	-102.3	-102.1
LAK051	90.5	5%	-227.5	-227.3	-227.0	-226.8	-226.6	-226.3	-226.1	-225.9	-225.6	-225.4	-225.2	-224.9	-224.7	-224.5	-224.2	-224.0
LAK053	6483.0	1%	-91.1	-90.4	-89.8	-89.1	-88.5	-87.8	-87.2	-86.5	-85.9	-85.2	-84.6	-83.9	-83.3	-82.6	-82.0	-81.3
LAK054	137.6	0%	15.8	17.2	18.7	20.1	21.6	23.0	24.5	25.9	27.4	28.9	30.3	31.8	33.2	34.7	36.1	37.6
LAK055	133.1	2%	-105.9	-104.6	-103.3	-102.0	-100.7	-99.4	-98.1	-96.8	-95.5	-94.2	-92.9	-91.6	-90.4	-89.1	-87.8	-86.5
LAK056	28.8	0%	13.4	14.7	15.9	17.2	18.5	19.8	21.1	22.3	23.6	24.9	26.2	27.5	28.7	30.0	31.3	32.6
LAK057	150.9	1%	-405.7	-404.4	-403.0	-401.7	-400.4	-399.1	-397.8	-396.5	-395.2	-393.9	-392.6	-391.3	-390.0	-388.7	-387.4	-386.1
MOE3	151.2	-3%	-605.2	-604.5	-603.8	-603.1	-602.5	-601.8	-601.1	-600.5	-599.8	-599.1	-598.4	-597.8	-597.1	-596.4	-595.7	-595.1
DCAS10A	48.9	-4%	-35.2	-35.0	-34.9	-34.7	-34.5	-34.3	-34.2	-34.0	-33.8	-33.6	-33.5	-33.3	-33.1	-32.9	-32.8	-32.6
DCAS10B	11.1	-4%	-26.0	-25.8	-25.6	-25.5	-25.3	-25.1	-24.9	-24.8	-24.6	-24.4	-24.3	-24.1	-23.9	-23.7	-23.6	-23.4
DCAS17A	239.5	5%	-421.9	-421.5	-421.2	-420.8	-420.5	-420.1	-419.7	-419.4	-419.0	-418.7	-418.3	-417.9	-417.6	-417.2	-416.9	-416.5
DCAS02C	0.6	-4%	-65.4	-65.0	-64.7	-64.3	-64.0	-63.6	-63.2	-62.9	-62.5	-62.2	-61.8	-61.5	-61.1	-60.8	-60.4	-60.0
DCAS07A	57.9	-4%	10.0	10.3	10.5	10.7	10.9	11.1	11.3	11.6	11.8	12.0	12.2	12.4	12.7	12.9	13.1	13.3
DCAS07B	142.1	-4%	10.1	10.3	10.6	10.8	11.0	11.3	11.5	11.7	12.0	12.2	12.4	12.7	12.9	13.1	13.4	13.6
DCAS09A	17.4	1%	-56.6	-56.3	-56.1	-55.9	-55.6	-55.4	-55.1	-54.9	-54.7	-54.4	-54.2	-53.9	-53.7	-53.4	-53.2	-53.0
DCAS09B	33.1	1%	-19.3	-19.1	-18.9	-18.7	-18.4	-18.2	-18.0	-17.7	-17.5	-17.3	-17.1	-16.8	-16.6	-16.4	-16.1	-15.9
MOE6	26.3	15%	-400.4	-398.0	-395.5	-393.0	-390.6	-388.1	-385.7	-383.2	-380.7	-378.3	-375.8	-373.3	-370.9	-368.4	-366.0	-363.5

Table 5-4. Sensitivity of exceedances (under 42 tpd) of new critical loads for EEM lakes to varying levels of deposition. The outlined cells show the results that are relevant to the new deposition estimates (based on the relative difference from the CR estimates). Red cells indicate positive exceedances of the lake's critical load.

			Exceedance of New CL for EEM Lakes under "Permit" Emissions (42 tpd)															
	Area (ha)	% Change in Deposition	0.5x Dep	0.6x Dep	0.7x Dep	0.8x Dep	0.9x Dep	1.0x Dep	1.1x Dep	1.2x Dep	1.3x Dep	1.4x Dep	1.5x Dep	1.6x Dep	1.7x Dep	1.8x Dep	1.9x Dep	2.0x Dep
LAK006	97.0	-27%	-15.0	-13.8	-12.6	-11.3	-10.1	-8.9	-7.7	-6.4	-5.2	-4.0	-2.8	-1.6	-0.3	0.9	2.1	3.3
LAK012	73.8	-27%	-54.1	-53.0	-51.8	-50.6	-49.4	-48.3	-47.1	-45.9	-44.7	-43.6	-42.4	-41.2	-40.0	-38.8	-37.7	-36.5
LAK022	50.3	-26%	-44.9	-43.8	-42.6	-41.5	-40.4	-39.3	-38.2	-37.0	-35.9	-34.8	-33.7	-32.6	-31.4	-30.3	-29.2	-28.1
LAK023	42.5	-28%	-19.5	-18.4	-17.3	-16.1	-15.0	-13.9	-12.8	-11.7	-10.6	-9.5	-8.4	-7.3	-6.1	-5.0	-3.9	-2.8
LAK028	33.6	-30%	-40.3	-33.9	-27.5	-21.2	-14.8	-8.5	-2.1	4.2	10.6	16.9	23.3	29.7	36.0	42.4	48.7	55.1
LAK042	33.9	-11%	-8.0	-7.6	-7.3	-7.0	-6.6	-6.3	-6.0	-5.6	-5.3	-4.9	-4.6	-4.3	-3.9	-3.6	-3.2	-2.9
LAK044	8.0	-7%	9.5	9.9	10.3	10.6	11.0	11.4	11.7	12.1	12.4	12.8	13.2	13.5	13.9	14.3	14.6	15.0
LAK007	324.6	8%	-1364.5	-1362.3	-1360.1	-1357.9	-1355.7	-1353.5	-1351.3	-1349.0	-1346.8	-1344.6	-1342.4	-1340.2	-1338.0	-1335.8	-1333.6	-1331.4
LAK016	41.4	-30%	-103.3	-102.0	-100.6	-99.3	-98.0	-96.7	-95.3	-94.0	-92.7	-91.4	-90.0	-88.7	-87.4	-86.1	-84.8	-83.4
LAK024	24470.8	8%	-537.3	-536.1	-534.9	-533.8	-532.6	-531.4	-530.2	-529.0	-527.8	-526.7	-525.5	-524.3	-523.1	-521.9	-520.7	-519.6
LAK034	67.0	-14%	-128.3	-127.8	-127.4	-126.9	-126.4	-126.0	-125.5	-125.0	-124.5	-124.1	-123.6	-123.1	-122.7	-122.2	-121.7	-121.3

Future pH

The results for future steady-state pH and changes in pH are shown in Table 5-5, Table 5-6, and Table 5-7.

For the majority of lakes, the new estimates of deposition are lower than the estimates in the CR and therefore the predicted changes in pH were further from the threshold for pH change (i.e., less negative or more positive changes in pH). Only two lakes have new deposition estimates that are higher than the CR estimates (LAK007 and LAK024). In both cases the difference is relatively small (<+10%) and their future steady-state pH is completely insensitive to changes in deposition across the entire spectrum of deposition levels that we tested, from -50% to +100%

Based on the new deposition estimates, **none of the lakes are predicted to exceed the 0.3 unit threshold for change in pH, and no lakes are predicted to show more than a 0.1 unit change in pH.**

Table 5-5. Sensitivity of future steady-state pH of EEM lakes under "Permit" Emissions (42 tpd) to varying levels of deposition. The outlined cells show the results that are relevant to the new deposition estimates (based on the relative difference from the CR estimates). Yellow and red cells indicate decreases in pH greater than 0.1 and 0.3 pH units, respectively. Note that the already observed pH decline in LAK034 (zero change predicted from post-KMP pH) is unrelated to the smelter, as explained in the evidentiary framework.

			0.5x Dep	0.6x Dep	0.7x Dep	0.8x Dep	0.9x Dep	1.0x Dep	1.1x Dep	1.2x Dep	1.3x Dep	1.4x Dep	1.5x Dep	1.6x Dep	1.7x Dep	1.8x Dep	1.9x Dep	2.0x Dep
	Area (ha)	% Change in Deposition	pH∞	pH∞	pH∞	pH∞	pH∞	pH∞	pH∞	pH∞	pH∞	pH∞	pH∞	pH∞	pH∞	pH∞	pH∞	pH∞
LAK006	97.0	-27%	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	5.9	5.9	5.9	5.9
LAK012	73.8	-27%	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1
LAK022	50.3	-26%	6.1	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
LAK023	42.5	-28%	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.8	5.8	5.8	5.8	5.8	5.8
LAK028	33.6	-30%	4.9	4.9	4.9	4.9	4.8	4.8	4.8	4.8	4.8	4.8	4.7	4.7	4.7	4.7	4.7	4.7
LAK042	33.9	-11%	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1
LAK044	8.0	-7%	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4
LAK007	324.6	8%	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
LAK016	41.4	-30%	6.7	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6
LAK024	24470.8	8%	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5
LAK034	67.0	-14%	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4

Table 5-6. Sensitivity of the change in pH from 2016-2018 (post-KMP values from CR) to future steady-state pH of EEM lakes under "Permit" Emissions (42 tpd) to varying levels of deposition. The outlined cells show the results that are relevant to the new deposition estimates (based on the relative difference from the CR estimates). Yellow and red cells indicate decreases in pH greater than 0.1 and 0.3 pH units, respectively. Note that the already observed pH decline in LAK034 (zero change predicted from post-KMP pH) is unrelated to the smelter, as explained in the evidentiary framework.

			0.5x Dep	0.6x Dep	0.7x Dep	0.8x Dep	0.9x Dep	1.0x Dep	1.1x Dep	1.2x Dep	1.3x Dep	1.4x Dep	1.5x Dep	1.6x Dep	1.7x Dep	1.8x Dep	1.9x Dep	2.0x Dep
	Area (ha)	% Change in Deposition	Δ pH	Δ pH	Δ pH	Δ pH	Δ pH	Δ pH	Δ pH	Δ pH	Δ pH	Δ pH	Δ pH	Δ pH	Δ pH	Δ pH	Δ pH	Δ pH
LAK006	97.0	-27%	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
LAK012	73.8	-27%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LAK022	50.3	-26%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
LAK023	42.5	-28%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
LAK028	33.6	-30%	-0.1	-0.1	-0.1	-0.1	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3
LAK042	33.9	-11%	0.0	0.0	0.0	0.0	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
LAK044	8.0	-7%	0.0	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.2	-0.2	-0.2	-0.2
LAK007	324.6	8%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LAK016	41.4	-30%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LAK024	24470.8	8%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LAK034	67.0	-14%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 5-7. Sensitivity of the change in pH from the 2012 baseline to future steady-state pH of EEM lakes under "Permit" Emissions (42 tpd) to varying levels of deposition. The outlined cells show the results that are relevant to the new deposition estimates (based on the relative difference from the CR estimates). Yellow and red cells indicate decreases in pH greater than 0.1 and 0.3 pH units, respectively. Note that the already observed pH decline in LAK034 (zero change predicted from post-KMP pH) is unrelated to the smelter, as explained in the evidentiary framework.

			0.5x Dep	0.6x Dep	0.7x Dep	0.8x Dep	0.9x Dep	1.0x Dep	1.1x Dep	1.2x Dep	1.3x Dep	1.4x Dep	1.5x Dep	1.6x Dep	1.7x Dep	1.8x Dep	1.9x Dep	2.0x Dep
	Area (ha)	% Change in Deposition	Δ pH (2012)	Δ pH (2012)	Δ pH (2012)	Δ pH (2012)	Δ pH (2012)	Δ pH (2012)	Δ pH (2012)	Δ pH (2012)	Δ pH (2012)	Δ pH (2012)	Δ pH (2012)	Δ pH (2012)	Δ pH (2012)	Δ pH (2012)	Δ pH (2012)	Δ pH (2012)
LAK006	97.0	-27%	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	0.1	0.1
LAK012	73.8	-27%	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
LAK022	50.3	-26%	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
LAK023	42.5	-28%	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1
LAK028	33.6	-30%	-0.1	-0.1	-0.1	-0.1	-0.1	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.3	-0.3	-0.3	-0.3
LAK042	33.9	-11%	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4
LAK044	8.0	-7%	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LAK007	324.6	8%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LAK016	41.4	-30%	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
LAK024	24470.8	8%	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
LAK034	67.0	-14%	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3

Future Gran ANC:

Results for the changes to Gran ANC are shown in Table 5-8 and Table 5-9.

For the majority of lakes, the new estimates of deposition are lower than the estimates in the CR and therefore the predicted changes in Gran ANC were further from the threshold for Gran ANC change (i.e., less negative or more positive changes in Gran ANC). Only two lakes have new deposition estimates that are higher than the CR estimates (LAK007 and LAK024). In both cases the difference is relatively small (<+10%) and their future steady-state Gran ANC is completely insensitive to changes in deposition across the entire spectrum of deposition levels that we tested, from -50% to +100%

Based on the new deposition estimates, **only 3 lakes are predicted to have decreases in Gran ANC, those changes are of a smaller magnitude than previously predicted and none of those predictions exceed the lake-specific Gran ANC thresholds (not shown).**

Table 5-8. Sensitivity of future steady-state Gran ANC of EEM lakes under "Permit" Emissions (42 tpd) to varying levels of deposition. The outlined cells show the results that are relevant to the new deposition estimates (based on the relative difference from the CR estimates).

			0.5x Dep	0.6x Dep	0.7x Dep	0.8x Dep	0.9x Dep	1.0x Dep	1.1x Dep	1.2x Dep	1.3x Dep	1.4x Dep	1.5x Dep	1.6x Dep	1.7x Dep	1.8x Dep	1.9x Dep	2.0x Dep
	Area (ha)	% Change in Deposition	Gran ANC ∞	Gran ANC ∞	Gran ANC ∞	Gran ANC ∞	Gran ANC ∞	Gran ANC ∞	Gran ANC ∞	Gran ANC ∞	Gran ANC ∞	Gran ANC ∞	Gran ANC ∞	Gran ANC ∞	Gran ANC ∞	Gran ANC ∞	Gran ANC ∞	Gran ANC ∞
LAK006	97.0	-27%	26.2	25.9	25.6	25.3	25.0	24.7	24.4	24.1	23.8	23.5	23.2	22.9	22.6	22.3	22.0	21.7
LAK012	73.8	-27%	57.2	56.9	56.7	56.5	56.3	56.0	55.8	55.6	55.4	55.1	54.9	54.7	54.5	54.2	54.0	53.8
LAK022	50.3	-26%	31.7	31.4	31.2	30.9	30.7	30.4	30.2	29.9	29.7	29.4	29.1	28.9	28.6	28.4	28.1	27.9
LAK023	42.5	-28%	25.1	24.9	24.6	24.3	24.1	23.8	23.5	23.3	23.0	22.8	22.5	22.2	22.0	21.7	21.4	21.2
LAK028	33.6	-30%	-6.4	-7.0	-7.5	-8.1	-8.7	-9.3	-9.8	-10.4	-11.0	-11.6	-12.1	-12.7	-13.3	-13.9	-14.4	-15.0
LAK042	33.9	-11%	4.9	4.7	4.6	4.5	4.3	4.2	4.0	3.9	3.7	3.6	3.4	3.3	3.2	3.0	2.9	2.7
LAK044	8.0	-7%	3.9	3.7	3.5	3.2	3.0	2.8	2.6	2.3	2.1	1.9	1.7	1.4	1.2	1.0	0.8	0.6
LAK007	324.6	8%	1385.9	1385.9	1385.9	1385.9	1385.9	1385.9	1385.9	1385.9	1385.9	1385.9	1385.9	1385.9	1385.9	1385.9	1385.9	1385.9
LAK016	41.4	-30%	88.9	88.7	88.6	88.4	88.2	88.0	87.9	87.7	87.5	87.3	87.2	87.0	86.8	86.6	86.5	86.3
LAK024	24470.8	8%	463.2	463.2	463.2	463.2	463.2	463.2	463.2	463.2	463.2	463.2	463.2	463.2	463.2	463.2	463.2	463.2
LAK034	67.0	-14%	139.1	139.0	138.9	138.9	138.8	138.7	138.6	138.5	138.4	138.3	138.2	138.1	138.0	138.0	137.9	137.8

Table 5-9. Sensitivity of the change in Gran ANC from the 2012 baseline to future steady-state pH of EEM lakes under "Permit" Emissions (42 tpd) to varying levels of deposition. The outlined cells show the results that are relevant to the new deposition estimates (based on the relative difference from the CR estimates). The lake-specific Gran ANC thresholds are not indicated because even at 2.0x deposition, none of the EEM sensitive lakes exceed those thresholds.

			0.5x Dep	0.6x Dep	0.7x Dep	0.8x Dep	0.9x Dep	1.0x Dep	1.1x Dep	1.2x Dep	1.3x Dep	1.4x Dep	1.5x Dep	1.6x Dep	1.7x Dep	1.8x Dep	1.9x Dep	2.0x Dep
	Area (ha)	% Change in Deposition	Δ Gran ANC (2012)	Δ Gran ANC (2012)	Δ Gran ANC (2012)	Δ Gran ANC (2012)	Δ Gran ANC (2012)	Δ Gran ANC (2012)	Δ Gran ANC (2012)	Δ Gran ANC (2012)	Δ Gran ANC (2012)	Δ Gran ANC (2012)	Δ Gran ANC (2012)	Δ Gran ANC (2012)	Δ Gran ANC (2012)	Δ Gran ANC (2012)	Δ Gran ANC (2012)	Δ Gran ANC (2012)
LAK006	97.0	-27%	0.5	0.2	-0.1	-0.4	-0.7	-1.0	-1.3	-1.6	-1.9	-2.2	-2.5	-2.8	-3.1	-3.4	-3.7	-4.0
LAK012	73.8	-27%	0.2	-0.1	-0.3	-0.5	-0.8	-1.0	-1.2	-1.4	-1.7	-1.9	-2.1	-2.3	-2.6	-2.8	-3.0	-3.3
LAK022	50.3	-26%	3.9	3.6	3.3	3.1	2.8	2.6	2.3	2.1	1.8	1.6	1.3	1.1	0.8	0.5	0.3	0.0
LAK023	42.5	-28%	5.3	5.1	4.8	4.6	4.3	4.0	3.8	3.5	3.2	3.0	2.7	2.5	2.2	1.9	1.7	1.4
LAK028	33.6	-30%	-2.4	-3.0	-3.6	-4.1	-4.7	-5.3	-5.9	-6.4	-7.0	-7.6	-8.2	-8.7	-9.3	-9.9	-10.5	-11.0
LAK042	33.9	-11%	25.3	25.2	25.1	24.9	24.8	24.6	24.5	24.3	24.2	24.0	23.9	23.7	23.6	23.5	23.3	23.2
LAK044	8.0	-7%	2.6	2.4	2.2	2.0	1.7	1.5	1.3	1.1	0.8	0.6	0.4	0.2	0.0	-0.3	-0.5	-0.7
LAK007	324.6	8%	-51.6	-51.6	-51.6	-51.6	-51.6	-51.6	-51.6	-51.6	-51.6	-51.6	-51.6	-51.6	-51.6	-51.6	-51.6	-51.6
LAK016	41.4	-30%	20.3	20.1	19.9	19.7	19.6	19.4	19.2	19.0	18.9	18.7	18.5	18.3	18.2	18.0	17.8	17.6
LAK024	24470.8	8%	163.7	163.7	163.7	163.7	163.7	163.7	163.7	163.7	163.7	163.7	163.7	163.7	163.7	163.7	163.7	163.7
LAK034	67.0	-14%	39.7	39.6	39.5	39.4	39.3	39.3	39.2	39.1	39.0	38.9	38.8	38.7	38.6	38.5	38.4	38.4

Comparing the New Plume to the STAR

In the STAR, the 10 kg/ha/yr isopleth was of critical importance to lake selection and defining the study area boundary. Figure 5-1Figure 5-2 maps the location of the 10 kg/ha/yr isopleths based on both the STAR and new deposition modelling and the location of all of the lakes (>1 ha) within the full study area. The map shows that there is one lake that fall *outside* the STAR isopleth but *inside* the new isopleth and therefore represent lakes that would have been candidates for sampling during the STAR (pending evaluation of exclusion criteria) if the STAR had been based on the new deposition modelling. This lake is further discussed below.

The map also shows that there are many lakes that fall *inside* the STAR isopleth but *outside* the new isopleth and therefore represent lakes that might not have selected for sampling during the STAR if the STAR had been based on the new deposition modelling estimates at that time. However, the STAR used more than just the 10 kg/ha/yr isopleth to define sampling regions (see Table 5-1). To better determine the number of lakes that were sampled in the STAR but would not have been sampled based on the new deposition modelling, we must look for STAR lakes that fall outside the new 7.5 kg/ha/yr isopleth and are not located in zones of bedrock with acid sensitivity of ASC 1 or ASC 2 (Figure 5-3 shows the new 7.5 kg/ha/yr isopleth and Figure 5-4 shows the ASC map and STAR lakes). There are 19 STAR lakes that were selected due to being located within the area of >7.5 kg/ha/yr that would not meet that criterion if the STAR had been based on the new deposition modelling; however, 3 of those lakes are also located within ASC 1 areas and would thus still be selected. This means that there are 16 STAR lakes that would not have been selected for sampling under the new deposition data, including the EEM sensitive lakes LAK006, LAK012, LAK022, and LAK023, and the EEM less sensitive lakes LAK016 and LAK034. Furthermore, if the STAR had been based on the new deposition modelling, it is likely that the entire study area would not extend as far north as it currently does. Although it is not possible to known exactly where the northern boundary would have been defined, it is reasonable to speculate that because Lakelse Lake overlaps the new 7.5 kg/ha/yr isopleth and is of high public value, the boundary may very well have been just to the north of Lakelse Lake. If that were the case, 4 more lakes at the northern end of the study area that would otherwise be retained based on bedrock sensitivity would have been excluded, including EEM sensitive lakes LAK042 and LAK044. There is also a possibility that the study area may have excluded some of the 5 lakes in ASC 2 between the Wedeene and Skeena Rivers based on their distance from the plume, but to be conservative we will not consider that any further. Given the new deposition modelling estimates and the reasonably conservative speculation about the study area, the STAR lake selection criteria would only result in 21 of the original 41 lakes being sampled, retaining only one EEM sensitive lake.

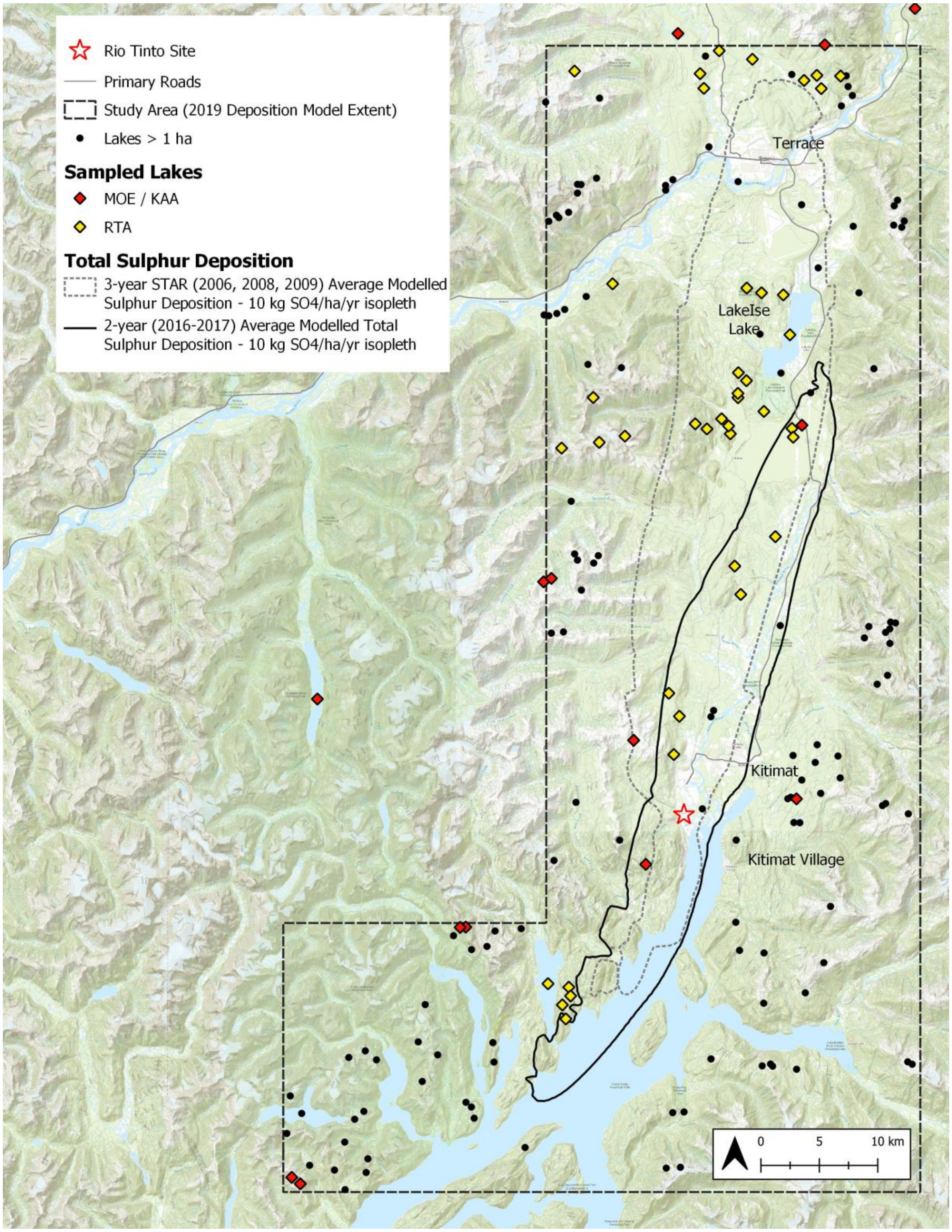

Figure 5-2. Location of the 10 kg/ha/yr isopleths for SO_4 deposition from the STAR and from the new deposition modelling. All of the lakes (>1 ha) in the study area are shown. Lakes that are located within the STAR isopleth but were not sampled during the STAR were excluded based on violating one or more of the selection criteria (Table 5-1).

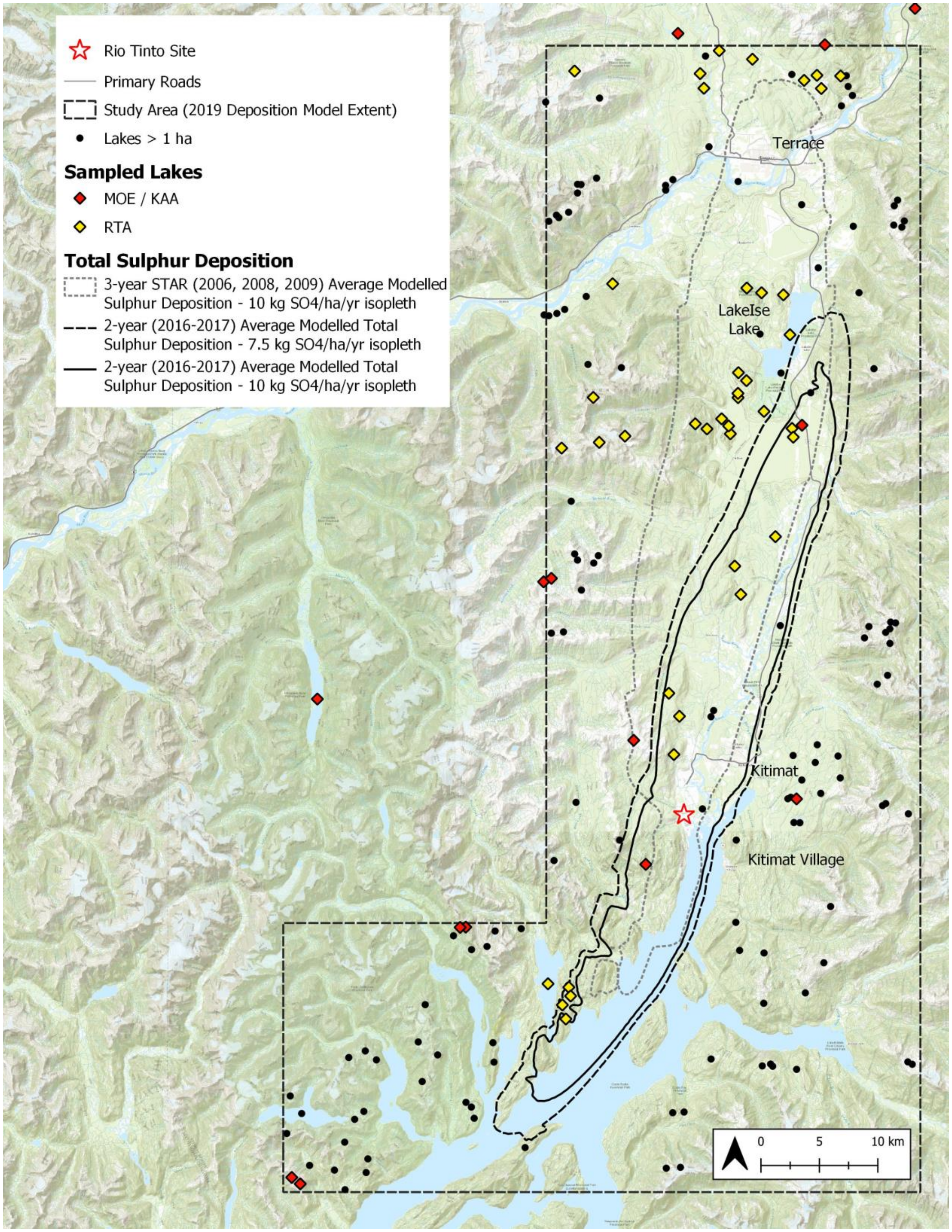

Figure 5-3. Location of the 10 kg/ha/yr isopleths for SO_4 deposition from the STAR and the 10 kg/ha/yr and 7.5 kg/ha/yr from the new deposition modelling. All of the lakes (>1 ha) in the study area are shown.

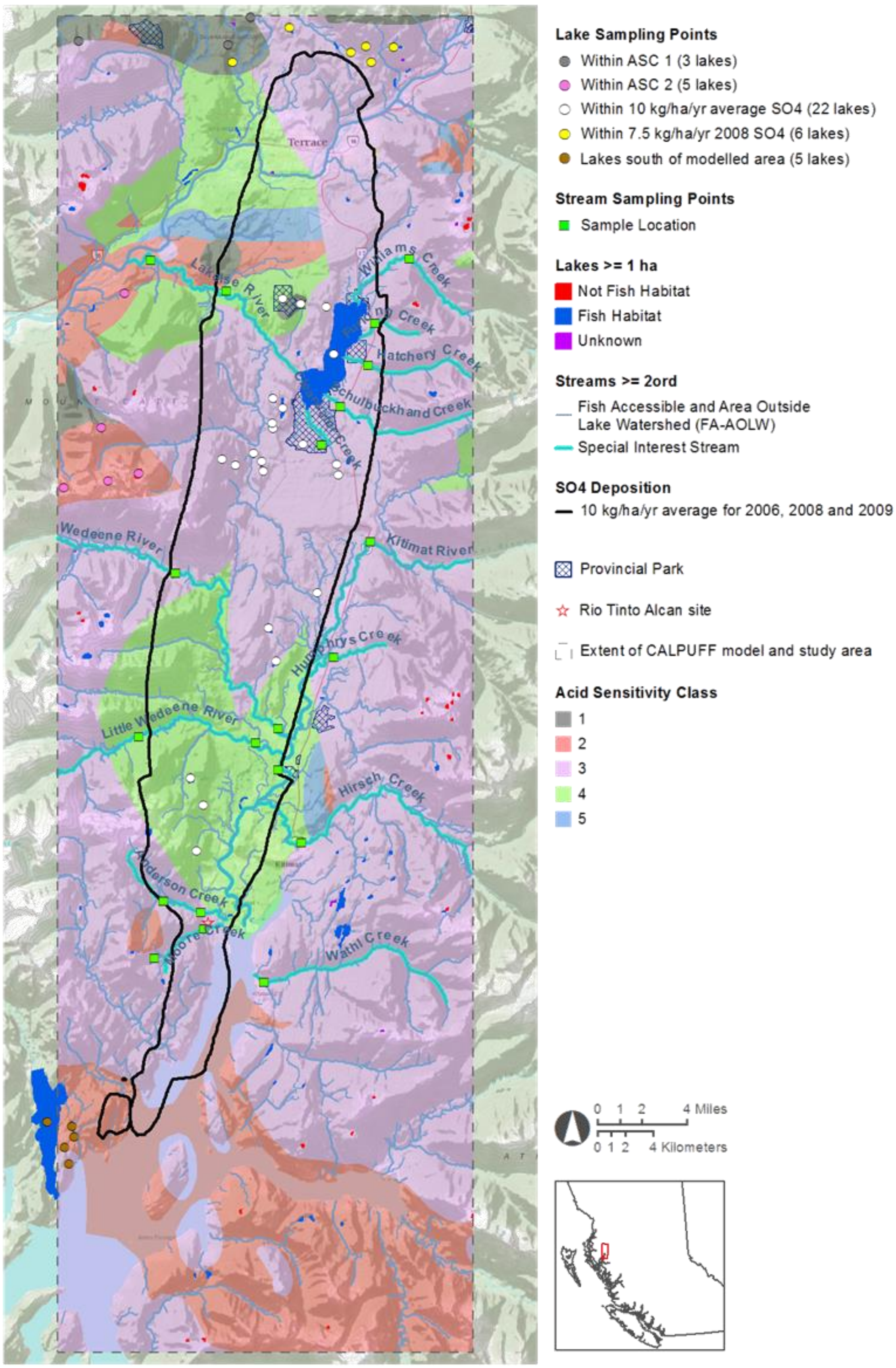

Figure 5-4. Overlay of STAR sampling sites and acid sensitivity classes (ASC). Grey and pink points show sampled lakes within ASC 1 and ASC 2, the two most sensitive sites. Source: Figure 8.6-4 in STAR Volume 2.

The "new" potential candidate lake

As described above, there is one lake that fall within the new 10 kg/ha/yr isopleth but did not meet that selection criteria (or any other) for the STAR.

This lake is located just north of Nalbeelah Creek Wetlands Provincial Park, just east of the highway (Figure 5-5). It is 1.02 ha in area. Based on the satellite images shown in Figure 5-6 and Figure 5-7, this "lake" appears to be a wetland. Coarse measurements indicate it is only 20-25 m across at its widest spot and the available images do not show much if any open water, both of which suggest that it is relatively shallow and truly a wetland rather than a lake. This initial examination suggest that the lake does not meet the STAR selection criteria (i.e., it is a wetland and also may not meet the depth requirements) and would not have been included in sampling.

Figure 5-5. Location of potential candidate lake.

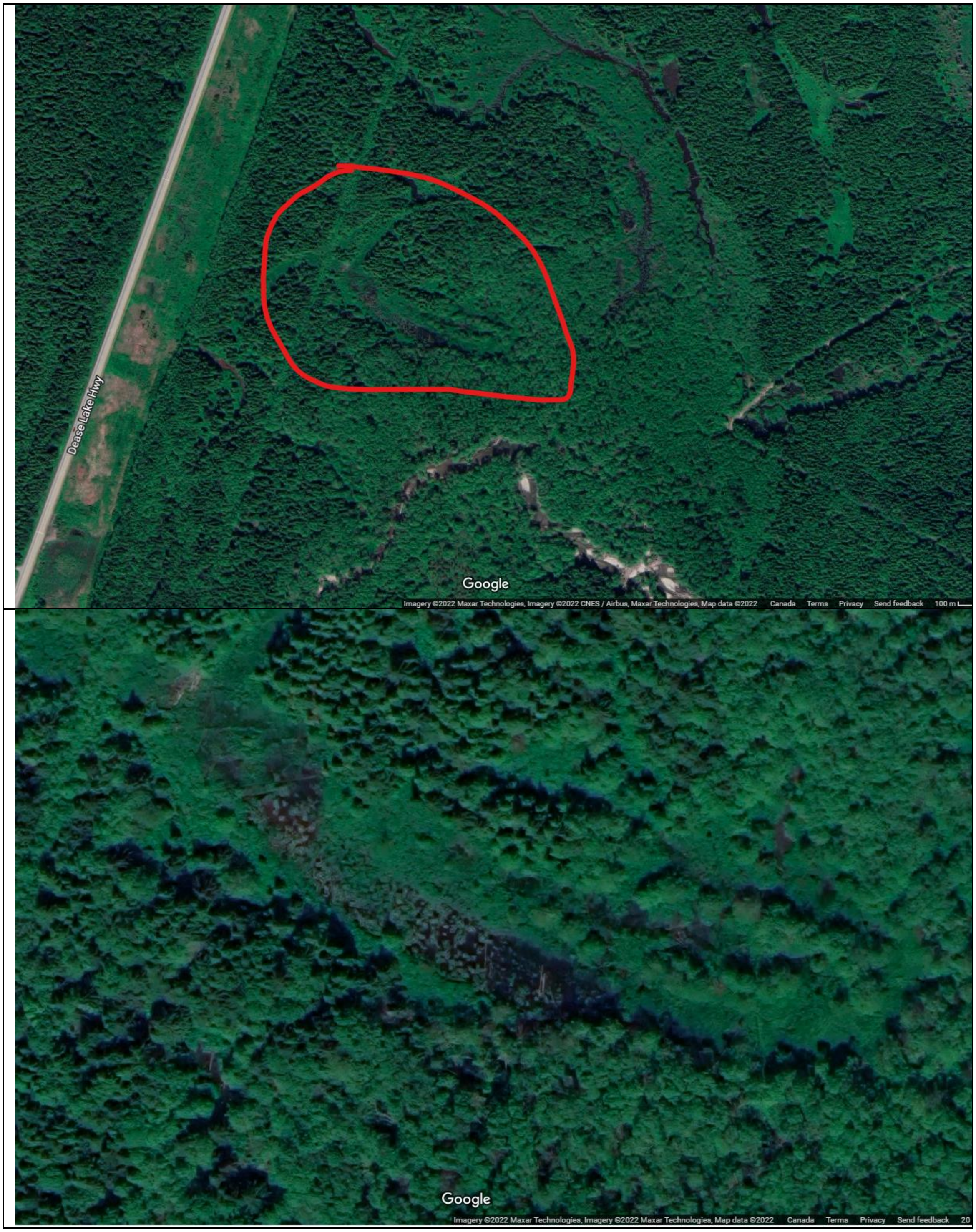

Figure 5-6. Satellite images of potential candidate lake at two different scales (source: Google Maps).

Figure 5-7. Satellite image of potential candidate lake with alternate orientation (source: Google Earth).

5.3 Conclusions

Deposition Sensitivity Analyses

Critical load exceedances: None of the lakes changed from non-exceedance to exceedance of critical loads (i.e., the only lakes with exceedances under the new results already had exceedances under the old results).

Future pH: None of the lakes changed conclusions with respect to predictions of future pH – one EEM sensitive lake is still predicted to decrease in pH but by a smaller magnitude than the prediction in the CR.

Future Gran ANC: None of the lakes changed conclusions with respect to predictions of future Gran ANC – three EEM sensitive lakes are still predicted to decrease in Gran ANC but by a smaller magnitude than the prediction in the CR and well below their lake-specific thresholds.

Overall, the new deposition estimates are lower for all of the EEM sensitive lakes and thus the predicted outcomes of that deposition were lower too. The new deposition estimates were higher, but only by a small degree, for LAK007 and LAK024, which are highly insensitive to changes in deposition.

These new results do not meaningfully change any of the predictions in CR Chapter 7 with respect to critical load exceedances, future pH or future Gran ANC and therefore do not change any of the conclusions in that chapter.

Location of the Plume

As per the terms of reference, we assessed the question, *" is the SO_2 EEM lakes work still looking in the right areas?"* The answer is predominantly "yes", with some nuance.

Based on the deposition estimates, there is one previously unsampled lake that meets the deposition criteria applied in the STAR. This lake does not meet additional selection criteria as it appears to be a wetland with limited/no open water. However, there are also many lakes that have been part of the STAR and EEM programs that no longer meet the deposition criteria applied in the STAR. This demonstrates that the STAR and EEM programs have been very precautionary. The monitoring program has examined lakes outside of the revised 10 kg/ha isopleth of deposition based on the 2016-2017 meteorological years. It is precautionary to retain the current set of EEM lakes given the differences between the STAR estimates of deposition based on 2006, 2008, and 2009 meteorological years and the more recent revised estimates of deposition based on the 2016 and 2017 meteorological years.

5.4 Recommendations

We do not recommend further reconnaissance or sampling of the potential candidate lake identified. The available satellite imagery, plus the size and orientation, provides sufficient evidence that the identified lake is in fact a wetland that does not meet the STAR selection criteria.

We recommend maintaining the current EEM lakes despite being outside the new 10 kg/ha/yr deposition isopleth. The new deposition modelling estimates will be included in future assessments of lake inclusion.

6 Holistic Synthesis

The revised estimates of SO_2 concentrations and SO_4 deposition from the CALMET and CALPUFF Sensitivity Study do not change any of the conclusions in the Holistic Synthesis of the 2019 CR.

The revised estimates of SO_2 concentrations and SO_4 deposition do not change the conclusions in the CR for vegetation. For four of the six listed species/communities, nearby SO_4 deposition from the wind-corrected modelling decreased under the 42 tpd scenario, and for the remaining two species/communities the increase was very small. Wind-corrected modelling estimates of the area in the study domain subject to SO_4^{2-} deposition show that the land area in the categories from 3.7 to 10 kg SO_4^{2-}/ha/yr essentially remained unchanged, differing by less than 0.2%. The only category in that range that increased was the 3.7-5 kg SO_4^{2-}/ha/yr category, by only 50 ha. The area subject to predicted SO_4^{2-} deposition of greater than 10 kg SO_4^{2-}/ha/yr increased by less than 1%. Based on these small changes under the maximum emissions scenario, and particularly the decreased area of the study domain predicted to be subject to the greatest deposition of SO_4^{2-}, there are no changes warranted to the conclusions in the CR. Under the wind-corrected 42 tpd modelling, less than 3% of the study area fell within the 10µg/m³ isopleth and about 0.6% fell within the 20µg/m³ isopleth. Under the actual scenario, about 1.4% fell within the 10 µg/m³ isopleth and less than 0.5% fell within the 20µg/m³ isopleth. All or parts of 24 old growth management areas fell within the >5 kg SO_4^{2-}/ha/yr deposition isopleth compared with 17 in the CR, due to the shift in direction of the modelled plume path. Under the shift in the program to biodiversity of vascular plants and cyanolichens, to a large extent the program is now focussed on mature and old growth forest

The revised estimates of SO_4 deposition do not result in any changes in the conclusions of the CR for terrestrial ecosystems (soils). The threshold for the first terrestrial ecosystems KPI was not reached (the area of critical load exceedance was < 1%), and the areal extent of exceedance was similar to what was found in the STAR and CR: a small area close to the smelter, which showed high levels of exceedance similar to those reported in the CR. The second terrestrial ecosystems KPI (change in soil base cations at the long-term soil plots between 2015 and 2018) is based on empirical measurements of soil physical and chemical attributes and those are unaffected by the revised estimates of modelled deposition to long-term soil plots.; the plots integrate the cumulative effects of all years of actual deposition. As reported in the CR, the long-term soil plots at Coho Flats and Lakelse Lake showed no statistically significant decrease in exchangeable base cations or base saturation between 2015 and 2018 in the 0–30 cm depth.

The revised estimates of SO_4 deposition do not meaningfully change any of the predictions for aquatic ecosystems in the CR with respect to critical load exceedances, future pH or future Gran ANC and therefore do not change any of the conclusions for aquatic ecosystems in the CR. None of the lakes changed from non-exceedance to exceedance, conclusions for none of the lakes changed with respect to predictions of future pH, and conclusions for none of the lakes changed with respect to predictions of future Gran ANC. Overall, the new deposition estimates are lower for all of the EEM sensitive lakes. The new deposition estimates were higher for LAK007 and LAK024, but only by a small degree, and these lakes are highly insensitive to changes in deposition.

7 Overall Recommendations

The revised estimates of SO_2 dispersion and SO_4 deposition from the CALMET and CALPUFF Sensitivity Study do not change any of the overall recommendations in 2019 CR. The recommendations for Atmospheric Pathways in the CR remain unchanged.

The recommendations for vegetation in the CR remains unchanged: the program should shift SO_2 EEM monitoring to long-term, more subtle effects that integrate vegetation more strongly with terrestrial ecosystems.

The recommendations for terrestrial ecosystems (soils) in the CR generally remain unchanged. The long-term soil plots at Coho Flats (higher deposition site) and Lakelse Lake (lower deposition site), as well as Kemano (control site) remain appropriate locations for monitoring gradual changes in soil chemistry. Higher predicted levels of deposition at Coho Flats make that site an even better early warning indicator of potential changes to soils. It is worth considering moving the NADP site from Haul Road to an air monitoring station closer to Coho Flats long-term soil plot. Deposition monitoring at the closer station would provide empirical measurements of changes in sulphate deposition over time to compare with observed changes in soil chemistry at Coho Flats, using statistical approaches and possibly dynamic modelling. Forest cover at the Coho Flats site is too extensive to fulfill NADP siting criteria.

The recommendations for aquatic ecosystems also remain unchanged. We recommend maintaining the current EEM lakes that are outside of the revised 10 kg/ha/yr deposition isopleth, and including the new deposition modelling estimates in future assessments of lake inclusion. We do not recommend further reconnaissance or sampling of new lakes.

8 References

ESSA Technologies, J. Laurence, Risk Sciences International, Trent University, and Trinity Consultants. 2020a. 2019 Comprehensive Review of Sulphur Dioxide Environmental Effects Monitoring for the Kitimat Modernization Project – Volume 1, V.3 Final. Prepared October 15, 2020 for Rio Tinto, B.C. Works, Kitimat, B.C.

ESSA Technologies, J. Laurence, Limnotek, Risk Sciences International, Rio Tinto Alcan, Trent University, Trinity Consultants, and University of Illinois. 2013. Sulphur Dioxide Technical Assessment Report in Support of the 2013 Application to Amend the P2-00001 Multimedia Permit for the Kitimat Modernization Project. Volume 2: Final Technical Report. Prepared for Rio Tinto Alcan, Kitimat, BC. 450 pp.